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# The Emissions Reduction Potential of Substituting Short-Haul Flights with Non-High-Speed Rail (NHSR): The Case of Finland

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## Abstract

Replacing short-haul flights with high-speed rail (HSR) has been widely discussed as one solution to mitigate the climate change impacts of aviation. However, although HSR can provide travel times similar to those provided by short-haul flights, and at lower emission levels, it also requires considerable investments in time and infrastructure to build. Instead, this study considers the feasibility of replacing short-haul flights with existing non-high-speed rail (NHSR). Our study is based in Finland, a country that has an extensive route network of short-haul flights but does not possess any HSR. We compared all 16 city pairs for which short-haul flights are offered with existing NHSR based on the total carbon dioxide equivalent emissions ($CO_2$-eq) and real travel times from door-to-door. Two scenarios were developed based on the results, which suggest replacing all short-haul flights with NHSR in Finland. This would result in a 95% emissions reduction. In terms of travel times, NHSR could remain competitive against air travel on distances up to 400 km.

**Keywords:** Emissions reduction, climate change, short-haul flights, train, modal shift, travel time.

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## 1. Introduction

The ongoing climate emergency necessitates urgent action in reducing anthropogenic greenhouse gas (GHG) emissions. Transport is a significant contributor to climate change, accounting for 14% of global GHG emissions (IPCC, 2014). For the transport sector, while road transportation remains the largest emitter, air transportation is rapidly expanding, and so are GHG emissions (IEA, 2009). Although aviation is currently responsible for about 10.6% of the transportation sector's total GHG emissions (IPCC, 2014), it is growing at an exponential rate of 5% annually, doubling its size every 20 years (Cohen and Higham, 2011; Dubois and Ceron, 2006). Therefore, new solutions need to be found to reduce the GHG emissions of the aviation sector.

When taking a closer look at different types of flights, short-haul flights produce the highest amount of GHG emissions per kilometer, even though longer flights mean more emissions in absolute terms. According to Grimme and Jung (2018), short-haul flights produce more than twice as much $CO_2$ emissions per kilometer than long-haul flights. This is not only because of the lower load factors and smaller amount of cargo carried but also due to the energy-intense take-off and climb phase, which is distributed over a much shorter flight distance compared to medium- and long-haul flights. Because short-haul flights are the least efficient, they are also the ones that could be replaced the most easily by other modes of transportation. One approach that has been discussed in the literature is modal shift (Ahanchian et al., 2019; Borken-Kleefeld et al., 2013; Dalkic et al. 2017; Lu, 2015). Modal shift could be seen as a solution for replacing flights on shorter distances where substituting modes could offer similar travel times. Follmer et al. (2010) found that aviation plays a minor role in distances up to 500 km, while it becomes the predominant mode of transportation on routes above 1,000 km.

Previous research has mainly studied modal shift from aircraft to land-based transportation modes, in particular replacing aviation with HSR (Danapour et al., 2018; D'Alfonso et al., 2016; Robertson, 2016; Zhang et al., 2019; Zhang et al., 2020). HSR can compete with aviation on distances up to 800 km (Button, 2012; Chen, 2017) and that competition can take place on some routes even up to 1,000 km (Chiara et al., 2017). While HSR can certainly deliver substantial gains in travel time, building the necessary infrastructure requires a significant amount of funding as well as time (Bukovac and Douglas, 2019) and might even have negative outcomes on climate change and biodiversity (Cornet et al., 2018). However, building an HSR might not be a feasible option for some countries or regions, but the replacement of short-haul flights with conventional (existing) trains could be a simpler and faster solution to implement. Our study examines the replacement of short-haul flights with conventional trains, which has not yet received much attention in the literature. As defined by the International Union of Railways (UIC, 2018), conventional trains can only run at speeds up to

200 km/h. In order to achieve higher speeds, a different type of infrastructure, rolling stock, signaling and operations are needed. In our study we therefore only focus on trains that run at maximum speeds of 200 km/h, which we regard as conventional trains or NHSR.

Our study is based on Finland, a country that has a well-developed transportation infrastructure but does not possess any form of HSR. Finland has an extensive route network of short-haul flights connecting the capital with 16 major cities. This study compares the per passenger $CO_2$-eq emissions of 16 city pairs in Finland from city center to city center as well as from city center to Helsinki Vantaa Airport between aircraft and NHSR. We took both destinations into account (downtown Helsinki and Helsinki Vantaa Airport) because short-haul flights are used to reach Helsinki as a final destination or to connect to flights abroad through Finland's major hub, Helsinki Vantaa Airport. In addition, we also took real travel time from door-to-door into account, which has, to date, received less attention in the literature (Zhao and Yu, 2018). On the basis of our results, we identified the carbon emissions reduction potentials achieved through a modal shift. In addition, we took into account those distances for which a replacement of short-haul flights with NHSR would be feasible based on real travel times from door-to-door, presenting different scenarios.

## 2. The case of Finland

Finland, one of the Nordic Countries and a member of the EU, is located in the north-eastern part of Europe and has a population of 5.5 million. Despite the country's small population, it operates an extensive network of 20 civil airports, of which 18 are open year round. The capital, Helsinki, is the major urban center, with more than a quarter of Finland's inhabitants living in the region. The region is also acting as a major hub with highly developed domestic flight, rail and road infrastructure. Almost all short-haul flights and trains starting or ending in Helsinki. Annually, Finland produces a total of 55.6 million t of carbon dioxide equivalent emissions ($CO_2$-eq), of which 20% (11.1 million t) accounted for domestic transportation[1] (Statistics Finland, 2017). Finns are among the highest emitters of $CO_2$, producing 8,700 kg annually (Finnish Environment Institute, 2013). The market share of trains (5.7%) and air transportation (1.7%) is small compared to road transportation, which accounts for 90.5% (Finnish Transport Agency, 2015). According to the Finnish Transport Agency (2015), Finnish railways carried 13.6 million passengers on long-distance trains in 2013, while air transportation accounted for only 2.4 million passengers. The load factors in 2013 for trains were 33%, and for aircraft, 62% (Finnish Transport Agency, 2015). These low load factors indicate there would be spare capacity on Finnish

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[1] International aviation excluded

trains to accommodate the passengers shifted from aircraft. In addition, the capacity of trains could easily be extended by adding more services to existing routes or additional cars to existing trains.

### *2.1 NHSR*

Passenger trains in Finland are run by the state-owned Finnish Railways (VR), which has a monopoly on passenger train services. VR uses two different types of trains on their long-distance routes: electric-multiple unit tilting Pendolino trains (type Sm3) and electric locomotive-hauled (type Sr2) double-decker push-pull InterCity train sets. Table 1 below gives an overview of the specifications for the different train types.

