UMEÅ UNIVERSITET

TOWARDS ELECTRIC AVIATION IN THE KVARKEN REGION

Lars Westin

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Foreword

This report is produced within the FAIR (**F**inding Innovations to **A**ccelerate **I**mplementation of Electric **R**egional Aviation) project. FAIR develops methods and insights to support an early and efficient commercialization of electric-powered regional flights in the Kvarken region. The possibility to establish a commercially viable airline across the Kvarken strait and the prerequisites necessary for the Kvarken region to capture the benefits of such an effort and to add wealth to the region are the topics at hand.

FAIR has had a broad partnership of actors. The Kvarken council has been the owner of and coordinator responsible for the project. FAIR has been financed by Interreg Botnia Atlantica, Region Västerbotten, Regional Council of Ostrobothnia, City of Vaasa, FAB Kronoby Flyghangar, Into Seinäjoki Oy, Lycksele Flygplats AB, MidtSkandia, Ostrobothnia Chamber of Commerce, Skellefteå City Airport AB, Skellefteå Kraft AB, South Ostrobothnia Chamber of Commerce, Storumans Kommunföretag AB, Swedavia Umeå Airport, Umeå Municipality, Vaasan Sähkö Oy, Vaasa Region Development Company (VASEK), Västerbotten Chamber of Commerce, and Örnsköldsvik Airport AB.

Supporting partners have been Air Traffic Network, BSR ACCESS, ELISE, Finavia, Funktionshinderrådet Umeå, Future Cleantech Solutions, Green Flyway, Grön Flygplats, Heart Aerospace, Helsinki Electric Aviation Association, Jonair, Luftfartsverket, NEA – Nordic Network for Electric Aviation, Umeå kommunföretag AB, Umeå Institute of Design, The Swedish 2030-secretariat and Transportföretagen.

Beneficiaries have been Kvarken Council (Lead part), BioFuel Region (BFR AB), Region Västerbotten, RISE (Research Institutes of Sweden), Umeå University, and University of Vaasa.

The daily management of FAIR, on behalf of the Kvarken council, has been carried into effect by Tyréns in Umeå. Andreas Forsgren and Isak Brändström at Tyréns have combined obedience with firm leadership in their excellent management of the project. The Swedish government agency Transport analysis has kindly shared its own studies, data on electric aviation, and data on the travelling market generally. Johan Lundberg and Jonas Westin at CERUM have been supportive and added inspiration to the work.

I am grateful for the support and for the wish to collaborate with and engage in the FAIR project shown by the above organisations and individuals.

Umeå in August 2021

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Abstract

The markets for aircraft, airlines and airports are in a phase of major reconsideration, transition and change. The COVID-19 pandemic has made this process turbulent and even more acute. Even before the pandemic, travellers questioned fossil-based aviation, a sign of the shift in preferences among consumers. Aircraft producers and airlines had not reacted fast enough; airlines introduced various CO_2 compensation schemes, but customers were not convinced. A shift from international air over to national and intra-continental rail had started. In addition, although the car industry was slow out of its start blocks, this part of the transport industry is now intensifying the development of electric engines, batteries, and other engines based on non-fossil fuel. Lastly, and inspired by this, electric aircraft appear to be entering the scene. In order for this vision to be realised, the industry of aviation has to change. Moreover, technical and design related attributes of electric, compared with fossil, aviation might move the competitive breaking points towards air, in relation to land- and sea-based transportation. One aspect of this is the assumed possibility of electric aviation to add new short-distance routes to the airline network, especially over sea. The Kvarken strait between Finland and Sweden, dividing the Bothnian Sea from the Gulf of Bothnia, is an example. This paper is a first investigation of the possibilities to establish a commercially viable regular commuter airline over the strait. Institutional solutions are proposed, as well as measures to be taken in order to reap the benefits of such a route.

Content

1. Introduction[1]

Technical progress in support of electric aviation is now advancing rapidly. Within the coming five-year period, several models of electric aircraft will be in the air for test cycles as demanded by international regulations. Electric aircraft do not produce any operational greenhouse gas emissions and do not create barriers in the land-based ecosystem. Thus, one could consider electric aviation to be one of the most climate-efficient ways of travelling. The electric driveline may also reduce energy and maintenance costs as well as stimulate the development of new design concepts in relation to aircraft. Altogether, this might open for an improved competitive position for aviation in relation to land and sea-based transportation. A new commercially-based regular regional airline market may thus be in the making.

However, for the moment this market is not here. For a time, battery capacity – and hence operational distance – will constrain the competitiveness of electric aviation. Regulatory issues and testing may also take substantial time. Various fossil-reducing fuels will continue to keep larger jet aircraft and their hub and spoke networks between major airports as the dominant alternative for medium to longer distances. They will thus also be a force that continues to redirect passengers from potential point-to-point regional networks into flows based on a larger scale in sparse national and international networks.

Nevertheless, the markets for aircraft, airlines and airports are in processes of change. The COVID-19 pandemic has made this transition even more turbulent and acute. Travellers had already questioned fossil-based aviation and a shift of preferences among consumers was initiated. The supply side of the industry, e.g. aircraft producers and airlines, did not react fast enough. Airlines introduced various CO_2 compensation schemes, but consumers were still not convinced; the shift from air to land-based and from global to shorter intra- national and intra-continental travel had started.

Also, the car industry was slow to adapt to the climate awareness among consumers. However, its recent introduction of electric engines, batteries and other non-fossil fuels has inspired new small actors to develop prototype electric aircraft. When technically, regulatory, and commercially feasible, the electric aircraft may remove environmental concerns, but may also improve the competitiveness of regional aviation in particular. Electric aircraft may change the competitiveness relative to various land- and sea-based modes of transport through the possibility to add new shorter routes to airline networks. This may increase airline competitiveness as well as accessibility to places and regions.

This paper introduces and discusses concepts, methods and policy options available to understand the future market for electric aviation. Although our approach is general, our case of analysis here is the Kvarken region. This region offers many interesting challenges as well as possibilities for electric aviation. Politically, the cross-border region is organised through the "Kvarken council"[2]. The core of the region consists of territories in both Sweden and Finland, bridging a strait with a territory including international waters. Currently a ferry line

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[2] https://www.kvarken.org/

and an “on-demand charter traffic” with smaller turboprop aircraft carry passengers across the strait.

The existence of the strait and the “Kvarken Council”, as a political body for this cross-border geography, makes the Kvarken region especially interesting for analyses of early implementations of electric aviation. Electric aviation has the potential to address three of the major challenges for the region; weak east-west communication, a need to reduce greenhouse gas emissions and environmental impacts generally, and an urgent need to develop an increased attractiveness on human as well as financial capital.

Evidently, the latter is also an important condition for the development of efficient and appropriate communication networks, internally and externally. A major question is therefore to what extent electric aviation may help to solve these challenges. Will it create a new balance between intra-regional, intra-national and international accessibility for the region? The answer is dependent on the evolution of aviation technology and design, in response to the introduction of electric drivelines for aircraft. What types of new attributes will, for example, an electric, fixed-wing aircraft bring with it, compared with current aircraft? Moreover, what may VTOL (aircraft with Vertical Take-Off and Landing possibilities) offer compared with current helicopters and commuter jets?

The outline of the report is as follows. In the next section, the most important question for a regional policy maker are discussed, namely, the sources to and the creation of wealth in the region. Precise knowledge regarding the answers to those questions is critical for actors and regions that want to reap the benefits of electric aviation. Thereafter, in section three, we describe and analyse the market for electric aviation from a purely travel-time perspective. We identify relations where electric aviation may be competitive and where technical constraints and travel time by other means limit the market.

In section four we suggest an institutional solution for the initiation of a regular commuter route over the Kvarken strait while observing that the aviation market is filled with what seem to be both policy and market failures. This discussion is important in initiating and preparing the region for the various alternative management options that might arise in the future. In section five, we return to the regional impacts of electric aviation, while lastly, section six summarizes and concludes the paper.

2. Wealth and population as constraints on demand for regional aviation

How can a region lay hold of any benefits generated by the introduction of electric aviation? Especially if the region plans to finance investments or other means itself with the ambition to secure its own growth, this is a most important question. How can the region strengthen its possibilities to gain those future and often uncertain benefits while its cost for such measures are secure and nearby in time?

Obviously, the Kvarken region should give priority to and consider such questions before investing scarce resources on any policy measure to promote the introduction of electric aviation in the region.

Aviation is a part of the infrastructure and transportation systems that build networks connecting nodes such as cities, regions, villages, real estate, etc. Changes in transport technologies will change the relative accessibility and communication possibilities between nodes in the networks. It will induce mobility and have impacts on the distribution of assets and their value between nodes. People will move, companies will increase in scale or be driven out of business. Relative property values will fall in some places and increase in others. Such changes in the distribution and prices of assets will thus also change relative wealth between actors and nodes. In turn, this will feed back on the attractiveness on movable assets, and thus on the possibility of developing sustainable attractiveness and growth in the future.

The wealth of a region, place or any node in a network of settlements is shown by the node's balance sheet as a representation of its assets. Classical economists, like Adam Smith and David Ricardo, in the shift from the 18th to the 19th century, focused on the wealth of nations and thus the balance sheet of national nodes. However, in the middle of the 20th century, this "long-run growth" oriented perspective in many respects lost against the interest for the income statement of nations and its primary measure, the Gross Domestic Product (GDP), as developed by Keynes and Stone. This shorter business cycle perspective became the major interest of governments, whose sights were set primarily on their three- to six-year voting cycles. Hence, Statistics Sweden and Finland today have more data on the GDP of nations and regions than data regarding their assets and balance sheets.

In an attempt to change this back to a more data-driven understanding of the growth of nations and thus ultimately of their cities, regions and countryside, the World Bank (2005) at the millennium attempted to estimate the amount of assets in nations, and thus the distribution among them. In this rather rough attempt to create globally comparable figures of the sources of growth, the balance sheet per inhabitant of Sweden turned out as in Table 1 below.

Table 1. The per capita wealth of Sweden in SEK around the last millennium. Excluding environmental (nature's) services. Source: Own calculations with data from *The World Bank Millennium Capital Assessment* by The World Bank (2005).

• *Minerals*	*2 367*
• *Forests*	*21 906*
• *Recreation/Hunting*	*8 172*
• *National parks etc.*	*13 941*
• *Vegetarian recourses*	*10 080*
• *Animal recourses*	*15 084*
■ **Sum of Ecological capital (Market valued)**	**71 550**
■ **Real Properties (Buildings, machinery)**	**524 979**
■ **Social, knowledge and cultural capital**	**4 024 287**
■ **Total assets per capita (SEK)**	**4 620 816**

The table illustrates a typical feature of Nordic welfare nations, the large share of social, knowledge and cultural capital in the total wealth of their assets. Although not shown here, Nordic countries also come out relatively high in total wealth per capita compared with many other countries. In other parts of the world, nations instead have a larger share of natural resources and real assets, compared with the share of assets that is related to various aspects of human capital and human relations.

Looking inside the Nordic countries and their regions, we would nevertheless expect the ratio between human oriented capital, natural capital and real assets to vary. Regions with larger cities and larger populations would have a larger share of human related capital, while northern parts of Sweden and Finland for example, with small cities, would be relatively more oriented towards natural and infrastructure capital.

Given this, what characterises places with a growth of wealth? For a long time, Sweden and Finland have been engaged in international trade with natural resources, especially after the institutional improvements – and thus of their social capital – during the first half of the 19th century, which gave these two countries the chance to gain a larger share of the value added by international trade. Private and public actors were able to invest some of this in human capital (schools, health care), in infrastructure and machinery, and in housing. As is shown in Figure 1, this meant that the share of natural capital assets in the growing total wealth declined over time.

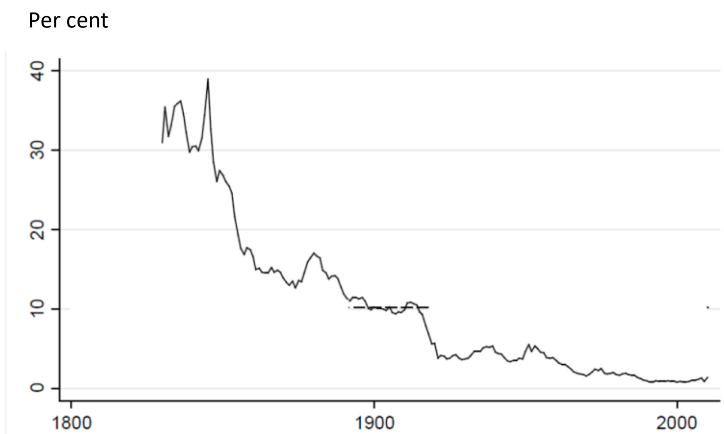

Figure 1. The share of natural capital (per cent) in the total wealth of Sweden 1830-2010.
Source: Lindmark, M. och L F Andersson (2014) CERE Working Paper.

