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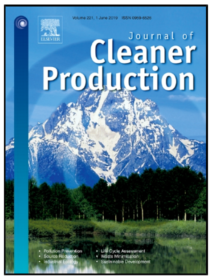

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Replacing short-haul flights with land-based transportation modes to reduce greenhouse gas emissions: the case of Finland

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Abstract

Even though air travel often provides the fastest transport option, it also has the highest climate impact. Especially on long-haul trips, an aircraft usually represents the only feasible option. Nevertheless, aircraft are more often used on short-haul routes as well. It is the short-haul flights that produce the highest emissions per passenger. These are also the ones that could be replaced the most easily by land-based transportation modes. This study investigates the greenhouse gas emissions reduction potential of replacing short-haul flights with train, coach and car travel within Finland while also taking into account real travel times from door to door. Our results showed that replacing short-haul flights could significantly reduce a country's climate impact. Furthermore, we found that existing land-based transportation modes can keep up with the travel times of aircrafts on routes up to 400 km.

Keywords: Modal shift, climate change, greenhouse gas emissions, short-haul flight, train, travel time.

1. Introduction

With 24% of the total, the transportation sector is the second largest producer of CO_2 emissions globally (IEA, 2017). According to Sivak and Schoettle (2016), transportation has become the fastest growing cause of greenhouse gas emissions. Between 1990 and 2015, the sector's CO_2 emissions grew by 68% (IEA, 2017). Most of the emissions stem from road transportation, but it is air transportation that shows the highest growth rates, despite the fact that its share of the transportation sector's total CO_2 emissions remains, at 12%, moderate (IEA, 2009). Between 1990 and 2015, aviation's CO_2 emissions grew by 105% (IEA, 2017). Although aviation is currently responsible for about 3% of the total CO_2 emissions (IEA, 2018), the sector is growing at a very fast rate of about 6% annually (ICAO, 2017). At the same time, the latest IPCC special report (Rogelj et al., 2018) calls for drastic reductions of greenhouse gas emissions in order to limit warming to 1.5 degrees above pre-industrial levels. It is therefore essential to develop new approaches to reduce CO_2 emissions in the aviation sector. One solution is seen in modal shift (Borken-Kleefeld et al., 2013; Dalkic et al. 2017). However, replacing aviation with other modes of transportation only makes sense for distances where substituting modes can offer similar benefits in travel time. According to Follmer et al. (2010), at distances of less than 500 km aviation plays a minor role while at distances above 1,000 km it becomes the predominant mode of transportation. All flights within this range fall under the category of short-haul flights (EUROCONTROL, 2005). The total emissions of short-haul flights are much lower than those of medium- and long-haul flights, but short-haul flights produce much higher emissions per ton kilometer. This, according to Grimme and Jung (2018), is not only because the energy-intense take-off and climb phase is distributed over a much shorter flight distance but also due to lower load factors and the smaller amount of cargo carried compared to medium- and long-haul flights. Based on Grimme and Jung's (2018) calculations, short-haul flights in Germany, for example, showed more than twice as high CO_2 emissions per ton kilometer (1,653 kg) compared to long-haul flights (706 kg). These flights are the least efficient flights, but are also the ones that could be replaced the most easily by other modes of transportation. Such replacement could be a significant contributor to meeting the IPCC's climate goals.

Previous research has addressed this issue mainly by studying the replacement of aircraft with high-speed rail (e.g. D'Alfonso, 2016; Dalkic et al. 2017; Givoni, 2007; Janic, 2003; Jiang and Bracaglia, 2016; Robertson, 2016). While high-speed rail certainly brings huge advantages in travel time, building the necessary infrastructure requires significant amounts of time and funding. Our study instead examines the replacement of short-haul flights with existing modes of transportation such as conventional trains as well as with cars and coach travel. Our study is based on data collected from Finland, a country that has a well-developed transportation infrastructure but which is also one where building a high-speed rail would not be feasible due to the small population. The aim of the study is to investigate the greenhouse gas emissions reduction potential of replacing all or part of the currently available short-haul flights with land-based transportation modes. Our study compares all 16 city pairs for which short-haul flights are offered with land-based modes of transportation. In addition, and compared with previous studies (e.g. Behrens and Pels, 2012; Cheng, 2010; Dobruszkes, 2011), we also take real travel time (RTT) from door to door into account, which so far has been under-represented in the literature (Zhao and Yu, 2018). Based on the RTTs, we created three scenarios: for routes where land-based transportation modes are faster than the aircraft, for routes where aircraft brings no significant time savings and a third scenario that considers the replacement of aircraft on all 16 routes. The greenhouse gas emissions reduction potential for all three scenarios were calculated separately.

2. Material and methods

Despite its small population of 5.5 million, Finland operates an extensive network of 20 civil airports, 17 of which are open year round. All domestic flights start or end at the major airport in Finland's capital Helsinki. The local rail and street network also centers around the country's capital. Helsinki is the major urban center of Finland, with about 27% of Finns living in the Helsinki metropolitan area. In 2015, Finland produced a total of 55.6 million t of carbon dioxide equivalent emissions (CO_2-eq), of which 11.1 million t accounted for domestic transportation (Statistics Finland, 2017). With 8,700 kg annually, Finns are among the highest emitters of CO_2 per capita (Finnish Environment Institute, 2013). The market shares of different transportation modes in Finland per passenger kilometer are as follows: car 84.0%, coach 6.5%, train 5.7% and air 1.7% (Finnish Transport Agency, 2015). In 2013, Finnish railway carried 13.6 million passengers on long-distance trains, while the share for long-distance coaches was 6.8 million followed by domestic air transport, which accounted for 2.4 million passengers. The occupancy rate of long-distance public transport in Finland for 2013 was 62% for aircraft, while it was only 33% for trains and 19% for coaches (Finnish Transport Agency, 2015). There certainly would be room on trains as well as coaches for passengers shifting from aircrafts.