**Table 1**. Overview of different train types in Finland VTT (2017).

| Train type | Capacity | Average load factor | Top speed |
|---|---|---|---|
| Pendolino | 309 seats | 40% | 220 km/h |
| InterCity | 509 seats | 40% | 200 km/h |
| FLIRT (Ring Line) | 260 seats | 35% | 160 km/h |
| RailCar | 63 seats | 35% | 120 km/h |

While Pendolino trains are capable of running at top speeds of 220 km/h, there are no rail lines in operation in Finland that would provide regular service at speeds beyond 200 km/h. All trains running within Finland can, therefore, be considered NHSR, which makes Finland an ideal case country for this study. The regular operating speeds on most lines is between 140 and 160 km/h. Only a few rail corridors can accommodate higher speeds of 180 to 200 km/h. These rail corridors can be found on the lines between Helsinki and the west towards Turku, to the north towards Tampere and Oulu as well as to the east towards Lahti, Kouvola and the Russian border. Of the 16 city pairs considered in this study, 12 are connected to Helsinki by non-stop services using Pendolino or InterCity trains. To reach Ivalo, Kittilä, Kuusamo and Savonlinna, passengers have to take transfers. Passengers travelling from Helsinki to Savonlinna have to change in Parikkala for a diesel-powered RailCar (type Dm12) bound for Savonlinna. Ivalo, Kittilä and Kuusamo are not part of the national rail network but can be reached by bus after taking the train from Helsinki to Oulu or Rovaniemi. VR sells through tickets to Ivalo, Kittilä and Kuusamo that include bus connections. Buses in Finland typically run at maximum speed of 100 km/h. Table 2 below provides an overview of the studied NHSR routes and their distances, travel times and services. Figure 1 shows a railway map of Finland with the 16 city pairs and the corresponding rail and bus connections. Travel times refer hereby to the times between the departure at the origin railway stations and arrival at the destination (Helsinki Central Station) as indicated in the official timetables.

**Table 2**. Overview of distance, travel time and train services to Helsinki for NHSR

| Route | Distance[1] | Travel time[2] | Train | Connection to Helsinki[3] |
|---|---|---|---|---|
| Tampere | 187 km | 1:33 | Pendolino | Non-stop |
| Turku | 194 km | 1:45 | Pendolino | Non-stop |
| Pori | 322 km | 3:15 | InterCity | Non-stop |
| Jyväskylä | 342 km | 3:07 | Pendolino | Non-stop |
| Savonlinna | 410 km | 4:05 | Pendolino & RailCar | Transfer in Parikkala |
| Kuopio | 439 km | 4:05 | InterCity | Non-stop |
| Vaasa | 420 km | 3:42 | Pendolino | Non-stop |
| Joensuu | 482 km | 4:18 | Pendolino | Non-stop |
| Kokkola | 481 km | 3:42 | InterCity | Non-stop |
| Kajaani | 607 km | 6:00 | InterCity | Non-stop |
| Oulu | 680 km | 5:40 | InterCity | Non-stop |
| Kemi | 786 km | 7:10 | InterCity | Non-stop |
| Kuusamo | 900 km | 9:05 | InterCity & Bus | Transfer in Oulu |
| Rovaniemi | 900 km | 8:32 | InterCity | Non-stop |
| Kittilä | 1,053 km | 10:30 | InterCity & Bus | Transfer in Rovaniemi |
| Ivalo | 1.232 km | 12:45 | InterCity & Bus | Transfer in Rovaniemi |

[1] Distance to Helsinki Vantaa Airport differs slightly
[2] Travel times to Helsinki Vantaa Airport differ slightly
[3] For reaching Helsinki Vantaa Airport, a transfer to Ring Line is necessary at Tikkurila or Pasila

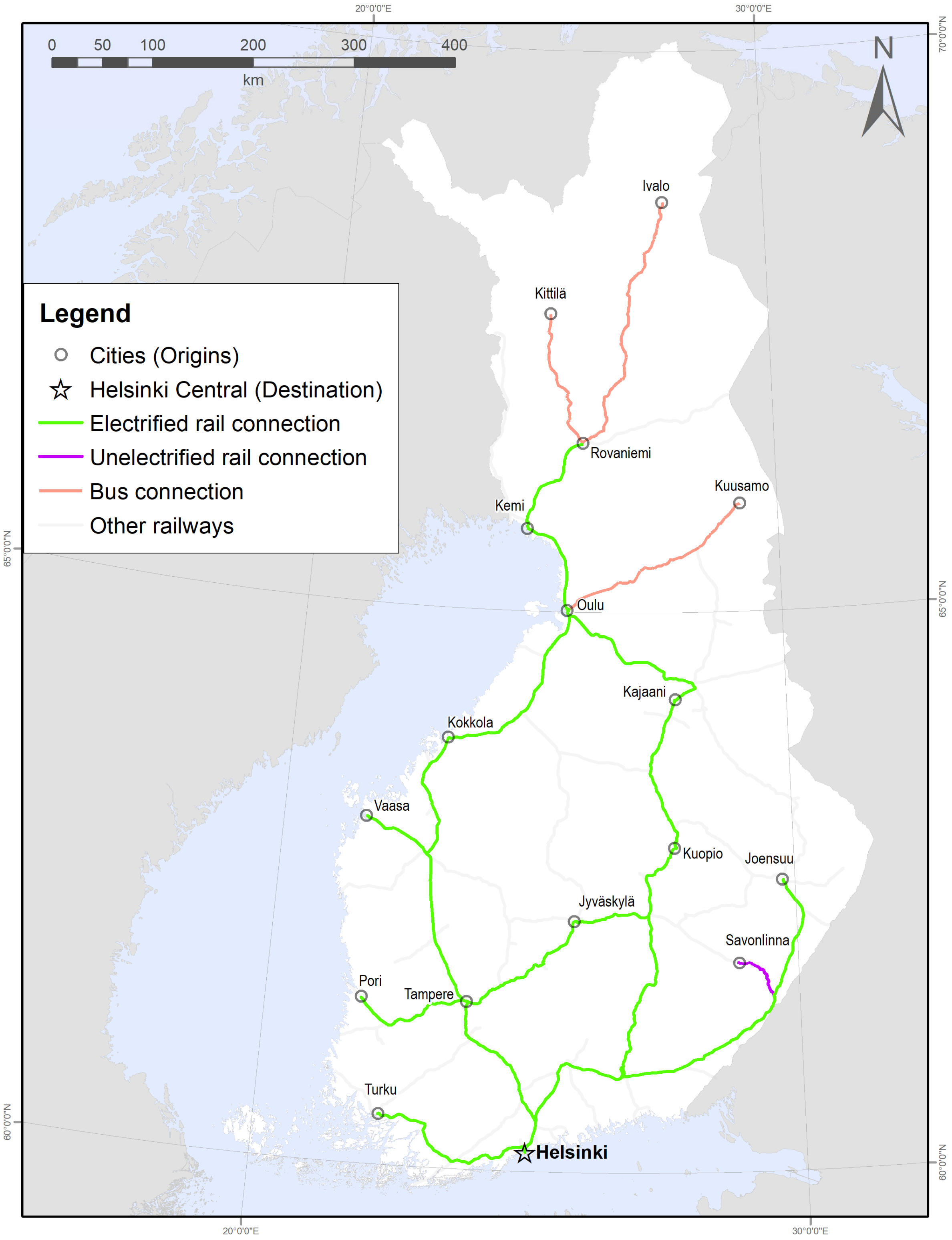

**Fig. 1. Railway map of Finland with all 16 city pairs.**

Most long-distance trains in Finland terminate at Helsinki Central Station, providing direct access to downtown Helsinki. To reach Helsinki Vantaa Airport, passengers have to change trains at Tikkurila and take the Ring Line airport train for an 8-minute trip to reach the airport. All long-distance trains stop in Tikkurila in order to provide fast access to the airport. The only exception are the long-distance trains from Turku, which do not travel through Tikkurila but provide connections to the Ring Line airport train at Pasila instead. All Ring Line airport trains are operated by four-car electric-multiple Stadler FLIRT units (type Sm5). The Ring Line allows for top speeds of 120 km/h.