For various reasons, not all countries and regions managed to make this conversion of their natural capital into human capital. Some countries were locked in as natural resource exporters to other countries, countries where growth from industrialisation took off instead. Within countries, a division between regions specialised in resource-based production and regions that managed to attract human capital also became visible. The latter regions have been characterised by their ability to develop larger cities where entrepreneurs and public actors transform information, ideas, and knowledge into advanced human capital-intensive services and products.

In regions based on information intensive activities, with their larger share of human capital, there is an increase in demand for and possibilities to establish hubs of regional, national and international networks for all sorts of transportation and communications. Hence we make the general observations that,

- The degree of centrality, the possibility to establish a hub instead of becoming a peripheral node in a network, is dependent on the size and the relative growth of the population and the markets in nodes more generally, within the network.
- Moreover, the density of the network connected with a node is dependent on the amount of activity in the node. A large node, with more inhabitants in its catchment area, may also have more destinations, arrivals and departures than smaller nodes.

The implication is that the absolute and relative growth and attractiveness of human capital should be the focus of an analysis of the impacts of measures in transportation networks. Taking a further look at the northern areas of Sweden and Finland based on these observations, the Kvarken region, we observe growth, at least until the middle of the 20th century. To illustrate this, Figure 2 shows this rapid growth of the population in the four northernmost counties in Sweden since 1800.

Figure 2. Population in the four northernmost counties of Sweden 1800-2000.
Data source: Statistics Sweden.

Although urbanisation of northern Sweden and northern Finland occurred late in the 17th century, especially compared with central Europe, their populations increased rapidly as from the beginning of the 19th century. Initially, this growth was based on exports of products from forestry and the sawmill industries. However, the population also grow thanks to the development of agriculture and fisheries. From around 1870, with the development of new technologies for metal production and the construction of a railway system towards northern Sweden, the mining and steel industries and the production of electricity grew consistently. With the shift from shipping to transporting food by rail, the vulnerability of northern regions due to bad harvests also decreased and the region was able to import engineering products at a faster and more stable rate. Hence the overall attractiveness of the region increased drastically.

On the other hand, after WWII, this import of machinery steadily led to increased mechanisation, especially of forestry and agriculture, but later also of the mining industry. During a decennium, this drastically changed the dynamics of growth in the region. With the parallel growth of industries based on engineering, services, and knowledge-based production, the region saw an accelerated shift from a dispersed pattern of localisation, governed by agriculture and forestry, to cities where services, health care, culture, airports, and schools for advanced studies developed instead. If railways had initially made natural resource-oriented locations in the north attractive, mechanisation and the establishment and improvement of a road network now created possibilities to gain returns from scale, reduce labour cost and increase concentration in the natural resource-oriented industries. With better roads, it had become less necessary labourers to live near mines and in the forest. The population began to concentrate in cities and villages, eventually commuting to work in the resource industries.

In this critical shift, the late and slow development of cities in the North became inhibitive for the accumulation of human capital. Larger cities, such as Stockholm and Gothenburg, had the advantage of their urban qualities, offering more diverse labour markets and broader housing opportunities.

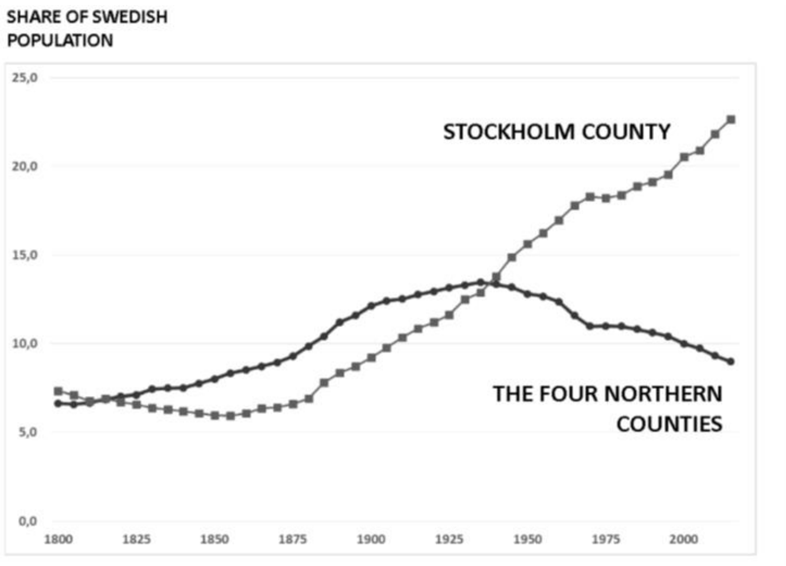

Figure 3. Share of Swedish population 1800 – 2015. Stockholm County and the four northern counties. Data from Statistics Sweden.

As shown in Figure 2 above, the population growth in northern Sweden stagnated. The fact that since then even central actors within the region itself have had a negative view of the need for and development of larger cities in northern Sweden has further added to the stagnation of the region.

In Finland, the development followed similar paths. The history of the northern parts of the countries are thus to some extent typical examples of the initial blessing and the subsequent curse so often generated by natural resources when they become the primary focus for regional development. Many regions have developed without a large amount of natural resources; a good harbour or another important junction in a communication network, good climate, a nice seaside, an efficient legal system, education, health and welfare systems, interesting people, housing and successful urban planning, etc. have been sources of wealth for cities. On the other hand, oil wells have also created cities with tremendous wealth, even though they now also face the threat of the curse, with restrictions being forced on fossil fuels. These cities are also in urgent need of transformation away from their dependence on the natural resource.

So far, northern Sweden has not accomplished the necessary transformation from a resource-based into a human capital-intensive region, combining attractive countryside dwelling with large cities. The region missed, or at times even counteracted, its own transformation from the revenue afforded by resources into a human capital-focused economy, where some larger cities, some villages and attractive countryside settings could have powered its growth. As is well known, an overall growth of a region's countryside cannot come about without growing cities.[3]

Most important for our study here although is to consider the outcome of this stagnation from the point of view of the airline network in the Kvarken region and its adjacent areas. Figure 4 illustrates the airline networks in the Nordic area in the 1960s and in 1990s.

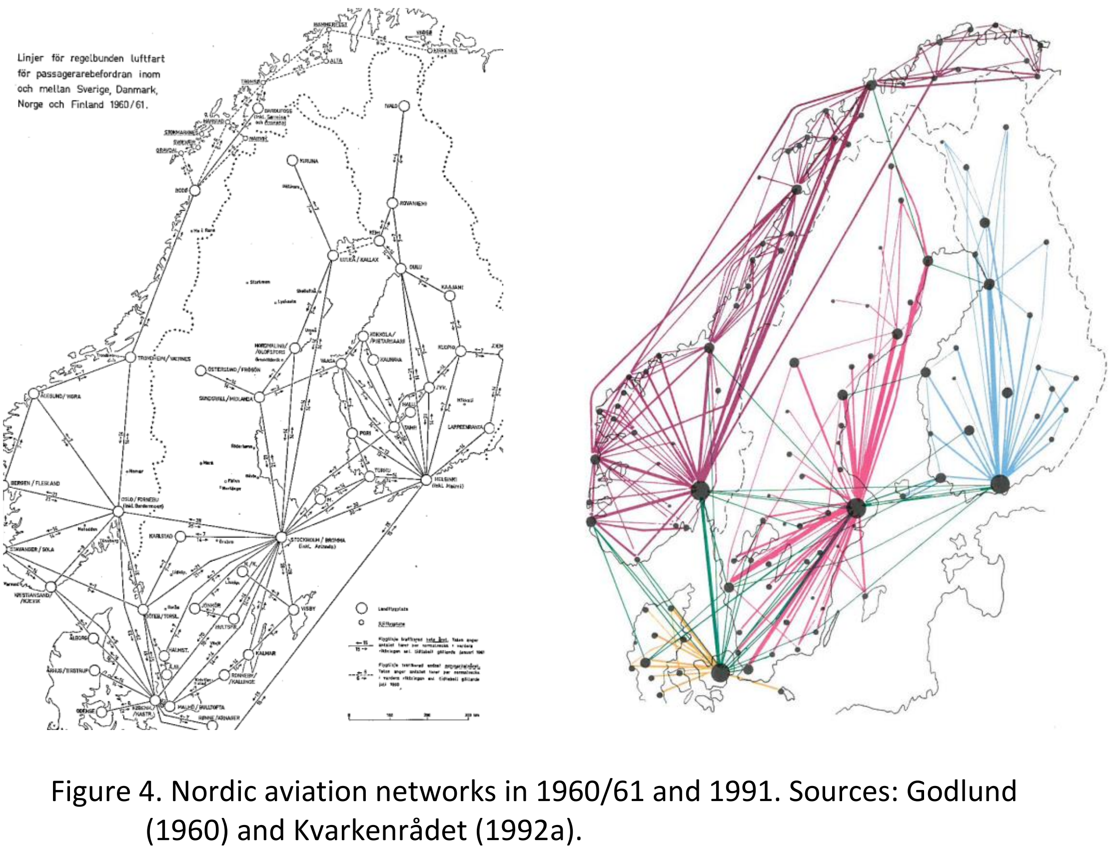

Figure 4. Nordic aviation networks in 1960/61 and 1991. Sources: Godlund (1960) and Kvarkenrådet (1992a).

[3] In Westin (2011) and Westin (2006), the reasons behind the difficulty in the development of Northern Sweden is explained and discussed further.

In the 1950s, aircraft were slower, their range was shorter, and they had fewer seats than in the 1990s. The map of the network from 1960/61 shows an emergent hub and spoke structure with high network centrality for the capitals in each nation. However, although this hub and spoke network did exist, it was not particularly strong. The centrality merely reflected the size of the capitals compared with other cities in each nation's city system. Instead, one may observe a tendency for some smaller cities at some distance from the capitals to function as regional hubs. In northern Sweden, Sundsvall and Luleå had some sort of centrality in regional networks. In Finland, Vaasa, Oulu and some other cities were centres for routes to nearby cities. In northern Norway, Bodö had a similar position.

The observant reader will also find that Umeå and Skellefteå had no commercial aviation or local airports before 1961. Between 1957 and 1961, the first years of commercial airline traffic to the Umeå-region, air traffic was directed to a former military airfield, Olofsfors Airport in Nordmaling, 60 kilometres to the south of Umeå. Skellefteå Airport in Falmark and Örnsköldsvik Airport in Arnäs both opened in 1961, while Lycksele Airport opened in 1968.

As from 1991, the hub and spoke nature of the networks within each county was strengthened. Since then, the continued development of national radial networks with the four capitals at the centres was a combined outcome of three forces. Improved aircraft capacity with respect to speed, range and size was one; the deregulation of the state monopolised market for airlines as of 1992, although combined with a strengthened governmental grip on the larger airports in Sweden through the Swedish Civil Aviation Administration (LFV, Luftfartsverket) was another; and lastly, the stagnation and relative decline of the share of population in northern Sweden and Finland. The latter, together with the smallness and dispersion of the cities, hindered the establishment of stronger regional hubs at airports in those areas. Given our earlier observations, this should not come as a surprise.

However, the map in Figure 4 above indicates that Umeå, Luleå, Oulu and to some extent Vaasa, at a small scale, functioned as nodes for regional aviation regardless. It seems that the use of these airports as nodes in regional systems, to some degree and in many various constellations with respect to routes and airlines, was developed and maintained from the late 1960s until the beginning of the new millennia. The rise and decline of this volatile system of regional aviation is interesting as such. However, the history of this is too long to go into here.

Anyhow, attempts to re-establish, develop and broaden a regional aviation network in the Kvarken region will meet strong competition from the dominating hub and spoke oriented airline network established at national levels. Hence, a conclusion may be added to our previous comments,

- The development of a regional aviation system is dependent on both the absolute number of inhabitants in the region and the strength of the region in terms of its human capital relative to larger cities.

Obviously, the internal structure of the region's urban system will also be important. The following comment can be added to the above,

- The size and number of cities at distances competitive for aviation is decisive in establishing a regional airline network with daily flights.

The current situation with respect to the number and size of nodes in the Kvarken region is presented in Figure 5 below.

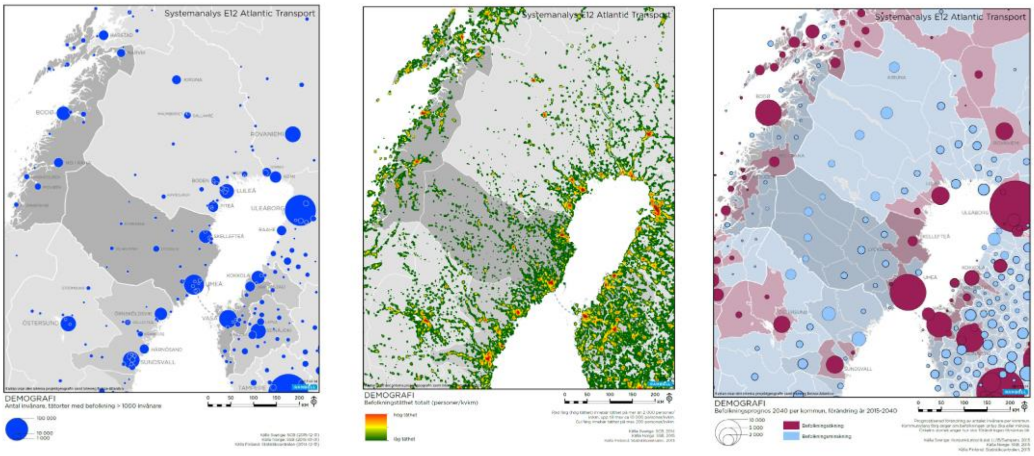

Figure 5. Inhabitants in the larger Kvarken region catchment area. Densely built up areas with more than 1 000 inhabitants (left), a more detailed map of population density (middle), and a forecast for 2040 of population and population change (right). Source: Kvarkenrådet (2017).

In the Kvarken region, cities are small, or generally very small, while the population outside cities is located in a particularly dispersed pattern. In addition to this, the larger cities in the region are located in different countries. A system of regional aviation would therefore have to compete with the national networks, as well as all sorts of barriers and obstacles imposed on relations between actors in different nations and institutional disparities.

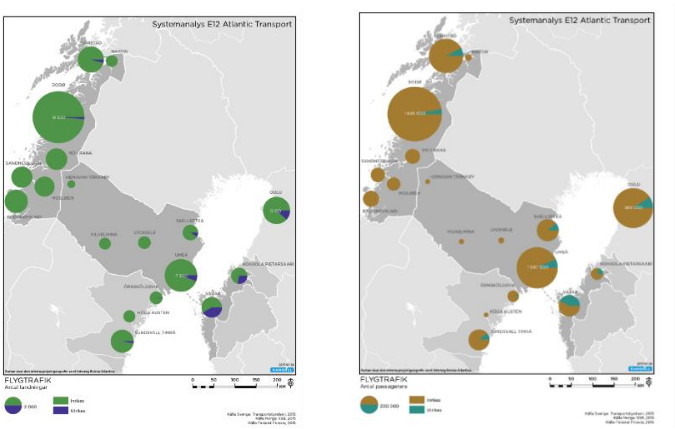

Figure 6. Number of domestic and international arrivals in 2015 at airports in the Kvarken region (left) and number of passengers (right). Source: Kvarkenrådet (2017).

A comparison of the airline network in Figure 4 with the number of arrivals and passengers at airports in the Kvarken region and Oulu in Figure 6 emphasises this conclusion. If the area shown in the maps were integrated into one nation, direct routes would be expected between airports in Oulu, Umeå, and Bodö in Norway. This is not the case, however.[4]

In this chapter, our analysis has stressed the fact that the weak development of population in the region relative to the development in the catchment areas of the national hubs and the current division of the Kvarken region into three nations poses major challenges for regular commercial aviation in the region. Even though demand for aviation at major airports in the region has increased due to population growth, increase in income, developed attractiveness and reduced fares, the overall weak development of sources of demand for aviation will be a drag on future aviation region. Hence,

- For relations in the Kvarken region in which a network of regional air traffic would be possible, the small size of cities and the dispersed population around airports mean that the possible benefits to scale in regional aviation will be hampered by a shortage of demand.

If a regional system of aviation is to add growth, the design of such a system must be supportive to an increasing number of inhabitants and to the growth of asset values in the region. This will then also proactively assist the demand for regional aviation. In order for aviation to fulfil such a function, political ambitions and planning in the region have to focus on a rapid and vigorous increase of its inhabitants. Otherwise, electric aviation may not even have a chance to contribute to the development of the region.

3. Competitiveness of Electric Aviation in the Kvarken Area

3.1. Supply of aviation. Travel time and speed

In the previous section, we concluded that a relatively weak population growth and a dispersed settlement pattern would, if not taken care of, continue to be overall constraints on future demand for aviation in the region. Weak demand implies smaller aircraft and loss of returns to scale on each route. An analysis of the market for aviation thus has to pay attention to the interaction between supply and demand, in aviation as well as in any alternatives. Given this consideration, in this section we make an introductory analysis of the supply side of aviation, since if aviation is to be of interest at all, determinants have to be identified that will make aviation competitive. In this respect, some initial observations gleaned from scanning the current market for aviation in the Kvarken region would be:

- Regional airline operator(s) with smaller turboprop or similar aircraft offer business charter/taxi flights with "on-demand booking of the entire aircraft" between airports over the whole Kvarken region, as well as to destinations outside the region.

[4] Sandberg Hanssen et al (2020) give examples of how obstacles between Nordic countries can hamper Nordic infrastructure investments.

- A regular commercial regional airline network for the Kvarken region, where individual seats may be booked, has not been viable for different reasons.
- State procured flights exist on the Umeå-Östersund and Arvidsajur-Lycksele-Arlanda routes.
- All other commercial flights are on routes with destinations outside the region.

Hence, the market for regular commercial aviation in the Kvarken region, excluding flights to Stockholm and Helsinki, is in principle absent or for some reason undeveloped. As was touched upon previously, attempts to establish a regional system of aviation were made during the second half of the 20th century, but became impracticable. This lack of a viable market may have been due to many reasons.

- The cost of flying these distances may be too high and competition from other modes too strong
- Lack of competition and monopolistic behaviour may have made the fare too high
- Demand for intra-regional aviation in the Kvarken region may not be large enough
- Airports may be located too far from travellers
- It may be too costly to inform potential customers, change habits and establish a market
- There may be other constraints (e.g. regulatory) on the regional market for aviation

Needless to say, a combination of such causes would make any market unprofitable. On the demand side, the lack thereof at given fares may, as we have claimed above, be due to a number of reasons. Low incomes, too few and too dispersed inhabitants and weak business relations are the most obvious. Competition from cars, coaches, the ferry over the Kvarken strait, and rail may also be too strong, especially along the coast of the Gulf of Bothnia. The small size of cities, mostly under 100 000 inhabitants, the distance between them, together with a number of administrative borders with both cultural and industrial differences may hamper intra-regional interaction generally and by air especially. The well-established connections by air with each of the much larger capitals may over the years have directed business in those directions while the persistence needed to inform and establish a new regional market may not be there, etc. Since by law aviation not is part of Swedish regional public transport policy, the public means that might have been used to develop regional aviation are not available.

Obstacles on the demand side will also spill over to the supply side, as the use of small aircraft that provide limited returns to scale may result in fares too high to attract travellers. However, not only is the fare important; a potential air traveller considers the complete set of door-to-door transportation alternatives before choosing to include a specific route and specific airline in a travel schedule. Both airlines and airports engaged in regional aviation must therefore consider, improve and inform the market about efficient “to and from” transportation options relative to an airport.

The travel alternatives “to-from” an airport are in principle all other, or a combination of all other existing modes of transport. In practice, the number of inhabitants in the catchment area of an airport – the demand – also constrains the diversity of alternatives at the supply side in this respect. Given available alternatives, choosing “to-from” modes will be a question of distance, speed, fare, waiting time, services, pre-booking possibilities, etc. for them too.

To summarize, Table 2 below lists the dominant features of the demand and supply sides of a market for aviation in a region. We will not consider them individually. However, the table emphasises the multi-attribute feature of network-based transport markets as well as the feed-backs that exist between supply and demand in the core of the economy for aviation. Hence, the market share of aviation in relation to other modes between two nodes and the market share of airlines on each such route are aspects that will govern the profitability of airlines active on the route. This indicates the importance of return to scale, return to network size, persistence and regulatory issues in aviation.

Table 2. Central determinants of demand and supply for aviation in a region.

<table>
<tr><th>DEMAND FOR AVIATION</th><th>SUPPLY OF AVIATION</th></tr>
<tr><td>

Size of and spatial organisation of the regional population
Attractiveness of places for inbound visitors
Incomes and assets of the population
Preferences for aviation

Electric aviation
Other non-fossil alternatives for aviation
Fossil-based aviation

Preferences for other modes of transport
Generalised cost of door-to-door travel relative to other modes:

Total travel time by air (speed, embarking, take-off/landing time)
Accessibility to airports (home/final destination)
Fare including taxes, etc.
To/From airport
Airline
Comfort/service/staff
To/From airport
Airline
Number of connections/changes at airports during flight

</td><td>

Cost of airline:

Number of aircraft in fleet

Type/size
Number of each type
Running costs of aircraft
Per flying hour
Per flight distance
Maintenance, service
Financing and insurance

Size of Network
Alliances with other airlines
Public support
Regulatory fees

Offered fare:

Route distance
Market share on route
Number of passengers
Aircraft size
Market/customer segmentation
Services offered

Cost at Airport/Airport fees

Choice of market segment
Location/Owner
Size of Airport
Accessibility to other modes
Aircraft used
Terminal services offered
Flow of passengers
Parking fees
Shopping
Security
Regulatory constraints
Public support
Financing and risk sharing

</td></tr>
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The main conclusion is, and this is further emphasised in Table 2, that the economics of airlines is a multifaceted, complex and adaptive process with strong aspects of gaming in how it relates to other actors in the network.

Having observed this, we will for the moment focus on door-to-door travel times between an origin and destination. The travel time with a mode needed to cover the destination between points a and b is given by the speed of the mode as,

$$s_{ab} = d_{ab}/t_{ab} \tag{1}$$

$$t_{ab} = d_{ab}/s_{ab} \tag{2}$$

Where t_{ab} is the travel time from point a to point b, d_{ab} is the distance between a and b, while s_{ab} denotes the average speed of transportation between these points. Higher speed reduces the travel time for a given distance. As we have touched upon above, a trip generally contains a main mode together with other modes of transportation, first to reach the main mode from the origin and lastly to reach the final destination from the main mode. If, for the sake of simplicity, we define t_a and t_b as the time it takes to approach and board the main mode as well as to disembark and reach the final destination from this mode, we obtain equation (3) below.[5]

$$t_{ab} = t_a + \frac{d_{ab}}{s_{ab}} + t_b \tag{3}$$

The equation gives a relation between the door-to-door travel time for a distance travelled, given the speed of the main mode, and the transit times to the main mode as well as to the final destination. Hence, for a given distance travelled with aviation as the main mode, the higher average speed will reduce total travel time. While on the other hand increased transit times to, at, and from the airport will increase total travel time and reduce the average speed of the total trip.

As indicated above in an elaborate analysis, transit times to, at and from the airport should be considered as specific trips, with their own distance travelled, speed and waiting time. Each such sub-trip before and after the "dominant mode", i.e. the mode that covers the largest distance travelled in the total travel chain, is made by modes such as walking, cycling, own car, taxi, bus, coach, train, helicopter, aircraft, etc.

We may also build such travelling chains with other modes as the "dominant mode", e.g. a train, own car, coach, etc. We consider each such combination of trips and modes as a "super-

[5] In a more elaborate notation, each of those would also be defined by their relevant distances and speed of travel.

mode" of possible connected transport alternatives to use to travel from any point of origin to any point of destination.[6] The travel time for each "super-mode" m needed to cover a distance between a and b would then be denoted as t_{ab}^{m},

$$t_{ab}^{m} = f(t_{a}^{m},\ d_{ab},\ s_{ab}^{m}, t_{b}^{m}) \tag{4}$$

The above relation gives the traveller the possibility to compare alternative "super-modes" with respect to travel time. Given information regarding the properties and attributes of each "super-mode", we may formulate an optimisation problem to choose the most suitable mode from each point of departure to any destination.[7] In Figure 7, we present a simplified graphic representation of such an algorithm.

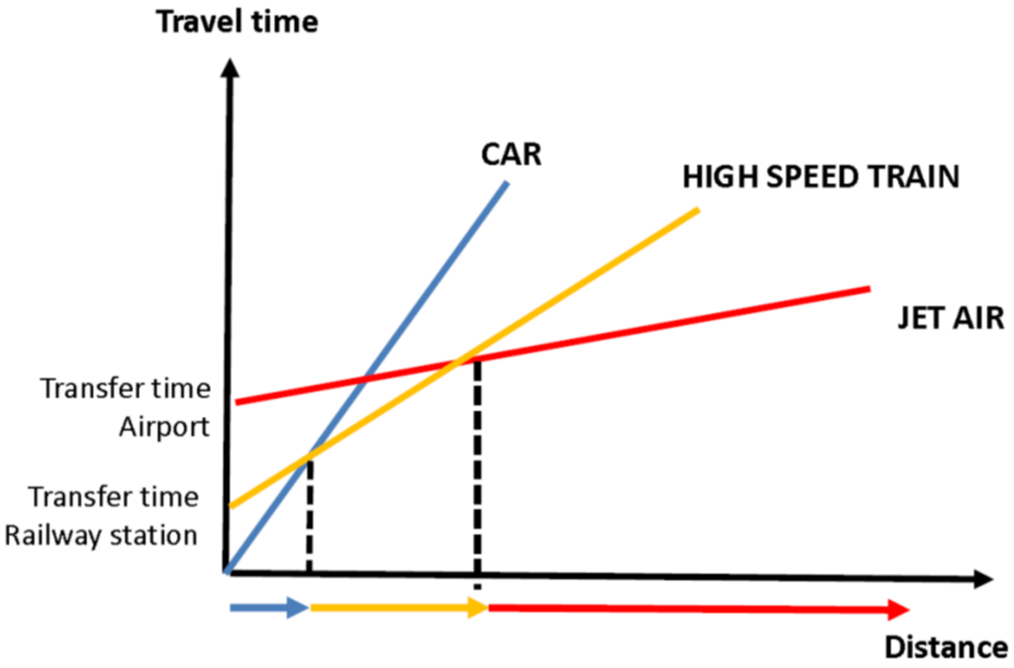

Figure 7. Total door-to-door travel time for three modes of transportation over distance and their respective market segments over distance.