### *2.2 Aircraft*

Domestic aviation in Finland centers around Finland's only major international hub, Helsinki Vantaa Airport, which offers non-stop flights to over 100 destinations around Europe, Asia and North America. In addition, there are 17 other airports in Finland (Ivalo, Joensuu, Jyväskylä, Kajaani, Kemi-Tornio, Kittilä, Kokkola-Pietarsaari, Kuopio, Kuusamo, Mariehamn, Oulu, Pori, Rovaniemi, Savonlinna, Tampere Pirkkala, Turku and Vaasa) that operate year-round scheduled flight services to Helsinki Vantaa Airport. In addition, Enontekiö Airport receives a small number of seasonal flights from Helsinki Vantaa, and Lappeenranta airport offers seasonal low-cost flights to destinations outside of Finland. This study, however, focuses only on 16 city pairs between Helsinki Vantaa Airport and 16 of the 17 airports that offer year-round scheduled flight service. The airport on the Åland Islands, Mariehamn, which is not part of the national rail network is excluded from this study. Any additional flights operated from these airports to any destination outside Finland were not considered. All domestic routes in Finland are within a range of 1,000 km from Helsinki Vantaa Airport. Therefore, these be considered short-haul flights.

Most of flights within Finland are operated by Norra (Nordic Regional Airlines), a subsidiary of Finnish flag carrier Finnair using ATR 72 turboprop aircraft. Some flights to the more distant destinations in the northern part of Finland are operated by Finnair itself. In addition, Norwegian Air Shuttle operates flights from Helsinki to Oulu and Rovaniemi. Pori- and Savonlinna-bound flights are only operated by FlexFlight. Table 3 provides an overview of all 16 city pairs, with the Great Circle Distance (GCD), flight times, operators, aircraft types and their seating capacity. GCD refers to the shortest distance between two points on the earth's surface while flight time indicates the times between the departure at the origin airports and arrival at the destination (Helsinki Vantaa Airport) as indicated in the official timetables. The map in Figure 2 below shows the flight routes of all 16 city pairs with the exact locations of their airports.

**Table 3**. Overview of distance, flight time, operators and aircraft types and capacity on flight services to Helsinki for aircraft

| Route | GCD | Flight time | Operator | Aircraft | Capacity |
|---|---|---|---|---|---|
| Tampere | 143 km | 0:35 | Norra | ATR 72 | 72 seats |
| Turku | 150 km | 0:35 | Norra | ATR 72 | 72 seats |
| Pori | 214 km | 0:45 | FlexFlight | Embraer 120 | 30 seats |
| Jyväskylä | 235 km | 0:45 | Norra | ATR 72 | 72 seats |
| Savonlinna | 278 km | 0:55 | FlexFlight | Saab 340 | 36 seats |
| Kuopio | 335 km | 1:00 | Norra | ATR 72 | 72 seats |
| Vaasa | 348 km | 1:05 | Norra | ATR 72 | 72 seats |
| Joensuu | 360 km | 1:00 | Norra | ATR 72 | 72 seats |
| Kokkola | 391 km | 1:05 | Norra | ATR 72 | 72 seats |
| Kajaani | 464 km | 1:15 | Norra | ATR 72 | 72 seats |
| Oulu | 514 km | 1:05 | Finnair | Airbus A319/A320/A321 | 131-201 seats |
| | | | Norwegian Air | Boeing 737-800 | 186 seats |
| Kemi | 609 km | 1:30 | Norra | ATR 72 | 72 seats |
| Kuusamo | 667 km | 1:20 | Norra | ATR 72 | 72 seats |
| Rovaniemi | 697 km | 1:20 | Finnair | Airbus A319/A320/A321 | 131–201 seats |
| | | | Norwegian Air | Boeing 737-800 | 186 seats |
| Kittilä | 823 km | 1:20 | Finnair | Airbus A319/A320/A321 | 131–201 seats |
| Ivalo | 931 km | 1:35 | Finnair | Airbus A319/A320/A321 | 131–201 seats |