Figure 7 compares travelling by car, high-speed rail and jet aircraft as the dominant modes. The car has the advantage of a short access transit time at point of departure and for leaving it at the destination. In principle, the function for car thus starts at the origin. The other three modes have longer total transit times until the dominant mode is reached, and from the end of that part of the trip to the final destination.

[6] Westin (1990) discusses how such "super-modes" may be introduced in integrated models of transport networks and structural change in regions.

[7] This may be seen as a reduced logit model where all travellers have the same characteristics and exact information regarding alternatives. Hence, the traveller arranges alternatives with respect to travel time only and chooses the mode with shortest travel time for each distance.

In the figure, all travel times to and from the dominant mode are aggregated into a "transfer time" that add a fixed travel time to each mode, expect in the case of travelling by car. This transfer time gives the intercept of each mode with the vertical y-axis. The gradient of the line for each dominant mode is given by its average speed. Less speed gives a slower journey, the steeper the line is and the longer it takes to travel a given distance. The figure thus shows how transfer times and the speed of each main mode will structure the market over distance. Here, one mode will be the optimal choice for each distance and the market will thus be completely segmented by distance travelled.

The graphical "optimisation" in Figure 7 gives as a result that cars dominate travelling short distances. At a certain distance, high-speed rail will begin to prevail over the car, while for longer distances jet air takes over the market for travelling. How might electric aircraft change this picture? Obviously, this will depend on the attributes of electric aviation. In Figure 8 below, we have assumed that electric aviation will use smaller aircraft with less security checks and terminal time and in addition be active at airports located closer to city centres and residential areas. Hence, the transfer time will be shorter compared with jet air, but still electric aircraft will not generally be able to compete with high-speed rail on shorter distances.

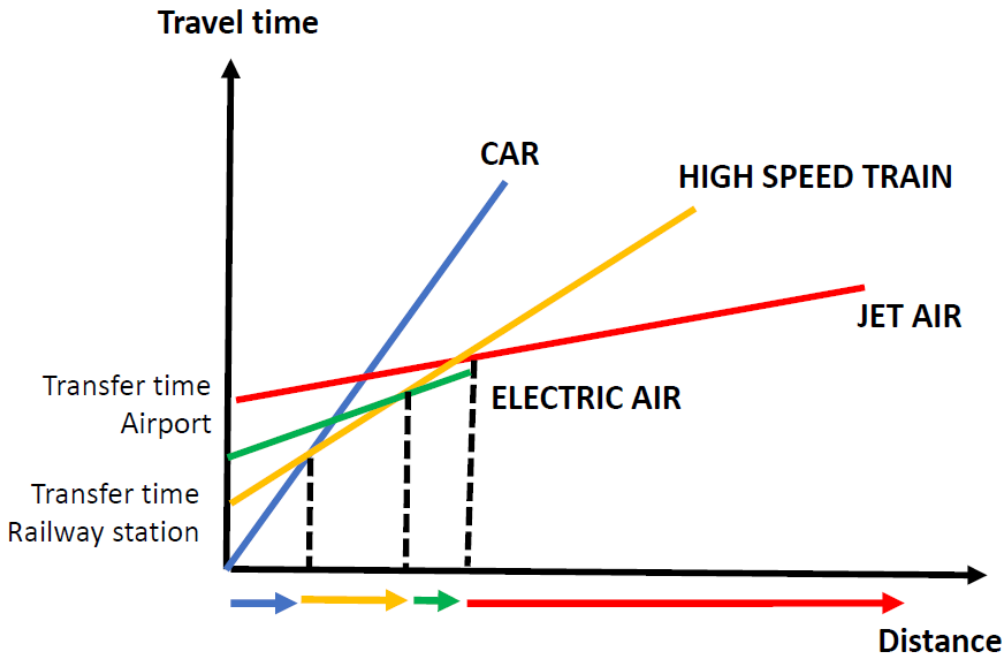

Figure 8. Door-to-door travel time for car, high-speed rail, electric aircraft and jet air with their market segment over distances.

Compared with jet air, electric air would be slower. It may initially offer cruising speeds of 250–350 kph. Moreover, electric air will also initially have a limited flying range due to capacity constraints of batteries. Hence, jet air (preferably partly based on non-fossil fuel) would compete with electric air over the same distances as it outcompetes rail. This gives the *technical space* of an electric aircraft as

- **The *technical space* for a type of electric aircraft at a specific airport**. This is a concentric circle limiting the reach of an aircraft given its technical properties.

The technical space is the distance to an imaginary airport at which the aircraft would have to land once it has run out of energy. Initially, this seems to limit the distance of electric aviation to 400 km for 19-seat aircraft. However, in due time the reach of such electric aircraft may probably be extended to 600 km or even 800 km. Especially for even smaller aircraft.

In Figure 8, the distance to the end of the green line is still shorter than the distance given by the *technical space* for an electric aircraft. Regulatory and security issues will constrain the operational distance far beyond those given by its technical space. In this case, this outer boundary may not be a regular circle since regulations may constrain the distance to alternative existing airports for landing.

Given the technical reach, we may then define the "competitive time space" of an electric aircraft starting from a given airport as:

- **The *competitive time space* for a type of electric aircraft at a specific airport**. Either the technical space, regulatory and security constraints or *other more competitive modes* limit *the outer border* of the competitive space. An *inner border* given by competing modes of transportation may also exist. Within those two borders, the electric aircraft has a competitive time space of door-to-door travelling.

In Figure 8, the electric aircraft would have to compete with cars and rail over short distances. This gives the inner border for its competitive time space. Over foreseen time, it will have a capacity limit at longer distances, where jet aircraft or high-speed rail would be more competitive. Even cars may be competitive again at this longer distance, if it not is possible to recharge or change airplane fast enough to continue a trip.

In Figure 9, such a stopover possibility is illustrated. Travellers may change electric airplane at an airport and thus extend the trip to longer distances. The stopover time then has the same impact as the transfer time to and from airports. In Figure 9 this will extend the competitive time space of the electric aircraft.

However, the possibility to make this extension of the competitive time space is of course dependent on attributes of the airline network, the transfer time between aircraft, or the time needed to recharge an aircraft at an airport.

We may note that if populations with similar assets were distributed equally and with the same density around each airport on a flat earth, airports would be located symmetrically at the same distance from each other and "the competitive time space" of aircraft would not be airport specific. In order for an electric aviation market to be competitive, the distance between locations of airports in such a flat land has to be within the competitive time space of an electric aircraft.

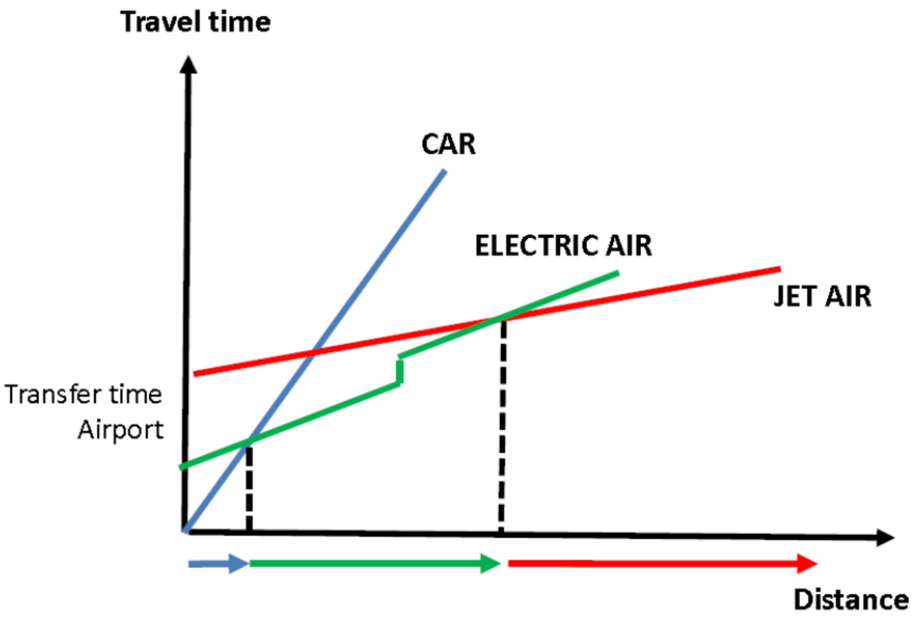

Figure 9. Door-to-door travel time for car, jet air and an electric aircraft with stopover/recharging, and their respective market segments over distance.

To summarize, the competitive time space of an electric aircraft will be determined by:

- The technical range of the aircraft as given by its speed and energy reserves
- The regulatory constraints on the distance the aircraft is allowed to cover
- The total transfer time from origin to the airport, at the airport, potential stopover time to change aircraft and from the airport to the final destination

Moreover, the size of populations and the demand for interaction between two places where airports are located have to be such that a market may be realised for the route. Hence, an electric aircraft may have a competitive time space between airports that would not otherwise generate commercial traffic. This gives a "commercial space" for an aircraft such that,

- **The *commercial space* of an electric aircraft at a specific airport** is bounded by its competitive time space. Even if a competitive time space exists, the commercial space may still be empty during specific periods of time or to some destinations.

Beside the critical attributes, e.g. the size (number of seats) and the speed of an electric aircraft, other modes may reduce the competitive space of the aircraft in certain directions. There may be "non-competitive sectors" even within a competitive time space. Spatially bounded modes like railways and ferries may establish such sectors of non-competitiveness. Nowadays cars and aircraft, including helicopters, are spatially relatively unbounded. Instead high-speed rail offers competitive travel times at distances similar to those that electric aviation does initially. The analysis above thus leads us to conclude that;

- For some time, electric aviation will have quite a narrow outer border of reach.
- Within this distance, e.g. up to 400 km, and in some directions, electric aviation and high-speed-railway will compete for the same market. Beyond this, high-speed trains

and/or jet aircraft will be more competitive. Ultimately, jet aircraft dominate the market for longer distances.

- The car, especially a non-fossil-fuelled car, will be a very strong competitor for distances up to 100 km and will, due to its high degree of flexibility, compete far beyond this within some segments of the market and some routes.
- High-speed rail requires expensive, spatially located infrastructure and needs larger agglomerations to be cost effective. In directions where high-speed railways or ordinary trains are inefficient, electric aviation may be competitive.
- In directions without land-based communication, such as over straits, seas and mountainous areas, electric aircraft may be very competitive.

For the time being, this limits electric aviation to a relatively narrow commercial space. Total demand for transportation falls drastically for trips beyond 100 km, while train and car still are competitive up to 400 km. Figure 10 below illustrates how the number of trips in Sweden rapidly decreases when distance increases from 100 to 500 km.

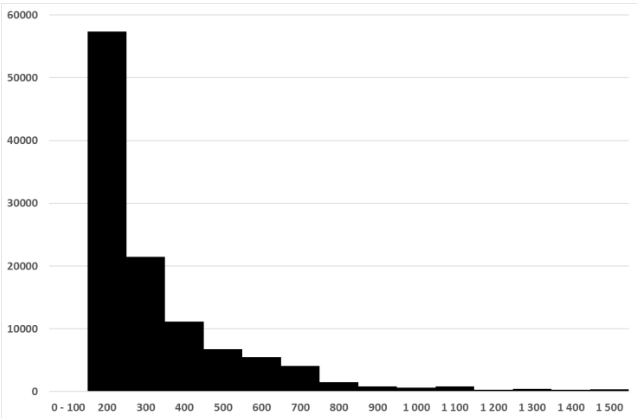

Figure 10. Number of trips over distance in Sweden. Average for the years 2011-2016 measured in 1 000 trips. Data from RVU Sweden and Traffic analysis.