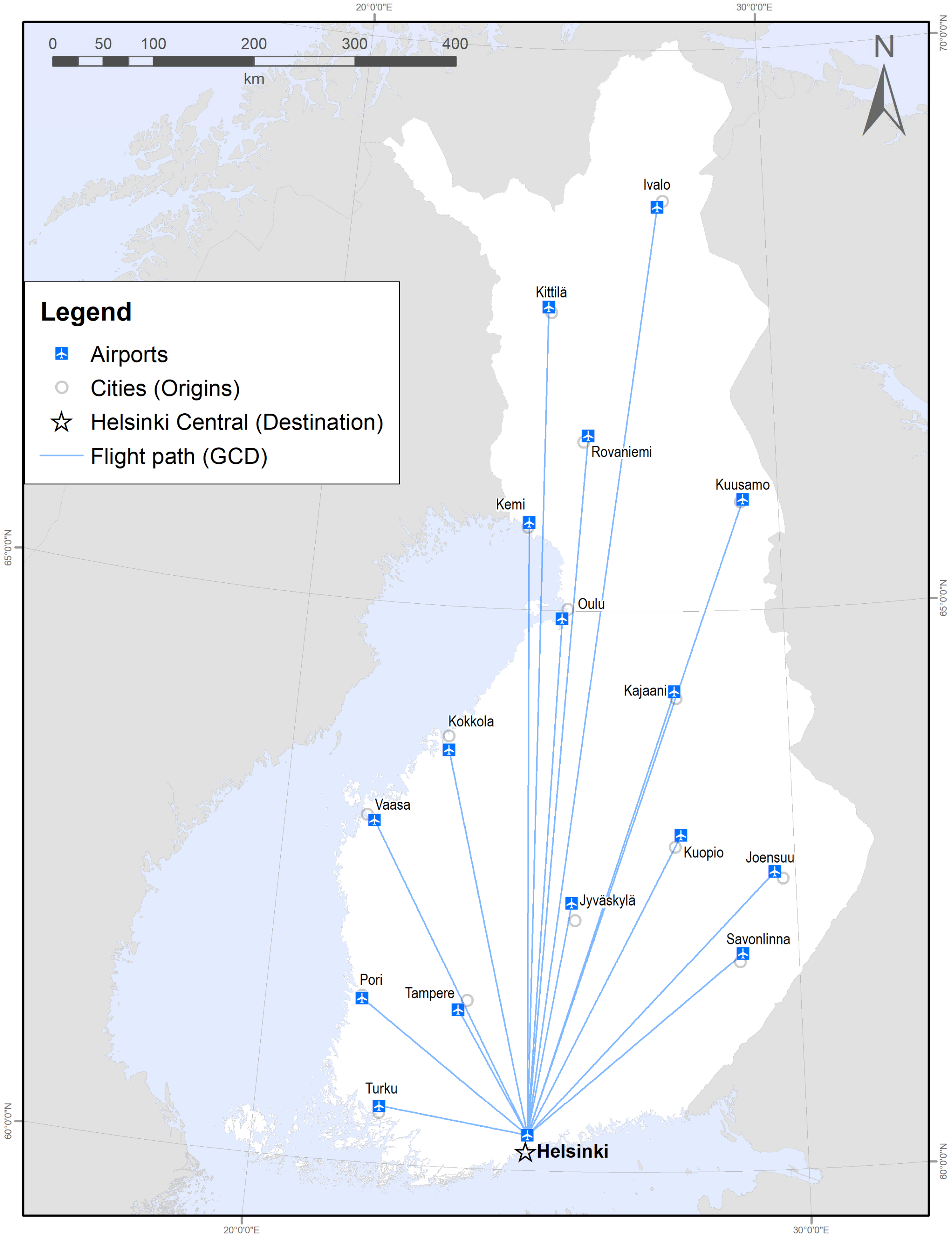

**Fig. 2. Flight route map of Finland with all 16 city pairs.**

### *2.3 Ground transportation*

In order to account for the door-to-door $CO_2$-eq emissions and real travel times from the city centers of the 16 origins to downtown Helsinki or to Helsinki Vantaa Airport, we also took into account transportation to the local airports as well as transportation from Helsinki Vantaa Airport to downtown Helsinki. With the exception of Pori Airport, all the airports at the remaining 15 origin cities are located 5 to 22 km away from the city centers. In the study, the local transport from the city centre to the local airports of these 15 origin cities is assumed to be done by car only because most of the local airports in Finland are poorly connected by public transport. This also reflects the fact that the use of a private car or taxi to reach the local airports in Finland is common. All train stations are located centrally and were therefore considered as being in the city center and no ground transport to reach them was considered. The same applies to Pori Airport. For trips between Helsinki Vantaa Airport and Helsinki Central Station, the fastest and most feasible option is by Ring Line airport train, which takes 31 minutes to cover the 19 km between Helsinki Vantaa Airport and downtown Helsinki.

## 3. Calculations

### *3.1 Emissions*

$CO_2$-eq emissions per passenger for each aircraft were calculated based on the aircraft type used on the particular route and the GCD to Helsinki Vantaa Airport as shown in Table 3. In addition to GCD, a lengthening factor of 14.3% was applied to all routes as recommended by Dobruszkes and Peeters (2019) for short-haul flights, accounting for stacking, traffic and weather-driven diversions. The fuel data were extracted from the EMEP/EEA Air Pollutant Emissions Inventory Guidebook (EEA, 2019) based on the aircraft type and GCD plus lengthening factor. $CO_2$ emissions were calculated by multiplying the fuel burned by 3.169, which equals the amount of $CO_2$ produced when burning 1 kg of aviation fuel (VTT, 2017). In order to account for the non-$CO_2$ effects of aviation, a factor of 1.9, as recommended by UK Government (2019), was applied to the $CO_2$ emissions. The non-$CO_2$ effects considered were $NO_X$, water vapor, sulphate aerosol, soot aerosol, linear contrails and induced cirrus cloudiness (Lee et al., 2009). For calculating the $CH_4$ and $N_2O$ emissions, 0.0005 g/MJ and 0.002 g/MJ were assumed. The assumed heat value of the fuel in MJ was 43 MJ/kg of fuel based on VTT (2017). Finally, in order to allocate the emissions per passenger, the total emissions per flight were divided by the total amount of seats provided on the flight, as shown in Table 3. This value was then multiplied by the average load factor for flights within Finland which, according to the Finnish Transport Agency (2015), is 62%. $CO_2$, $CH_4$ and $N_2O$ emissions per passenger in kg were hereby calculated as,

$$CO2 = \frac{(fb*3.169)}{(ns*lf)} * 1.9 \qquad (1)$$

$$CH4 = \frac{(fb * hv * 0.0000005)}{(ns * lf)} \tag{2}$$

$$N2O = \frac{(fb * hv * 0.000002)}{(ns * lf)} \tag{3}$$

where *fb* stands for fuel burned in kg, *hv* for the heat value of 43 MJ/kg for $CH_4$ and $N_2O$ emissions, *ns* for number of seats available on the aircraft and *lf* for average load factor. VR runs all electric trains on hydropower. Concerning the emissions produced by trains, because almost all trains covered in this study run on electric lines (with the exception of RailCars), there are no direct emissions produced during the journey. However, instead of setting the emissions to zero we considered the emissions released from electricity production. The electricity consumption per passenger-kilometer (pkm) of the different train types used in this study was referenced from the LIBASTO unit emissions database published by the Technical Research Center of Finland (VTT, 2017). The $CO_2$ and $CH_4$ emissions released during energy production were based on Hertwich (2013) with 85g of $CO_2$ and 3g of $CH_4$ per kWh. $N_2O$ emissions were not taken into account because, according to Hertwich (2013), they barely occur in boreal regions. $CO_2$ and $CH_4$ emissions per passenger in kg were hereby calculated as,

$$CO2 = ec * dt * 0.085 \tag{4}$$

$$CH4 = ec * dt * 0.003 \tag{5}$$

where *ec* stands for electricity consumption per pkm in kWh and *dt* for distance travelled in km. $CO_2$-eq emissions per passenger for the RailCar between Savonlinna and Parikkala and ground transportation such as car and bus were directly calculated based on the LIBASTO database (VTT, 2017), based on emissions per pkm and distance travelled. For buses, we assumed an average vehicle with a mass of 18 t, a carrying capacity of 5 t, and 50 seats, 14 of which were assumed to be occupied. The car occupancy was considered to be 1.7 passengers per car, while the share of diesel car mileage was considered to be 41%, as is typical in Finland (VTT, 2017). Distance and real travel time were determined using the Google Maps route planner. We always considered the fastest and most direct routes, assuming normal traffic conditions. The emissions data provided by VTT are Finland specific, based on weather, local traffic and geographical circumstances and therefore suit this study well. The time frame chosen for the Global Warming Potential for this study was 100 years ($GWP_{100}$). In addition to $CO_2$, we also took $CH_4$ and $N_2O$ emissions into account. The $CO_2$-eq emissions per passenger in kg for all transportation modes were calculated based on IPCC's Fifth Assessment Report (IPCC, 2014):

$$CO2-eq = CO2 + CH4 * 28 + N2O * 265 \tag{6}$$

Table 4 provides an overview of all the mode-specific per pkm emissions considered in this study. Because emissions on short-haul flights are far from linear, aircraft emissions per pkm differ considerably depending on the distance. The aircraft emission numbers shown below represent the average value for pkm emissions, based on the distance range covered in this study. In the final results, the emissions have been calculated based on the exact GCD plus the lengthening factor.

**Table 4**. Emissions per pkm for the different transport modes.

| Mode specifications | g $CO_2$ | g $CH_4$ | g $N_2O$ | g $CO_2$-eq |
|---|---|---|---|---|
| Aircraft, Airbus A319/A320/A321 | 361.20 | 0.00129 | 0.00516 | 362.60 |
| Aircraft, Boeing 737-800 | 317.63 | 0.00113 | 0.00454 | 318.86 |
| Aircraft, ATR 72 | 276.46 | 0.00099 | 0.00395 | 277.53 |
| Aircraft, Saab 340 | 350.52 | 0.00125 | 0.00501 | 351.88 |
| Aircraft, Embraer 120 | 457.58 | 0.00163 | 0.00654 | 459.36 |
| NHSR, Pendolino | 9.35 | 0.33 | 0 | 18.59 |
| NHSR, InterCity | 4.59 | 0.162 | 0 | 9.13 |
| NHSR, FLIRT (Ring Line) | 6.04 | 0.213 | 0 | 12.00 |
| NHSR, RailCar | 76.00 | 0.004 | 0.0012 | 76.43 |
| Bus, highway | 39.00 | 0.00016 | 0.0015 | 39.47 |
| Car, urban driving | 155.00 | 0.0015 | 0.0046 | 156.46 |

### 3.2 Real travel time

Train stations in all 16 origin cities are centrally located and no additional ground transport is needed. Whereas, the local airports considered are between 8- and 22-minute drives from the city centers. The only exception is Pori Airport, which is located in the city center. Nevertheless, for ensuring enough time to find the right platform and to board the train safely prior to departure, we added 10 additional minutes to the real travel time for NHSR. Scheduled train travel times were extracted from VR's 2019 summer timetable. The fastest available train connection was always considered for the study even though the differences between the speeds of different trains was not significant. Scheduled flight times were retrieved from the Official Aviation Guide

(OAG) timetable for summer 2019. Further, for NHSR passengers bound for Helsinki Vantaa Airport, we added 45 minutes to account for time before check-in and security clearance, which is also the official recommended time for passengers to arrive before flight departure. Here the Schengen terminal on the airside was considered as the final destination. For the local airports, because they are significantly smaller, easier to navigate and far less busy than Helsinki Vantaa Airport, we added only 30 minutes of prior arrival time to the real travel time before check-in closes. Check-in at Finnish airports closes 45 minutes prior to departure, which should allow passengers enough time to clear security and reach the departure gate in time. For transfer at Helsinki Vantaa Airport from aircraft to the Ring Line we assumed 40 minutes. This included walking time, train ticket purchases and the waiting time for the next train. Trains typically run every 8 to 10 minutes during the day when most of the flights arrive. Table 5 offers a detailed overview of the different elements and times used in the calculations.

**Table 5**. Overview of real travel times for aircraft and NHSR.

| Mode | Used in equations 7 and 8 | Aircraft | NHSR |
|---|---|---|---|
| Transfer to local airport (car) | tc | 8–22 min | |
| Transfer to Rovaniemi/Oulu (bus)[1] | tb | | 115–230 min |
| Check-in at local airport | ci | 30 min | |
| Security control, transfer to gate | sg | 45 min | |
| Early arrival at station and boarding | ab | | 10 min |
| Scheduled flight time / travel time | st | 35–95 min | 91–512 min |
| Baggage claim, transfer to Ring Line[2] | bt | 40 min | |
| Ring Line airport train to downtown Helsinki[2] | rl | 31 min | |
| Early arrival at Helsinki Vantaa Airport to reach Schengen Terminal airside[3] | ea | | 45 min |

[1] When traveling on NHSR from Ivalo and Kittilä / Kuusamo, a bus to Rovaniemi / Oulu needs be used
[2] When traveling by aircraft to Helsinki Vantaa Airport and downtown Helsinki is final destination
[3] When traveling by NHSR to Helsinki Vantaa Airport in order to depart from Helsinki by aircraft to destinations outside Finland

Real travel times *RTT* of aircraft and NHSR in minutes were hereby estimated as,

$$RTT\ Aircraft\ = tc\ +\ ci\ +\ sg\ +\ st\ +\ bt\ +\ rl \tag{7}$$

$$RTT\ NHSR\ =\ tb\ +\ ab\ +\ st\ +\ ea \tag{8}$$

where *tc* transfer to local airport by car, *tb* transfer to Rovaniemi or Oulu railway station by bus, *ci* for check-in at local airport, *sg* for security control and transfer to gate at local airport, *ab* for early arrival at the railway station and boarding the train, *st* for scheduled travel time, *bt* for baggage claim and transfer to Ring Line at

Helsinki Vantaa Airport, *rl* for travel time on Ring Line airport train to downtown Helsinki and *ea* for early arrival at Helsinki Vantaa Airport to reach the Schengen Terminal on the airside.

## 4. Results

### *4.1 Emissions*

In terms of $CO_2$-eq emissions, for one passenger to reach Helsinki, NHSR achieves much lower emissions than the aircraft, as shown in Figure 3. Our results show the same journey from one of the 16 origins to Helsinki could be completed between 11.1 and 48.5 times by train in order to release the same amount of $CO_2$-eq emissions as taking the aircraft, depending on the route (see Figure 3). The substantial differences in number of trips that could be completed with the same level of emission stems mainly from the differences in aircraft and train types used on the various routes. In terms of NHSR, the routes served by InterCity trains produce less $CO_2$-eq emissions than routes served by Pendolino trains. This is due to the higher seating capacity of InterCity trains and the newer rolling stock used on InterCity services. On the route to Savonlinna, the use of diesel powered RailCars leads to a significant increase in $CO_2$-eq emissions. Fortunately, these types of trains are only operated on a few unelectrified routes within Finland (purple line in Figure 1). Finally, on those routes (red line in Figure 1, such as to Ivalo, Kittilä and Kuusamo) where rail has to be partially replaced by bus services, the emissions produced by buses per pkm are significantly higher than those by trains run on electric lines. However, the $CO_2$-eq emissions of buses are significantly lower than those of trains considering the pkm emissions of buses against VR's RailCars (see Table 4). Using buses instead of RailCars on unelectrified routes could be a way to further reduce NHSR's emissions.