Moreover, Figure 11 below illustrates how market shares for transport modes change with increased distance, as we would expect from our graphical analysis of optimal distance above. However, contrary to the results of our graphical analysis, data show that no single mode dominates – i.e. monopolises –each distance. Instead, all modes are used by travellers over all distances. All the same and as expected, travel time explains much of the market shares. Cars dominate short distances, while aircraft dominate long distances.

Railways, buses and coaches are also used by travellers for both short and long distances, with a larger market share up to 800 kilometres. The car is a flexible mode with the capacity to carry both people and equipment, and is used over all distances. Especially, of course, on routes where rail and airports not are available, but also when it can be also used for short trips at the destination.

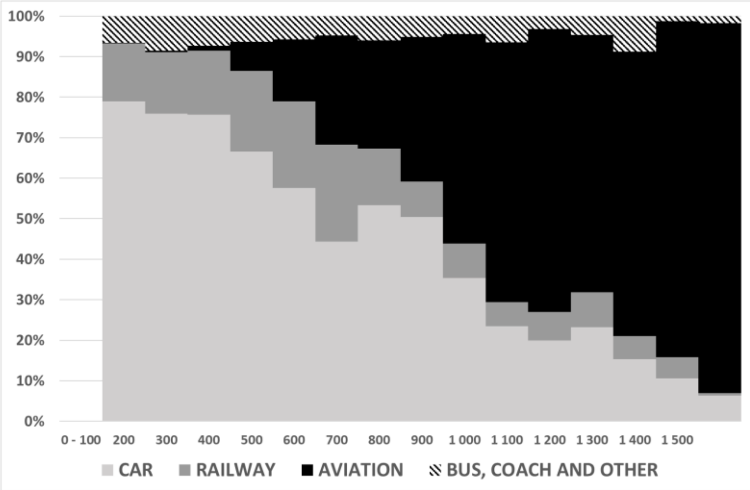

Figure 11. Market share of modes over travel distance in Sweden. Average for trips 2011-2016. Data from RVU Sweden and Traffic analysis.

Figure 11 clearly indicates that the market share for air at distances under 400 km is limited. Competition from car and high-speed rail are evident at these distances. This does not mean that travellers make no short trips at all by air. As seen in Figure 12, trips are made at distances under 400 km, e.g. the over-sea route between Stockholm and Visby is around 200 km. In Sweden, trips within the 600–800 km interval still make up around 35 per cent of the trips below 1 600 km made by air; this interval thus dominates domestic air travel. This reflects the geography of Sweden. At such distances, cities outside Stockholm are smaller and aviation has an advantage compared with other modes.

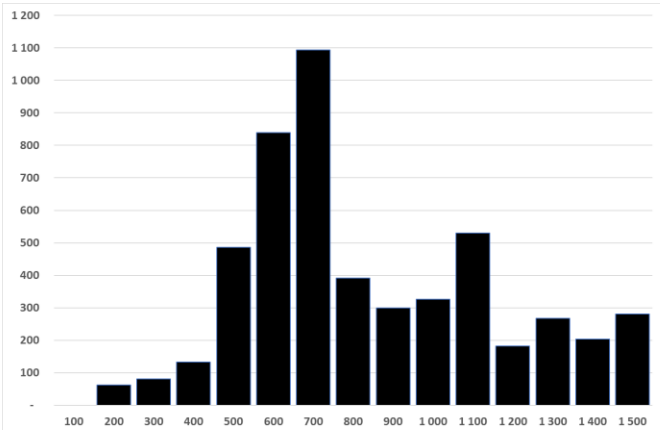

Figure 12. Number of 1 000 trips by air over travelled distance in Sweden. Average for trips during years 2011-2016. Data from RVU Sweden and Traffic analysis.

On the other hand, the small number of flights by air for distances from 200 to 400 km may also reflect institutional constraints in the Swedish market for aviation. In a sparsely populated country like Sweden and at such distances, one would expect aviation to be used more frequently for regional transportation.

The difference between our previous results from "graphical optimization" and the empirical pattern presented here illustrates the diversity of the travel market. Preferences, household and business budget constraints, fares, demand for individual versus collective mobility, possibilities to bring luggage and equipment, availability of a mode, schedules, etc. are important, besides the door-to-door travel time we used in the graphical analysis. All together this creates overlapping areas of demand for modes over distance.

When we assume, as in our graphical analysis, that customers evaluate alternatives only with respect to travel time, we end up with distance monopolies for each mode. The only travel cost considered therefore is time spent, time with an alternative use, such as for work, leisure, etc. We may nevertheless extend our graphical analysis to a generalised transport cost for each part of the trip by a specific "super-mode", where fare, comfort, service, security, luggage constraints, waiting time, etc. are included. We may also assume that customers weight these attributes differently, have diverse preferences and have more or less binding budget constraints. If we introduce such aspects, we would obtain a network model of travel behaviour where, even if each traveller were to make decisions based on considerations like those given in our graphs, the societal outcome of many such decisions over a given period would resemble what we have illustrated in figures 10-12.[8]

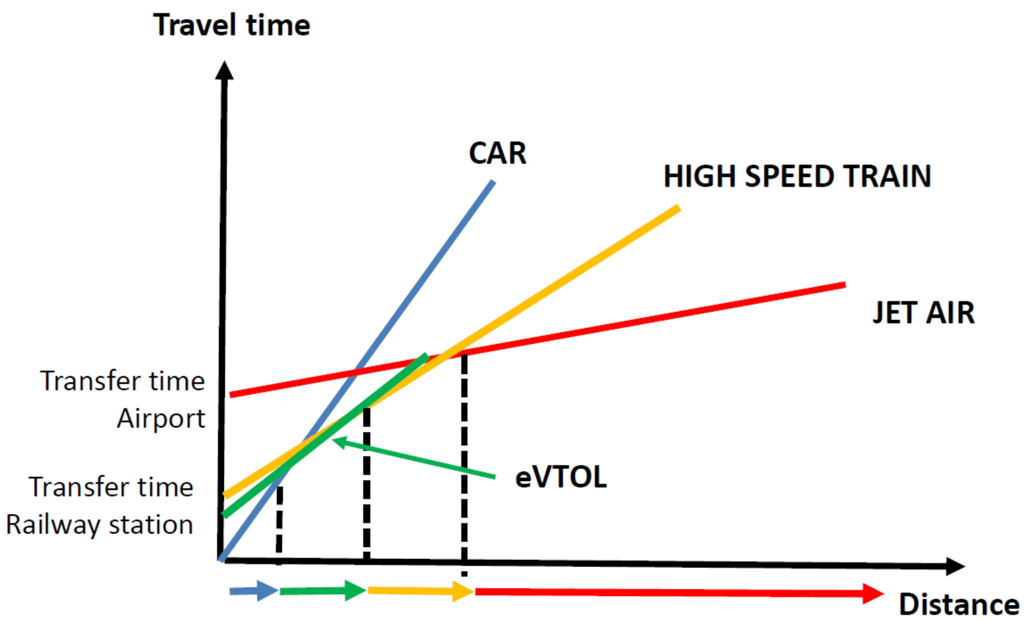

Figure 13. Total travel time for modes over distances, with an eVTOL in green.

In the pipeline of electric aviation, we also find the electric VTOL, (eVTOL). An eVTOL may offer attributes for transportation that lie between an aircraft and a helicopter. It only needs a

[8] This is actually what we would expect from a multinomial logit model where travellers have different characteristics, do not have perfect information and consider factors not modelled explicitly, but are taken care of with an error term. Compare our comments in an earlier footnote.

heliport to land and take-off, a fact that will shorten transfer times drastically once heliports are integrated into the urban landscape. The eVTOL will compete with both cars and public transportation over short to medium-long distances. It may offer time efficient commuter alternatives between home and office similar to a taxi. In figure 13 above, we have introduced an eVTOL into the previous simplified graphic analysis.

The figure illustrates how an eVTOL reduces the distance near home, offices, etc. where the car currently has a very strong position. However, dependent on the outer reach of the eVTOL and the speed it may offer, trains may also lose their competitive position. A combination of eVTOL and electric aircraft may thus be a strong competitor for ordinary rail as well as high-speed rail.

3.2. The competitive space for electric aviation across the strait of Kvarken

In the Kvarken region, the ferry over the strait between the cities Umeå and Vaasa connects and offers a short cut between European, national and regional road networks. The ferry tour took 4.5 hours. The new ferry has reduced this to 3.3 hours, thus to some extent limiting the competitive advantage for aviation measured in travel time alone across the strait.

In their interesting study of electric aviation, Traffic Analysis (2020), use a concept to identify competitiveness along the lines presented above, with travel time as the only factor of determination, in order to identify the competitive range of electric aircraft. In the following two tables, we have extended their approach somewhat, used some data from their report, and added some new data. Here we focus on the Kvarken strait relations between cities Örnsköldsvik, Umeå and Skellefteå on the Western side of the strait with Jakobstad and Vaasa on the Eastern side. Travellers choosing electric aviation from Örnsköldsvik or Umeå to Seinäjoki would have similar travel times as those travelling from Skellefteå to Vaasa and to Karleby/Jakobstad.

There are, however, alternatives to the ferry, which is contested to some extent, especially for freight. The ten-hour route by car or truck around the Gulf of Bothnia is one alternative. The distance of this route is 835 km. According to Google maps, this would take 600 minutes without stops, at an average speed of around 85 km/h. A third alternative is to fly by jet Vaasa-Helsinki-Arlanda-Umeå, a distance of 1 250 km. The travel time in the air would be approximately 160 minutes; adding transfer time to include two changes of aircraft at airports, the total travel time could reach 380 minutes, at an average speed of 200 km/h. Even though this alternative offers the highest speed, the distance makes it inferior to the ferry line, especially the new vessel. A fourth alternative is the charter/taxi aviation option with smaller aircraft. Since this alternative, from a pure travel time perspective, is close to a possible electric aircraft, we will not consider it further here.

Table 3 compares the three alternatives for travelling between Vaasa and Umeå with the new option to fly with an electric aircraft. We also compare alternatives by electric aircraft between Skellefteå, Karelby and Örnsköldsvik. Lastly, we have considered a possible eVTOL between Umeå and Vaasa.

Table 3. Approximate distance (km), travel time (min) and speed (km/h) by mode for the Vaasa-Umeå relation over the strait of Kvarken. Source: Google Maps, Traffic Analysis (2020).

Route and Mode	Distance (km)	Transit time (min)	Travel time, main mode (min)	Total travel time (min)	Average speed main mode	Average Speed of trip, km/h
Vaasa – Haparanda – Umeå (Car)	835	0	600	***600***	85	85
Vaasa – HEL- ARL – Umeå (Jet Air)	1 250	220	160	***380***	470	200
Vaasa – Umeå (New Ferry)	110	100	195	***295***	35	25
Vaasa – Umeå (Electric Air)	110	100	30	***130***	220	50
Vaasa – Skellefteå (Electric Air)	190	100	40	***140***	285	80
Karleby/Jakob. – Skellefteå (Ele. Air)	150	100	35	***135***	255	65
Vaasa – Örnsköldsvik (Electric Air)	100	100	30	***130***	200	45
Vaasa – Umeå (eVTOL)	110	30	50	***80***	130	80

Following Traffic Analysis (2020), and in order to simplify, we have assumed transit times to be 100 minutes for all flights not involving a change of aircraft. Our aim here is to compare electric aircraft with other transport alternatives. The analysis may be developed with more detailed estimates of transit times where distance of airports to city centres or accessibility in general may be important to estimate the overall accessibility to the market of an airport. This would be relevant in relations where transit times may be important for the outcome.

There are other factors that also add uncertainty to the analysis. For example, it is still too early to have a specific opinion regarding the speed of electric aircraft. Traffic Analysis (2020) assumed travel times to exceed "conventional aircraft" by 30 per cent. In our case, the short distance over the Kvarken strait, and the small size of aircraft, will mean that speed differences not will matter much. On the routes from Skellefteå to Vaasa and to Seinäjoki (not shown in the table) speed differences may be more conspicuous, but according to the table this would not make the new ferry, for example, a competitive alternative on these relations. Instead, our conclusion regarding the competitive situation between electric aviation and other modes of transportation for passengers and freight of smaller entities is that,

- Electric aviation will be a competitive alternative for many routes over the Kvarken strait.
- Although not shown explicitly, the table also indicates that the short distance means that a fixed link over the strait would make "land-based" transportation by car and rail very competitive. However, the greater the distance of the origin and destination of a flight over the strait from such a fixed link, the less the advantage is.

In the table we have assumed the same transit times for the ferry as for electric air, 50 minutes on each side. A faster and smoother boarding process for aviation would thus add to the competitiveness of electric air.

Moreover, in the last row we have included the prospective eVTOL. Those will operate from more central heliports in cities. Thus, we assume in total only 30 minutes for approach, boarding and embarking to the destination. The total time for the eVTOL may thus also be seen as a goal for aviation over the strait by electric aircraft, where airports should be located as close to city centres as possible, while time on airport shuttles/taxis/trains and terminal time is minimised. An eVTOL with a large enough operating area may therefore also compete with electric aircraft for short distances, such as over the Kvarken strait.