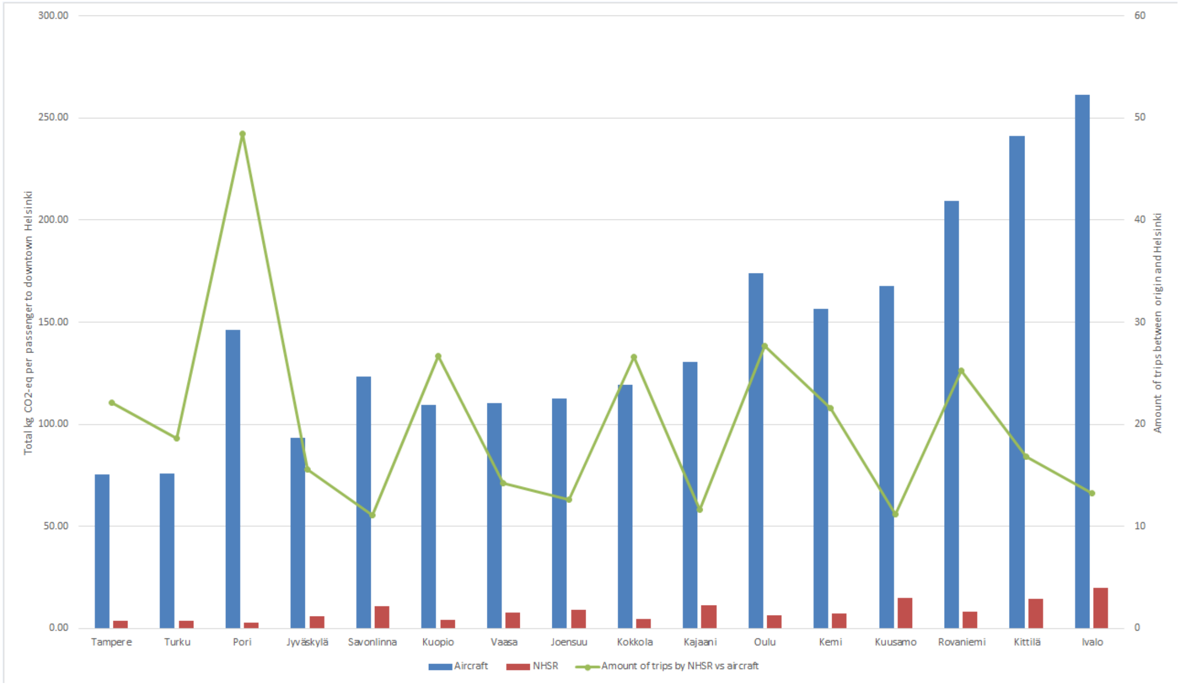

Fig. 3. kg $CO_2$-eq emissions per passenger for all 16 city pairs.

Although it was not a surprise that aircraft in Finland showed much higher emissions figures than NHSR, the numbers are still rather modest compared to other countries. One of the reasons is that short-haul flights within Finland have relatively high load factors - 62% on average. Another explanation is the flights in Finland are using aircraft at their optimal stage lengths. For shorter routes, fuel-efficient turboprop aircraft of the type ATR 72 are commonly used. On longer routes, jet aircraft such as the Airbus A320 family and the Boeing 737-800 are usually deployed. According to Babikian et al. (2002), using turboprop aircraft on shorter routes can mean significant emissions reductions compared to jet aircraft. There are some exceptions. For the Helsinki flight pairs with Pori and Savonlinna, the higher per passenger $CO_2$-eq emissions are caused by older aircraft such as Saab 340 and Embraer 120 models. Another exception is Oulu Airport. Oulu is served by jet aircraft due to the higher passenger demand, violating the plane’s optimal stage length.

### *4.2 Real travel time*

In terms of real travel time, as Figure 4 below shows, downtown Helsinki can be reached much faster by NHSR from Tampere and Turku than by aircraft. In terms of Tampere to Helsinki, the aircraft takes almost twice longer than NHSR. On routes to Pori, Jyväskylä, Savonlinna, Kuopio, Vaasa, Joensuu and Kokkola, NHSR offers similar travel times to downtown Helsinki when compared with aircraft. But for longer trips with distances of more than 400 km (such as Kajaani or further north), the aircraft begins to provide significant time savings compared to NHSR. It is notable that NHSR still outperforms the aircraft on routes to Vaasa (GCD =

348 km) and Kokkola (GCD = 391), which is probably explained by the well-developed rail corridor between Helsinki and Oulu, which allows for top speeds of 200 km/h on most of the sections of that route. However, flights to Oulu (GCD = 514 km) are significantly faster than the train despite the well-developed rail corridor. The increasing distance adds advantage to the aircraft's real travel time, outperforming the NHSR. It can therefore be concluded that NHSR can compete with air transportation on routes up to 400 km from city center to city center.

Some geographical disparity is observed. As seen in Figure 4, NHSR offers lower performance in real travel times on routes to eastern Finland (including the cities of Savonlinna, Kuopio, Joensuu and Kajaani), than the routes towards the north, west and central Finland (Tampere, Pori, Jyväskylä, Vaasa and Kokkola), where trains can take advantage of better built-up rail corridors that more often allow speeds up to 200 km/h. For routes bound for eastern Finland, most sections of the journey can only be operated on speeds of 140 to 160 km/h. Upgrading existing lines to 200 km/h could help NHSR to better keep up with travel times of aircraft on routes beyond 400 km.

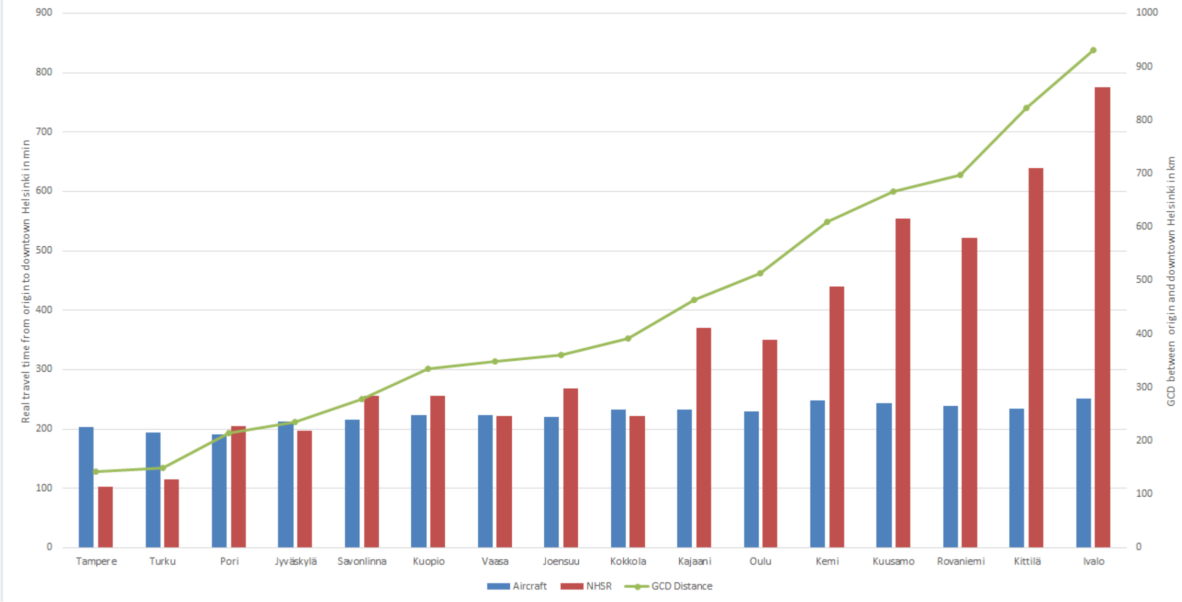

**Fig. 4. Comparison of real travel times to reach downtown Helsinki.**

In terms of real travel time for reaching Helsinki Vantaa Airport, where the Schengen Terminal on the airside was considered as the final destination, the picture looks completely different. As Figure 5 shows, aircraft outperforms NHSR on all the 16 routes. Only in the case of Tampere–Helsinki, NHSR could almost keep up with the aircraft. In terms of real travel time, aircraft passengers have the advantage that after arrival at Helsinki Vantaa Airport on their domestic flight they can directly proceed to the next departure gate. For NHSR passengers an additional 45 minutes had to be added to the real travel time in order to account for completing check-in procedures and passing security. Because Helsinki Vantaa Airport is busier than other airports in Finland, more time had to be allocated for these procedures. With Helsinki Vantaa Airport as the final destination, the transfer and travel time for air passengers from the airport to downtown Helsinki was also left out, which is one of the reasons NHSR had outperformed aircraft on so many routes in the previous comparison, as long-distance trains were directly headed for Helsinki Central Station. It can therefore be concluded that for those passengers using aircraft to reach Helsinki Vantaa Airport in order to catch a connecting flight, flying is clearly the fastest option.

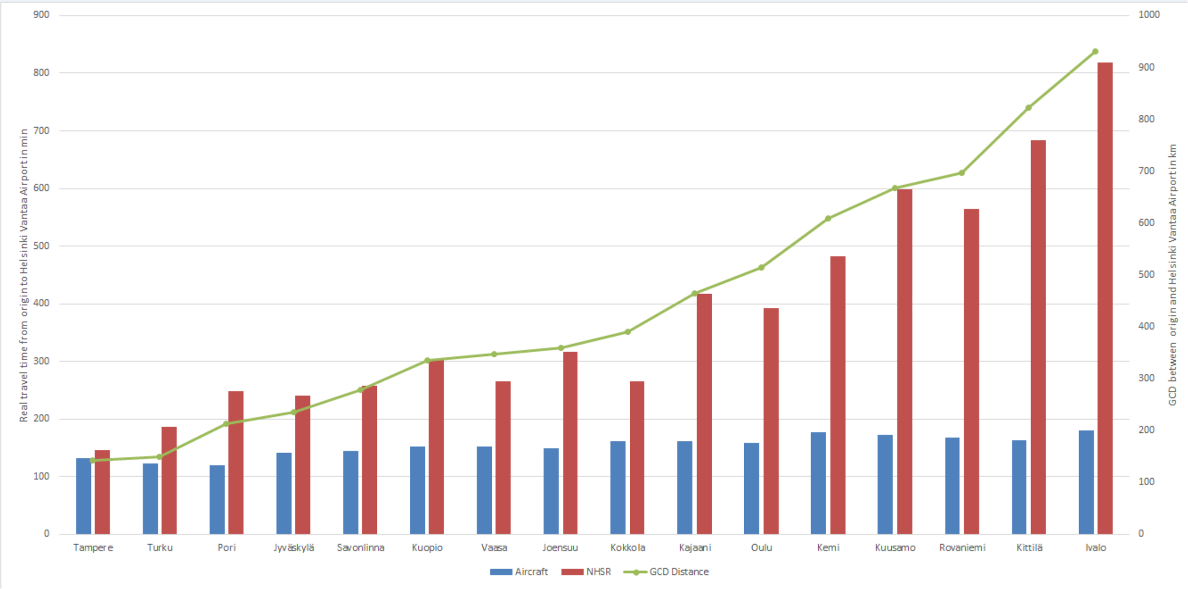

**Fig. 5. Comparison of real travel times to reach Helsinki Vantaa Airport.**

Finally, when looking at the time-distance diagram displayed in Figure 6, it can clearly be seen that the real travel time of aircraft increases only a little with distance while with NHSR it increases significantly beyond the distance of 400 km.

**Fig. 6 Time-distance diagram for aircraft and NHSR.**

### *4.3 Scenarios*

After comparing $CO_2$-eq emissions per passenger and real travel times of airplanes and NHSR for all 16 city pairs, we looked into the emissions reduction potentials of replacing all short-haul flights or parts of them with NHSR. As shown in Table 6, in 2018 on the 16 routes studied, domestic aviation in Finland carried 2.93 million passengers, which produced 494,319 t CO2-eq emissions in total. Based on the findings concerning the real travel times to downtown Helsinki, we have created two scenarios. Scenario 1 considers the replacement of aircraft on all 16 routes, abandoning short-haul flights in Finland entirely (as shown in Table 6). Scenario 2 considers replacing the aircraft on nine routes (Tampere, Turku, Pori, Jyväskylä, Savonlinna, Kuopio, Vaasa, Joensuu and Kokkola) where aircraft brings no significant time savings (distances up to 400 km, as shown in Table 7). Both Table 6 and Table 7 also compare the emission reduction potentials using the total annual emissions of the transportation sector in Finland, which accounts for 11.1 million t $CO_2$-eq.

**Table 6**. Air passenger numbers (Finavia, 2019) and emissions reduction potentials for scenario 1.

| Route | Air passengers (2018) | Aircraft | NHSR |
|---|---|---|---|
| Tampere | 81,705 | 6,140,969 | 277,542 |
| Turku | 105,746 | 7,967,955 | 428,554 |
| Pori | 5,789 | 845,067 | 17,428 |
| Jyväskylä | 59,516 | 5,534,542 | 355,959 |
| Savonlinna | 7,628 | 936,730 | 84,226 |
| Kuopio | 213,856 | 23,292,005 | 872,167 |
| Vaasa | 166,195 | 18,312,444 | 1,284,413 |
| Joensuu | 111,114 | 12,475,380 | 986,796 |
| Kokkola | 57,286 | 6,803,863 | 255,586 |
| Kajaani | 85,286 | 11,096,714 | 955,602 |
| Oulu | 991,161 | 172,261,986 | 6,222,167 |
| Kemi | 65,004 | 10,145,838 | 470,955 |
| Kuusamo | 79,515 | 13,301,323 | 1,188,438 |
| Rovaniemi | 512,033 | 107,108,645 | 4,242,385 |
| Kittilä | 208,835 | 50,305,646 | 2,989,239 |
| Ivalo | 182,934 | 47,789,674 | 3,613,194 |
| Total passengers and $CO_2$-eq emissions | 2,933,603 | 494,318,779 | 24,244,650 |
| Total kg $CO_2$-eq savings when shifting to NHSR | | | 470,074,129 |
| Total $CO_2$-eq savings when shifting to NHSR | | | 95.10% |
| Total transportation sector emissions savings | | | 4.23% |

**Table 7**. Air passenger numbers (Finavia, 2019) and emissions reduction potentials for scenario 2.

| Route | Air passengers (2018) | Aircraft | NHSR |
|---|---|---|---|
| Tampere | 81,705 | 6,140,969 | 277,542 |
| Turku | 105,746 | 7,967,955 | 428,554 |
| Pori | 5,789 | 845,067 | 17,428 |
| Jyväskylä | 59,516 | 5,534,542 | 355,959 |
| Savonlinna | 7,628 | 936,730 | 84,226 |
| Kuopio | 213,856 | 23,292,005 | 872,167 |
| Vaasa | 166,195 | 18,312,444 | 1,284,413 |
| Joensuu | 111,114 | 12,475,380 | 986,796 |
| Kokkola | 57,286 | 6,803,863 | 255,586 |
| Total passengers and $CO_2$-eq emissions | 808,835 | 82,308,955 | 4,562,670 |
| Total kg $CO_2$-eq savings when shifting to NHSR | | | 77,746,285 |
| Total $CO_2$-eq savings when shifting to NHSR | | | 94.46% |
| Total transportation sector emissions savings | | | 0.70% |

As the results in Table 6 show, replacing all short-haul flights on the 16 routes studied with NHSR could result in a significant reduction of the $CO_2$-eq emissions of the Finnish transportation sector. The emission released by NHSR were found to be 95.10% lower in Scenario 1, and 94.46% lower in Scenario 2 (Table 7). For the case of Scenario 1, where all short-haul flights were replaced by NHSR, the total saving of $CO_2$-eq emissions would be

4.23% (Table 6). In the case of Scenario 2, the savings would be much smaller but still significant when one considers the small market share the aircraft has in Finland (Table 7). It should be noted that only 0.1% of passengers in Finland are carried by aircraft (Finnish Transport Agency, 2015).