In the table we also observe that the average speed of an electric aircraft, as for current aircraft, depends on the distance and travel time of a route. It takes time to get permission to start, taxi out, take off and reach cruising speed. The average speed of this part of a flight, as well as for landing and taxiing to terminal, is less than the cruising speed. Flights with small aircraft between small airports may, on the other hand, offer fewer obstacles of this sort. In short, the average speed of the flight will be less than the cruising speed, which in turn is, less than the maximal speed of the aircraft. With increased distance, the average speed will approach, though not reach, the aircraft's cruising speed, unless non-cruising time is compensated by periods of flying faster than the cruising speed. Hence,

Average speed (kph) = Distance / [Time to reach cruising + Time cruising + Time faster than cruising speed + Time from cruising to landing]

This also means that the larger the share of time to reach cruising speed is of total flying time, the less the benefit of flying is compared with its alternatives. Since the cost of reaching the flight altitude, and thus cruising speed, is much higher compared with cruising, average speed will decrease and the cost of the flight per km increases for shorter distances. In addition to this, costs of inspection and maintenance correlate with the number of flights made with an individual aircraft (due to material exhaustion during landing and take-off), which make short distances, such as over the Kvarken strait, relatively costlier than longer flights. In order to compensate for this, the number of empty seats must be reduced, the cabin factor has to be higher, or fares increased on passengers with low price elasticity.

3.3. Is aviation across the strait of Kvarken commercially feasible?

As became obvious from Table 3 above, alternatives with aviation would outcompete other alternatives over the Kvarken strait from a travel time perspective. The new ferry needs around two hours and forty-five minutes in additional travel time. The current ferry takes four and a half hours to cross the strait. As mentioned, for the moment there is no regular commercial airborne traffic on the route. This may come as a surprise given the time advantage. Either travellers do not value less travel time enough to choose the air option, or the airfare is too expensive to justify the time saved. The latter may be explained by either monopolistic behaviour in the market or the costs to operate and market a regular route over the strait.

We have already touched upon the fact that the longer it takes to reach cruising speed, the costlier a flight becomes compared with the alternatives. Here we have one of many features in aviation characterised by return to scale. Together with other fixed costs of various types, this reduces competition, creates a barrier to entry and favours oligopolistic and monopolistic behaviour. As is well known, such behaviour would increase fares and reduce output compared with a more competitive environment. This is especially so if demand is a binding constraint or an airline needs financial persistence to reach out to and learn the market; that is, how a route may be included in customers' travel alternatives. This demand for persistence calls for a financially strong actor willing to assume any initial costs until the market has been established.

In this respect, the choice of aircraft for a specific route relative to the demand on this route becomes crucial. A large aircraft needs more passengers to reduce the gap between unit cost and fare. A small aircraft may on the other hand have too few seats to cover the fixed costs of the airline, fees at airports and regulatory costs connected with staff, etc. The profitable "window" for regular line-based flights may thus be quite narrow when a new line is initiated.

In the Kvarken strait case, the ferry currently offers daily connections. If we assume that 200 000 passengers will use the new ferry during an ordinary year, this would give an average of 275 passengers per day in each direction.[9] The capacity of the new ferry will be 800 passengers and the seasonal pattern will reduce the number of passengers in winter time. In the summer the ferry may reach its daily capacity, both in terms of number of passengers per tour and number of tours possible. Currently, a single adult ticket with the ferry is €36/SEK380 during winter and €41/SEK430 in the summer. There are discounts for various groups.

What fare would some of these travellers be willing to pay for a seat in the air on the same route? According to Trafikverket (2020), the most current estimate by ASEK 7 of the value of a saved hour for an ordinary passenger by air is around 130 SEK per hour. This gives a willingness to pay 360 SEK to save time by using of aviation instead of the new ferry, and 520 SEK if the current ferry were the alternative. Hence, an air ticket of around 750 SEK/€74 or below would be competitive for ordinary passengers.

As touched upon above, the further from Umeå and Vaasa a flight starts and lands while the distance in air does not increase too much, as in the case of Skellefteå – Karleby/Jakobstad or Örnsköldsvik – Vaasa, the possibility of saving time by flying instead of going by ferry increases. Hence, willingness to pay to save time may increase on those relations.

In the case of business travel, the value of a saved hour is higher, namely 340 SEK. Saving two hours and forty-five minutes for a Swedish business traveller between Vaasa and Umeå would thus imply a willingness to pay around 1 350 SEK/€133 for a single ticket over the strait. An airline that offers a smooth time saving approach to, from and at airports, may increase this amount slightly. During peak seasons for the ferry, an airline may also increase the fare or increase the number of flights per day.

With the option of flying over the strait, a full one-day visit on either side becomes an alternative, an alternative that may save the cost of a stayover at a hotel. Moreover, the differences in time zones between Sweden and Finland may add an interest to reduce the travel time in at least one direction. A combined ferry ticket, with air in one direction, at a

[9] Over the years, 1991 generated a record in number of passengers: 1 208 634 passengers used the ferry that year. Although seasonal variations are large, this means an average of around 1 650 a day in each direction. There were at that time attempts to initiate a regular airline, but none was viable.

price of 1 700 SEK/ €178 could thus be an alternative, e.g. for the business traveller engaged in a workshop or conference during the ferry part of the trip.

A competing airborne alternative is to fly Umeå – Stockholm/Arlanda – Helsinki/Vantaa – Vaasa. This involves three changes of aircraft. The estimated travel time for this was shown in Table 3. A ticket for this route may cost around 3 000 SEK/€295 or more. Since the travel time in this case would be similar to the current ferry connection but exceed the travel time of the new ferry, in general this alternative would be inferior to the ferry.

Seasonally there has been a direct flight Umeå – Helsinki/Vantaa. This alternative and the tour via Arlanda would of course compete with travellers flying Umeå – Vaasa with Helsinki as their destination. These alternatives are today used for conferences and meetings. Helsinki and Arlanda are therefore preferred venues over Umeå or Vaasa. The timetable and frequency of the flights between Umeå and Vaasa would then determine the competitiveness of the direct route and the willingness to change venue to the Kvarken region.

Given the existing alternatives and the price of their tickets, together with our estimates of willingness of passengers to pay for a flight, an operator of an airline has to find a timetable, size of airplane and terminal solutions at airports that make it possible to offer fares within the intervals discussed above and to reach a large enough group of customers.

The airline has an average total cost for a specific aircraft used on a route. The fare will, given the competitive situation, be dependent on the number of passengers per flight. The average cabin factor may then be calculated as the quota between paying passengers and number of seats in the aircraft. In Figure 14 we have illustrated this ratio with three cases.

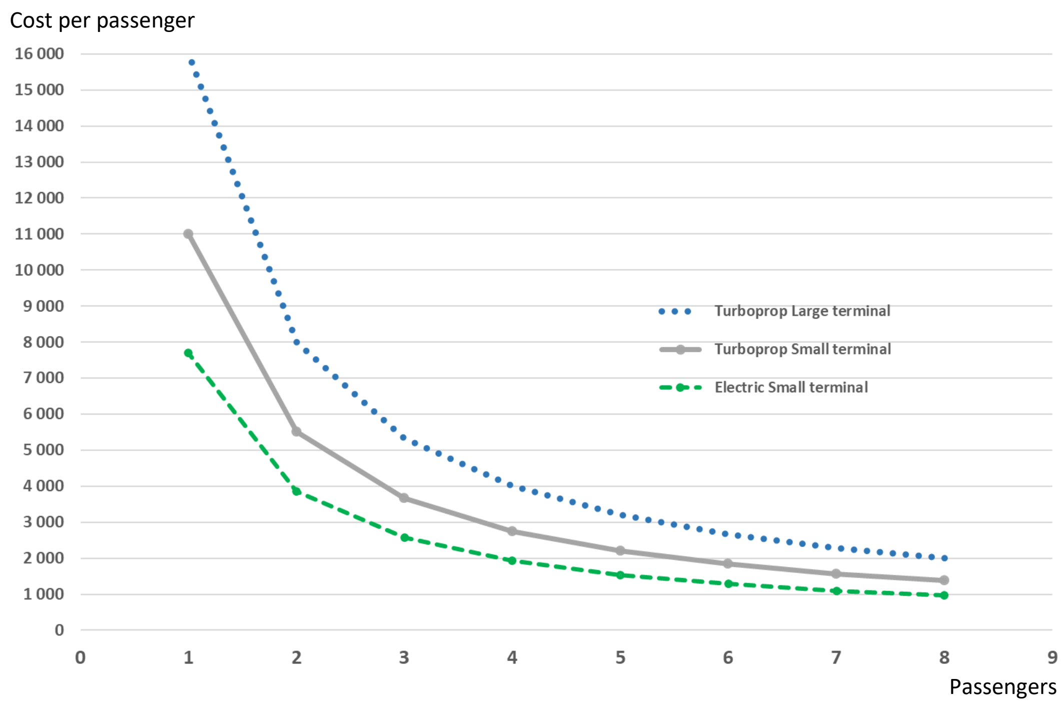

Figure 14. Total cost per passenger in SEK of an eight-seat aircraft for three alternative options.

The "Turboprop large terminal" case assumes that the cost of an eight-seat aircraft on the route is 16 000 SEK/€1 578. This includes the cost for mandatory services at a large full-scale airport.[10] If all seats are sold, a fare of 2 000 SEK/€197 is needed to cover the cost of the flight. With six seats sold, and thus a cabin factor of 75 per cent, the fare has to be raised to 2 700 SEK/€266. Since our previous discussed estimated willingness to pay for time saved are averages, there may be a group of business travellers that accepts this fare, especially if a hotel night may be saved. On the other hand, this also indicates that for other business travellers and ordinary travellers this fare may be too high.

The second alternative, Turboprop small terminal, implies an agreement between an airport and an airline, where the latter not makes use of the ordinary large terminal building, its services and associated costs, but instead has its own downsized smaller terminal and takes care of handling the aircraft before and after a flight in house. We estimate, for the moment on weak grounds, that this would reduce the cost per flight by around 5 000 SEK/€493.

In this case, the cost per passenger with a full plane and eight passengers would be around 1 375 SEK/€136. With six passengers, a cabin factor of 75 per cent, the fare would have to increase to 1 850 SEK/€183. Clearly, such fares are closer to those necessary given our willingness to pay for saved travel time calculations above. Combinations of higher business fares and cheaper "stand by" fares may fill the aircraft in a way that covers this cost. For a charter/taxi-oriented airline this case seems viable, while a regular timetable driven airline may be more vulnerable to instability in demand. In much, the viability of the route for an airline will then be dependent on the total capacity utilisation with regard to aircraft, staff, terminal, etc. for the airline.

Lastly, the third alternative, identified here as "Electric small terminal", is a future alternative with an electric aircraft used by an airline that, as in the previous case, operates from a low-cost small terminal at an airport. We assume that the sum of capital and operative costs for an electric aircraft will reduce the total costs of a flight by 30 per cent.[11] In this case, six passengers (75 per cent cabin factor) and a fare of around 1 300 SEK/€128 would make a flight viable. Four passengers and a fare of 2 000 SEK/€198 would also cover the costs of the flight.

With a larger (e.g. a nineteen-seat) aircraft that still is managed from a small terminal, the possibility to offer lower priced tickets would obviously increase. The cost per flight would increase, but not at the same proportion as the number of seats. However, demand also has to increase in order for the average cabin factor to be at a sustainable level. A larger aircraft may, however, offer possibilities to allow more crowded flights to cover losses from flights

[10] Due to the network character and broad variety of services offered, production, cost and profit functions for airlines are complex to formulate analytically and numerically. Economies of scale in many parts of the production function and the airline market share on individual lines as well as over the network the airline is active on are important factors adding to the complexity.

[11] The costliest part of a flight with an aircraft with jet engines is from start until cruise speed is reached. The cost function is thus dependent on the length of flights. A short flight is costly per km travelled. For aircrafts with few seats, this cost has to be distributed among few passengers. The hope is that electric engines may reduce this cost to some extent. Besides this, maintenance costs may also be reduced. On the other hand, capital cost may increase to cover the cost of batteries. Initially capital costs may also increase since there will not be a second-hand market for electric aircrafts. The second-hand market is an important way for many airlines to reduce the capital cost of an aircraft.

with too few passengers. With an eight-seat aircraft, the vulnerability to instabilities and demand shortage on each flight may be higher.

In a market with fluctuating and uncertain demand, a situation where smaller aircraft are too small to secure enough yields to be in regular line-based traffic, while the next size of aircraft is too large, the economic risk of operation may be prohibitive for an airline to enter the market.