## 5. Discussion and conclusion

Based on Scenario 1, replacing all short-haul flights in Finland with NHSR would bring a significant reduction of $CO_2$-eq emissions in the Finnish transportation sector. Our study complemented the findings of Borken-Kleefeld et al. (2013), which considered the climate benefits offered from aircraft to train mode shifts. Our results further demonstrated that there are significant differences between the $CO_2$-eq emissions reduction potentials on different routes due to the deployment of different train and aircraft types. However, even on routes where less efficient RailCars or buses were used, emissions were still at least 11 times lower than those of the modern ATR 72 aircraft. On the opposite, where modern InterCity trains competed with older aircraft, the emissions reduction potentials increased up to 48 times. This study further revealed that, in terms of $CO_2$-eq emissions, aircraft on most of the routes perform well in Finland with extensive use of newer aircraft deployed on optimal stage lengths and with relatively high load factors. Nevertheless, even with an efficient air transport system in place, NHSR still outperforms aircraft significantly. We concluded that replacing aircraft with NHSR is mostly beneficial for reducing $CO_2$-eq emissions even when a highly efficient air transport system is in place, as is the case in Finland. Compared to other countries with less efficient air transport systems, or where aviation has a much larger market share, the $CO_2$-eq emissions reductions potential might be even higher than our results found in Finland. Shifting all or parts of the air passengers of a country to NHSR would require enough spare capacity in trains to accommodate the additional passenger load. Considering current load factors, this transition would not pose as a major problem in Finland. Also in general, it is rather easy to extend the capacity of trains by adding additional services to existing routes or additional cars to existing trains. In addition, NHSR needs to be well connected with the major airports of a country in order to guarantee fast and convenient transfers, as was shown in this study for Helsinki Vantaa.

Regarding Scenario 2, in which modal shifting was only allowed for routes up to 400 km where NHSR can keep up with the real travel times of aircraft, the emissions reduction potentials were moderate. This is in line with the findings of Chen and Hall (2011), indicating the travel times of conventional trains can compete with aircraft for distances up to 400 km. However, in order to extend the radius in which trains could compete with aircraft, the shift to HSR would be inevitable. Upgrading rail corridors to NHSR’s maximum speed of 200 km/h alone, as has been done on some lines in Finland, would not help to push the boundaries beyond 400 km. In Finland, there has been recent discussions on building high-speed lines from Helsinki to Tampere and Turku. While NHSR already outperforms aircraft on these two routes, the destinations beyond Tampere could benefit from this upgrade. Nevertheless, for rail to remain competitive on all of the 16 routes studied, construction of longer HSR corridors to the northern and eastern parts of Finland would be necessary. However, while shifting air passengers to HSR would reduce travel times and trip-related $CO_2$-eq emissions, the construction of high-speed lines come at considerable environmental costs. According to Cornet et al. (2018), these are not only the high carbon costs of building the lines and trains but also the use of resources, changes in landscape and loss of biodiversity. Based on the current travel demand in Finland, the debate on whether true HSR should be built remains unsettled. According to de Rus and Nombela (2007) investing in HSR only is socially profitable if patronage in the first year of operation reaches 8-10 million passengers for a line of 500 km in length. Whereas in 2018, VR carried 13.6 million passengers on its entire long-distance network (VR Group, 2019). Even mode shifting 2.93 million air passengers to rail would most likely not justify the construction of HSR corridors for environmental purposes in Finland.

Concerning passengers using Helsinki Vantaa Airport as a gateway for international flights, NHSR is unlikely a feasible option to reach the airport due to the additional time needed for completing check-in procedures and passing security. In addition, a change of transport modes also bears the risk of missed connections in case of delays. One solution discussed in the literature to shift air passengers from short-haul flights to trains is air–rail integration (Jiang et al., 2017; Xia and Zhang, 2017). A modal shift from short-haul flights to NHSR could be made easier through a closer collaboration between Finnair and VR. Through an air–rail integration, air passengers could purchase NHSR tickets treated as an additional flight leg from the origin to the flight destination after transiting at Helsinki Vantaa Airport. Check-in facilities at origin railway stations, baggage drop facilities on the arrival platform at Helsinki Vantaa Airport railway station, dedicated guiding staff at the airport and a separate security check could reduce the real travel times of NHSR passengers significantly, making it a real alternative to short-haul flights.

This study offers some wider policy implications. Replacing short-haul flights with NHSR could certainly help a country to better meet its climate goals and potential commitments made under the Paris Climate Agreement. Among prevailing long-distance travel modes, train creates the least climate change impact in terms of direct emissions (Borken-Kleefeld et al., 2013). As our study found, in the case of Finland, shifting all air passengers to NHSR could reduce $CO_2$-eq emissions by 95%. On routes up to 400 km this could be implemented with little effort. On routes beyond 400 km, investments in infrastructure allowing HSR operations would be necessary in order to compete with the aircraft. This, however, should only be considered in countries where the traffic volume would justify the massive investments and environmental costs associated with the construction of HSR. As an alternative, for countries with lower passenger numbers like Finland, the use of overnight sleeper trains could be a feasible alternative to air travel. VR, for example, already operates overnight trains between Helsinki, Oulu and Rovaniemi.

Banning flights for climate reasons could be a feasible option for countries that have pledged for becoming carbon neutral. Finland has committed to carbon neutrality by 2035, a very ambitious goal requiring drastic measures. Replacing domestic flights with NHSR would be a simple solution based on existing infrastructure and technology. Although $CO_2$-eq emissions of the Finnish transportation sector could only be reduced by 4.23%, any easy to implement solution that helps driving down emissions towards zero would be welcome at this stage. In contrast, it also has to be highlighted that only 0.1% of passengers in Finland are currently carried by air. To further increase the attractiveness of NHSR in Finland, investments into existing infrastructure such as upgrading lines to speeds of 200 km/h, adding a second track on single-tracked lines, updating and replacing aging rolling stock as well as introducing additional night trains could be recommended. Furthermore, the Finnish Government, as an owner of Finnair, VR and Finavia, could accelerate the air-rail integration between Finnair and VR and the further development of Helsinki Vantaa Airport into an intermodal hub for both domestic and international travel. Besides that, banning short-haul flights would also reduce the costs and emissions created by operating unnecessary airports as well as reduce congestion at major airports like Helsinki Vantaa due to the reduced amount of flights.

Finally, our results also highlighted the importance of considering real travel times from door-to-door when comparing travel times of different transportation modes as focusing on scheduled travel times alone would not provide a realistic picture and could easily lead to false decisions in policy making.

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