Hence and as mentioned, many reasons may account for why a regular commuter line is not operating over the strait today. The most obvious is that demand is a constraint. As we have seen, in order to have a regional commuter line over such a distance as the strait, short though it is, an airline with a small aircraft has to fill each tour every day with business travellers. The population and economy of the Kvarken region may be too small, and too poor, to provide such a route with sufficient passengers. The industries on either side of the strait, the international border, different currencies and, for many, different languages may also make the Kvarken region insufficiently integrated to build the commercial basis for such a line.

On the other hand, today it is possible to use the charter flight option. It is unclear how many passengers this alternative attracts today. Given that in an ordinary year an average of 275 passengers travel daily on the ferry in each direction, it is not unlikely that there are at least eight persons among them that would be willing to pay to reduce their travel time. However, as we have seen, at this level this would still be a line characterised with substantial risk. An alternative that offers a reduced cost for flying – e.g. an electric aircraft – as part of a regional public transport system, would clearly reduce this risk.

4. Creating regular regional aviation for the Kvarken strait

4.1. Market failures and policy failures

Looking back at the history of aviation over the Kvarken strait, many attempts have been made to initiate regular lines, none of which have been long standing. As discussed earlier, passenger figures for the ferry indicate the existence of a potential demand to travel over the strait more quickly than on the ferry, but the repeated failures to establish a regular airline indicate the contrary. Besides the fare offered for a flight, there must be other reasons why demand for aviation not has been sufficient for regular operations to start.

For a long time, traffic on the ferry line was “boosted” by subsidies from tax-free sales. Together with strong restrictions on the number of permissions to offer alcohol at restaurants in Umeå as well as a restrictive policy including high taxes on alcohol at the national liquor store monopoly “Systembolaget”, this induced a “party concept” on international ferries, which did not generally exist on domestic ferries operated by the Swedish Transport Administration, for example, and its precursor for roads “Vägverket”[12]. The Kvarken trip offered a perfect distance for this type of “over the day” or weekend travel. The situation has

[12] The Swedish National Road Administration, “Vägverket”, had a road ferry division responsible for domestic ferries. This is now the shipping company STA Road Ferries, “Trafikverket Färjerederiet”.

now changed. It has nonetheless taken almost two decennia to restore the ferry line from this "tax free party hang over". With the new ferry this "turn around" of the market may be said to have been completed.

However, not even during the period after the abolition of tax-free fares – when the ferry line almost closed down – was a regular commercial airline opened. This may be a sign of very low demand for business or faster travel over the strait in general. However, it may also be an indicator of various institutional failures in the market for travel, or that business models have been applied that failed to distribute risk and awards to the right actors.

Needless to say, if Finland and Sweden had been one country, the "National transport administration" would have been responsible for the Kvarken ferry as a domestic line, and as a part of the European road E12. On the "road ferry" we would also find coaches which, to greater or lesser extent, were parts of national or regional public transport systems for the integrated country.

In such a case there would probably also be regular flights between larger cities in Northern Sweden and Helsinki and vice versa from Northern Finland to Arlanda. The number of flights would obviously be dependent on whether Stockholm, Helsinki, or another city, was the capital for such an integrated country.

Other arguments may also be put forward to explain the absence of long-standing sustainable flights over the strait. Attempts have been made with excessively large aircraft, as if actors had overestimated the demand that could be captured from the ferry. Not surprisingly, a low cabin factor soon motivated close down. This may clearly be a sign of demand shortage. However, there have recently been regular seasonal flights between Umeå and Helsinki, some of which are feeder traffic for routes further on to Asia. This may indicate the existence of a slowly increasing demand based on the collapse of the Soviet Union, the new independent states in Eastern Europe and the increased interest in China, Japan, and South East Asia.

Nonetheless, demand may still be too weak or too volatile to cover the cost of larger aircraft, while on the other hand smaller aircraft are too small to offer competitive fares and, as we have illustrated, may be too vulnerable to seasonal passenger shortages. Hence, the cost structure of aviation (permissions, staff, etc.) may currently be such that there is a shortage of demand due to high fares in small aircraft, while the needed persistence for an airline to create a market for nineteen-seat aircraft, for example, is not currently available, at least not in the market.

Aviation, the complete chain of airlines, aircraft, airports, etc. is costly. Economically, it has long been difficult for many airlines to survive. Mergers and acquisitions are common. At the same time, low cost carriers have forced air travel into directions similar to other modes of public transport, but without it being considered public transport in all aspects. Low cost carriers have tended to use smaller airfields, avoiding the fees of larger often government-owned airports. There are economies of scale both within airports and in networks created by airports. This gives owners of airports relatively strong monopolies in relation to specific cities, cities that are competing for flights with nearby cities and their airports. The value of land near city centres is also high, so municipalities avoid having competing airports within their jurisdictions even though this would increase competition. Added to this, airports, number of passengers and networks of flights, especially to larger and international cities, continue to be signals of exclusivity and attractiveness, signals used by municipalities as well as nations to attract business, tourists and inhabitants. Obviously, accessibility of this kind is important and many aspects of indivisibilities and returns to scale may, to some degree, motivate airports to be a kind of local public good and be treated as public monopolies. The question is what aspects of the market for aviation this holds for and how public bodies use any monopoly positions gained.

As we have observed a number of times, airlines act in environments characterised by returns to scale. The importance of market shares and international network collaboration are signs of this. Even small airlines deal with various indivisibilities and regulations, creating a demand for scale and a need to manage risks associated with an excessively diversified and scattered business. This can result in oligopolistic market structures or even local spatial monopolies.

All together this may have created market structures and “lock ins” where small airlines have difficulty in finding larger airports that are economically feasible as their base for operation. State-owned public airport systems may find operating with small airlines costly when they are competing with other nations to have a large airport near their capital.

This has set, or redirected, the integrated industry of aviation on a path shown by larger aircraft, larger airlines and a focus on fewer and larger airports, visible for many years. What has been lost or what has not been developed further in this development of events? Given the situation in northern Sweden and parts of Finland, with small cities at some distance from each other and many small villages in the forest land and in mountain areas, one would expect to find small- and medium-sized airlines active in developing networks between them, commercially or as part of a regional public transport system. More like buses and taxis, and as complements to the public procured and tax-financed rail operators found in many dense areas.

Instead, the regional public transport administrations in Sweden (“Kollektivtrafikmyndighet” or “Regionala kollektivtrafikmyndigheten”) are not allowed to procure airlines, though they can procure most land-based modes. Instead, procurement of airlines is monopolised at the national level and the Swedish Transport Administration (“Trafikverket”)[13] which, with a few exceptions, procures flights from sparsely populated regions directly to Arlanda and the capital with feeds to Brussels and the EU, instead of procuring flights to regional hubs that may be core lines in a network for regional systems of aviation. If this creates social-economic inefficiencies in regional transportation networks, it is a sign of institutional and policy failure. Since market failures often result from unregulated companies with control over markets characterised by strong returns to scale, it is likely that *the market for regional aviation is hampered by combinations of market and policy failures.*

[13] In Finland “Traficom”.

4.2. Towards efficient cross border travelling in Kvarken

For the moment, the shipping company Wasaline owns the ferry operating the Umeå-Vaasa route. Wasaline is owned by Umeå and Vaasa municipalities through Kvarken Link Oy. These two municipalities are also members of the Kvarken Council (Kvarkenrådet/Merenkurkun neuvosto), recently transformed into an EGTC.[14] The Kvarken council "strives to promote and develop a strong and viable region with the help of cross-border cooperation". Over the years its focus has been on maritime traffic, such as the ferry line. However, now and then attempts have also been made to develop airlines. In particular, when the European airline market was deregulated in 1992 and the concession rules that constrained airlines to operate in other countries were abolished [Kvarkenrådet (1992b)], visions were created and attempts made to initiate regular traffic. These visions to create a viable network of airlines for a larger Nordic region pointed in the right direction but were never realised. The obstacles we have already discussed were probably important but the fact that Nordic economies stagnated during the 1990s may also have played a role. When tax exemptions were abolished in 1999, efforts were focused on the ferry line, while instead the hub-spoke national air networks with airports in capitals developed even stronger in the new deregulated and even more global aviation environment.

Meanwhile, the population in Västerbotten grows, the interest in flights to Helsinki has increased slightly, the investment in a new ferry signals a continued demand to travel and to ship goods across the strait, and the recent demand for labour in the new battery related industries makes a Nordic network of airlines interesting again. If costs can be reduced by electric power systems, this will add to the interest in aviation.

As discussed however, institutional peculiarities still seem to constrain the development of such a network. Who are the actors that might undertake such initiatives? For the moment, it seems that airlines need a more stable market and more risk sharing in order to take the lead. Airports might be interested, once markets and aircraft are larger, while regional public transport administrations are prohibited by law to deal with aviation and the national public transport administration, at least in Sweden, is focused on airlines bound for Arlanda.

The Norwegian situation, however, with public procurement of airlines for transport to and from airports on islands in the archipelago, shows that this need not be the case. Having observed this, the Norwegian solution may not be a socially efficient transport solution for Sweden and Finland. As a newly established EGTC, what role the Kvarken council may play to establish a socially efficient cross-border transport system for Swedish and Finnish tax payers still is an open question, besides its role to promote, support and undertake initiatives. One such initiative could be not only to promote the ferry but also to pick up the ideas from the 1990s and undertake initiatives within air transportation. Along with the owners, the municipalities could investigate whether the shipping company Wasaline may extend its role from its historical one as facilitator of sea communication to communication in general over the strait, thus also including transportation by air?

[14] European Grouping of Territorial Cooperation. An EGTC is a European legal instrument designed to facilitate and promote cross-border, transnational and interregional cooperation. The EGTC is a legal entity and as such, will enable regional and local authorities and other public bodies from different member states to set up cooperation groupings with legal entity.

Wasaline already markets the cross-border sea route and has knowledge regarding the travel market in this respect. It might therefore be advantageous if Wasaline were also responsible for marketing an airline on the same route. The airline option would complement the offer to ship and move between Umeå and Vaasa with a ferry. As mentioned above, various forms of combined tickets could be offered. Wasaline may also have the economic possibilities and persistence to develop such a line, find and develop a suitable business model with risk sharing, financing and award sharing among actors, and make the line known to a larger market. Such a route could also potentially be extended in various directions while collaborations with designated airlines could further increase markets and possibilities.

Would it be socially efficient? Would it be a burden for Wasaline? To start with the second question, surely not. In a first step, a test with one morning and one afternoon flight back and forth could be scheduled for, say, 300 days a year. According to our pervious figures (eight-seat turboprop aircraft operating from a small terminal) this would imply 1 440 flights at a total cost of 15 480 000 SEK/ €1 529 522 a year. If each flight had an average of six passengers (a cabin factor of 75 per cent) this would be 7 200 passengers altogether, i.e. 3.6 per cent of the annual stock of ferry passengers as assumed above. With a fare of 1 835 SEK/€181, all costs for this route would be covered by the passengers.

If those 7 200 passengers all came from the ferry, the ferry line would lose around 2 900 000 SEK in tickets. Add to this a loss of income from on-board offers. Some of this could be compensated by offers to passengers that have booked the ferry to be "stand-by" for air and "fill up" each aircraft if they add, say, 400 SEK to the price of the ferry ticket and then receive a seat on the aircraft. Alternatively, the fare for the flight could be increased. But such parasitizing by the airline on ferry passengers is only one outcome.

Another outcome is for the airline to add new passengers to the ferry by offering a faster trip in one direction. It could also attract new travellers for whom the ferry trip and the time it takes has never been an alternative. By extending the routes to other airports such as Örnsköldsvik, Skellefteå and Karleby-Jakobstad/Kokkola-Pietarsaari, new markets may open up. Fast and more frequent airline interaction may as such also generate new reasons for travelling and shipping freight over the strait. Lastly, the airline could provide extra capacity in the summer on days when the ferry exceeds its capacity, thus increasing the total number of travellers on the combined sea and air route over the Kvarken strait during peak seasons.

What about the social costs and benefits? We saw earlier ordinary and business travellers' willingness to pay for shorter travel times. If, as we calculated, 7 200 ferry passengers wished to use the airline for a year instead, the value of their time saved would be between 2.6 million SEK/€255 160 and 9.7 million SEK/€951 942, depending on whether or not they were business travellers and not considering any changes in consumer surpluses. As in any CBA for road and rail investments, those benefits should be related to the social costs of flying. We estimated earlier the private cost of managing such an airline at around 15 million SEK/€1,47 million. In an extended CBA, such benefits and costs can be calculated more in detail, and be inputs to negotiations regarding a division of fares and costs between public and private interests. Would those foregone benefits due to time saving be a motivation for public initiatives? Surely not, with no barrier to entry, the fact that there is no airline would merely be a sign of how costly it is to fly over short distances. Electric aircraft may or may not reduce these costs enough for an airline to be established. But if there are barriers to entry from returns to scale economics or institutional constraints, then this might motivate a policy to overcome those obstacles.

Regarding the operation, there are obviously various alternatives available, both for Wasaline and for the Kvarken Council. Wasaline could undertake the initiative to manage an airline themselves or engage an airline already operating as a subcontractor and negotiate how costs and revenues should be shared. To start, a less demanding flight schedule should be developed and tested. This reduces total cost and the risk during a period when persistence is needed, when the market should be informed about the availability of the route and develop experience from a new option to travel over the strait. Instead of Wasaline, The Kvarken council could, perhaps together with other actors, e.g. chambers of commerce, companies, public bodies, etc. on either side of the strait

The calculations above were based on a hypothetical eight-seat aircraft. With a slightly larger aircraft, the cost per passenger could be reduced and revenues during peaks could cover costs during periods with less demand. If more travellers find the possibility to save time with the airborne alternative, the social benefits would increase while the cost per passenger may decrease. Electric aircraft would reduce the social/environmental external cost further. These impacts of returns to scale and innovation would motivate an airline option even more.

Another option is for the Kvarken Council EGTC, if legally possible, to act as a regional public transport administration and procure or guarantee a certain number of seats in advance. Seats used in its own operations or sold to its members. In parallel, municipalities, regional public actors and the Kvarken Council EGTC could actively argue for the integration of the ferry and air routes into the regional and national public transport systems on both sides. This would be a way to create a socially efficient Nordic transport system in order to "promote and develop a strong and viable region with the help of cross-border cooperation".[15]

Finally, one or more private actors may undertake initiatives and offer regular traffic via airlines. In order to avoid a tendency to monopoly pricing with fares higher than the social marginal cost and a constant risk of termination from low cabin factors due to fixed costs and underutilisation of returns to scale, public monitoring of the traffic would be needed. Monitoring by tax payers of the public involvement in all forms of traffic over the strait is equally important to guarantee the efficient use of tax funds. The latter is especially important in situations of uncertain demand. In order to say whether a measure will be welfare increasing, we need a model that may be used to, within some reasonable interval of confidence, forecast future demand as well as other impacts in society. Without such confident estimates, tests may be conducted but impacts and benefits in relation to costs must be steadily considered.

[15] It would also be in line with the Nordic Council of Ministers' ambition to make "the Nordic Region… the most sustainable and integrated region in the world".

5. How can the Kvarken Region gain possible benefits from regional aviation?

Initially, we discussed how regions can act to increase the impact of transportation and infrastructure generally, and more specifically any investments made, on its own wealth by a strong focus on the relation between communication on its links and localised assets in its nodes; its human and social capital, the efficiency of its housing markets and the attractiveness of its properties and built environment. Ultimately, the aim for the region from activities in the transport market should be to develop the sum of private and public assets owned by actors in the region.

Aviation and rail have as a qualification that accessibility to airports and train stations are necessary in order for a place to be able to gain a direct benefit from such networks. For a region characterised by attractiveness, longsighted planning of land use and efficient land related markets one would expect a positive correlation between the location of an airport and the stream of value adding assets in the region. However, there are places where assets not are drawn to an airport or railway station. To some extent this may be understood by the fact that in modern mechanised capital intense natural resource industries, value added and value added per employee may be very high, although the number of employees and thus its human capital is relatively low and even shrinking. Ownership may furthermore be external to actors in the region. In other cases, regions or parts of regions may not be sufficiently attractive to compete with other nodes with respect to assets generated by the network. Hence, airports and railway stations may offer no attractiveness or may even be negative for a place. An airport may thus have an initial positive impact, which may diminish if it not is taken care of.

A message pervading this paper has been that weak demand may be the ultimate explanation for all the obstacles the establishment of an airline over the Kvarken strait must come up against. With larger populations on both sides of the strait, the likelihood of more business connections and other forms of exchange, and hence for the existence of a regular airline, would increase. Therefore the Kvarken Council, its members and supporters, political and business related, should never lose its focus on the growth of the regional population. This will secure that the benefits of their investments in communication possibilities are also locked in within the region at the same time as they increase the share of human capital in the balance sheet and the flow of ideas through the region, thus increasing the potential for cross-border interaction even further.

An attractive region and a larger population will in many different ways create jobs and income possibilities that will create new job opportunities and further attract inhabitants through positive feed-back and cumulative causation. Adding to this, when the transport sector has eventually entered the path to a fossil-free future, this will also create windows of opportunities for industries related to electric drivelines for the transport sector and emergent new designs, concepts, steering systems and management ideas associated with this.

The Kvarken region has a history of strong enterprises within the transportation industry, long experience in electric power systems, and schools of design and engineering with "AI" and related information intensive competences. The region should therefore not only be a consumer of traveling opportunities produced by a regional network of aviation, but also become a producer of a wide array of equipment and services demanded by the growing transport industry based on electric drivelines. The location of units for battery production in the region is a sign of this opportunity, but should not be the endpoint of the industrial development in a broad sense within the region.

6. Summary and conclusions

In this paper we have studied options for aviation generally, and the possibility to establish regional commuter flights over the Kvarken strait more specifically, especially with aircraft based on an electric driveline. We have also analysed aspects of the aviation market at large, its political institutional regulations in Sweden and the many features of the aviation industry that are characterised by returns to scale, and thus tend to push the market into oligopolistic or even local monopolistic outcomes, with few actors and constrained output. Our ambition has been to understand the reasons for previous failures and identify the risks that must be taken and distributed among the right actors, if a regular airline over the Kvarken strait is to be set up. We have observed that,

- The development of a regional network of aviation in the Kvarken region is dependent on the absolute number of inhabitants in the region, but also the relative strength of the region in terms of its internal human and network-related social capital relative to its connections with larger cities in each nation.
- Currently, airports in the Kvarken region are peripheral in relation to hubs in the national capitals. This position favours feeder lines to the capital at the expense of establishing networks around regional hubs. The Kvarken region needs one or more such hubs in the region, centres in regional networks of aviation.
- The possibility of establishing regional hubs instead of becoming peripheral nodes depends on regional demand and ambitions, but also on legislative and institutional constraints and options.

These observations and conclusions are in line with our overall message in the paper: Ambitions to develop communication and transportation possibilities should never be a substitute for measures within the real estate and housing markets of the region and ambitions to develop a relatively fast-growing Kvarken region, characterised by steadily immersed attractiveness. Instead, measures within the transport market should be considered as complements which, at the right moment and with the right institutional and market design, can support the overall creation of regional wealth.

Given these basic statements, we have found that for the moment there is no regular airborne connection across the Kvarken strait. Attempts to establish such a route have been made on several occasions but have not been viable. We identified reasons that might explain why this is the case.

- Most obviously, *demand is a constraint*. As we have seen, in order to have a regional “commuter line” with a small aircraft over a distance like the strait, albeit short, almost every tour, every day, would have to be booked by business travellers prepared to buy tickets with a fare around four times the price at the ferry.
- Moreover, the *integrated economy of the Kvarken region* may have been too weak and lack sufficient integration to provide passengers with such a route. The structure of industries on both sides of the strait, the national border, different currencies, and different time zones and languages may be obstacles for the establishment of a commercial basis for an airline. The small cities and the dispersed populations around airports reduce possibilities to realise the benefits of scale needed for a viable airline.
- On the other hand, *there is a charter flight option*. Added to this, the ferry line is being renewed and is attracting passengers. Given the average number of daily passengers on the ferry, it is possible that under the right circumstances there should also be an emerging demand for the shorter travel times offered by aviation.
- For a time, the Kvarken strait may still be *a route characterised by substantial risk* for the engaged airline. The alternative of offering a fare less expensive than today’s would clearly reduce this risk. Slightly larger aircraft, with electric drivelines, may be a way to actualise such an alternative.

We have analysed the possibility to undertake this option from different perspectives. Thereby we initially identified three “spaces” for a specific type of aircraft:

- **The *technical space* for a specific type of electric aircraft at a specific airport**. This would be a concentric circle limiting the reach of an aircraft given its technical properties.
- **The *competitive time space* for a type of electric aircraft at a specific airport**. Either the technical space, regulatory and security constraints or other more competitive modes limit the outer border of such a competitive space. An inner border given by other competing modes also exists. Within these two borders, an electric aircraft has a competitive space given by its door-to-door travel time determined by the complementary modes available at the airport.
- **The *commercial space* of an electric aircraft at a specific airport** is bounded by its competitive time space. Even if a competitive time space exists, the commercial space may nevertheless be empty in certain directions or during specific periods of time.

Our investigations of the technical and competitive time spaces, given some basic assumptions regarding the properties of a future electric aircraft have lead us to conclude that,

- Electric aviation *will offer a competitive time alternative* for many routes over the Kvarken strait. We have then assumed the same transit times for the ferry as for electric air. A faster and smoother boarding process for aviation would add to the competitiveness of electric air.

Regarding *the commercial space* of electric aircraft, we had to be more speculative. Even today, travel time is competitive for a regular commuter airline across the Kvarken strait. However, such a line does not exist. Our calculations also indicated that it seemed possible to establish a regular line but the initial uncertainties concerning demand for such a regular route, and the time and persistence needed to establish the route would, if there is a latent demand, involve a high risk for a single market actor. We found that with a small aircraft, *the vulnerability in relation to demand shortages may be too high*. We also observed that airlines with small aircraft seem unable to cover or avoid *the airport fees* associated with larger governmental terminals for passenger handling and aircraft services. Hence, small airlines prefer to operate from separate small terminals or even airports.

- With a slightly larger aircraft, which could still be managed from a small terminal, the possibility to offer lower fares would increase. In addition to this, a larger aircraft may offer possibilities to take on board more passengers during peaks, and thus cover losses from flights with too few passengers during valleys.
- An airline that operates on a larger network with different sized aircraft could obviously manage its fleet in order to optimise fares, passengers and airline costs.

We also studied the "competitive time space" for an eVTOL. Those operate from heliports, like taxi stops, more centrally located in cities or villages. We also assumed faster approach, boarding and embarking. The arrival of commercially viable eVTOLs will fundamentally reshape urban planning and the structure of cities and regions. The electric driveline, with less noise and shorter runways, will create pressure to move airports closer to consumers, with eVTOLs operating from spots even nearer their customers. An eVTOL with a large enough technical space may thus also compete with electric aircraft at short distances, perhaps at distances long enough to fly over the Kvarken strait.

Finally, we added a ***fourth space*** to our previous three, ***the institutional space***, that constrains the operation of an airline using a specific aircraft on a route, considering global, national and regional institutional regulations. If we zoom out and observe the situation in northern Sweden and parts of Finland, with small cities at some distance from each other, and many small villages in the forest land and in the mountain areas, one would expect to find small- and medium-sized airlines active to develop networks between them, commercially or as part of a regional public transport system. More like buses and taxis, as complements to public procured rail operators found in many dense areas.

- Instead, ***regional public transport administrations*** (In Sweden "Kollektivtrafik-myndigheter") *are not allowed to procure airlines*, but are allowed to procure most other, land-based, modes. Public procurement of airlines is monopolised at the national level by the Swedish Transport Administration ("Trafikverket") which, with a few exceptions, procures flights from sparsely populated places, direct to the capital, instead of procuring flights to regional hubs that may establish the core in networks of regional systems of aviation.
- We observed that the integrated industry of aviation has been on a path characterised by larger aircraft, larger airlines and a focus on fewer airports. We raised the question of whether this is socially efficient. Might it not hamper the development of an efficient

regional communication and transportation system whereof airlines are an integrated part? If the answer is yes, this *may be a sign of institutional and policy failures*.

- Since market failures are often created in markets characterised by strong returns to scale, there is also the possibility that *the market for regional aviation is being hampered by combinations of both market and policy failures.*

It takes time to change laws and institutional structures. What initiatives and options could then be tested for the moment to prepare the Kvarken region for electric aviation? Clearly tests of the strength of the market could be made with current aircraft. Some actors, such as the Kvarken Council EGTC, the ferry company Wasaline and its owner the Kvarken Link Oy, are especially relevant for such initiatives.

- This option could be investigated by the municipalities around the Kvarken strait along with their main stakeholders. Perhaps the ferry company Wasaline could extend its role from sea communication over the strait to communication in general, thus combining transportation by shipping and aircraft.

- In parallel, the municipalities, regional public actors and the Kvarken EGTC could actively argue for an integration of the ferry and air routes into the regional and national public transport systems on both sides. This would be a way to create a socially efficient Nordic transport system in order to "promote and develop a strong and viable region with the help of cross-border cooperation".

Lastly, from a regional development perspective, the regional actors should not only be consumers of traveling opportunities produced by a regional aviation network, as these are important for business development, attractiveness and wealth creation in the region, but also establish the region as a producer of a wide array of equipment and services demanded by the growing transport industry based on electric drivelines. The location of units for battery production in the region is a sign of this process, but this should not be the endpoint in a development of a regional transport industry based on electrically powered communication.

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