2.1 Aircraft

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 with all available transportation modes such as aircraft, train, coach, car and combinations of these in cases where one mode of transportation fails to provide service for the entire trip. We took both destinations into account (Helsinki City and Helsinki Vantaa Airport) because domestic flights are used to reach Helsinki as a final destination or Helsinki Vantaa Airport to connect to one of the over 100 non-stop destinations that Finland's major international hub offers around Europe, Asia and North America. In Finland, in addition to Helsinki Vantaa, there are 16 airports (Ivalo, Joensuu, Jyväskylä, Kajaani, Kemi-Tornio, Kittilä, Kokkola-Pietarsaari, Kuopio, Kuusamo, Mariehamn, Oulu, Pori, Rovaniemi, Tampere Pirkkala, Turku and Vaasa) which operate year-round scheduled flight services to Helsinki Vantaa Airport. In addition, there are two more airports that operate a very small amount of flights to Helsinki Vantaa during special events (Savonlinna and Enontekiö) as well as Lappeenranta airport, which only offers flights to destinations outside of Finland. This study, however, focuses only on the 16 city pairs between Helsinki Vantaa Airport and the 16 airports that offer year-round scheduled flight service. Any additional flights operated from these airports to any destination outside Finland or between these 16 airports were not considered in this study. Figure 1 provides an overview of all Finnish airports and their locations.

[Figure 1]

Fig. 1. Map of Finnish airports (Plane Flight Tracker, 2014).

Almost all routes within Finland are solely operated by the Finnish flag carrier Finnair through its subsidiary Nordic Regional Airlines (Norra). Norra operates most of the routes within Finland with ATR 72 turboprop aircraft. A few flights, mainly to the more distant destinations in the northern part of Finland are also operated by Finnair itself with different types of aircrafts of the A320-family. In addition, Norwegian Air Shuttle is operating flights with Boeing 737-800 aircraft on the Helsinki–Oulu and Helsinki–Rovaniemi routes. The Helsinki–Pori route is solely operated by NextJet with Saab 340 aircraft. We used different per passenger-kilometer (pkm) CO_2-eq emissions values for different route lengths (domestic short distance <=463 km and domestic long distance >463 km) and took the differences between turboprop and jet-engine driven aircraft into account.

2.2 Train

To reach the city center of Helsinki, the fastest and most feasible option is the Ring Line airport train that connects the airport with the Helsinki Central Station in 31 minutes. Ring Line airport trains are operated by four-car electric-multiple Stadler FLIRT units. All passenger trains in Finland are run by the state-owned Finnish Railways (VR), which has a monopoly on passenger train services. The two types of trains mainly used by VR on long-distance routes are six-car electric-multiple unit tilting Pendolino train sets that can run at a top speed of up to 220 km/h and electric locomotive hauled double-decker push-pull InterCity train sets that normally consist of four to six cars which can reach a top speed of 200 km/h. Nevertheless, the regular operating speeds are mainly around 140-160 km/h. Only on a few rail corridors in the south these trains can run on higher speeds of 180-200 km/h such as on parts of the routes between Helsinki and Seinäjoki, Turku and the Russian boarder. Nevertheless, there are no high-speed trains in operation in Finland. Of the 16 city pairs, 12 are connected by rail non-stop, with the exception of Ivalo, Kittilä, Kuusamo and Mariehamn. All 12 cities can be reached by electrified lines, either with Pendolino or InterCity trains. Ivalo, Kittilä and Kuusamo can be reached by coach after taking the train from Helsinki to Rovaniemi. To reach mainland Finland from Mariehamn, a ferry needs to be used between Mariehamn and Turku. A direct ferry connection between Mariehamn and Helsinki is available, but this ferry takes about 5 hours more to reach Helsinki while trains, coaches and cars need only about 2 hours to cover the distance between Turku and Helsinki. Therefore, only the ferry connection between Mariehamn and Turku was considered. The car ferry used on this route is a gas driven ferry with a capacity of 2,800 passengers that operates at an average speed of 18 knots. Additionally, Helsinki Vantaa Airport can be reached by train from all 16 origin cities using the Ring Line airport train. This, however, requires changing trains once at Tikkurila station for all train connections, with the exception of the trains from Turku, which require a one-time change to the Ring Line airport train at Pasila. Timetable data were retrieved from VR's 2017 summer timetable. The fastest available train connection was always considered for the study even though the differences between the speed of different train types was not very significant.

2.3 Car

The airport in Helsinki can also be reached from all 16 origin cities by highway. The same applies to Helsinki city center. Highways in Finland usually allow for top speeds of up to 100 km/h. In addition, some motorways, specifically those built around major cities as well as the one between Helsinki and Tampere and the one between Helsinki and Lahti allow speeds up to 120 km/h. Although we used average CO_2-eq emissions per pkm of Finnish cars in 2016, without distinguishing between diesel, gasoline or cars that use any other fuel, we still used different factors for driving on highways or urban driving. For car occupancy, we used estimates, made by VTT Technical Research Center of Finland (2017), of what is typical in Finland: 1.9 passengers per car for highway driving and 1.3 per car for urban driving. For the share of diesel car mileage in Finland, we used the estimate of 41% (VTT, 2017). Distance and RTT were determined using Google Maps route planner and always considering the fastest and most direct routes assuming normal traffic conditions. In order to reach the local airports of the 16 origin airports, only car travel was considered because most of the local airports in Finland are poorly connected by public transport and the use of a private car or taxi is common.

2.4 Coach

Long-distance coaches also run mainly on highways, which are equipped with stops that serve smaller communities on demand. In addition, long-distance coaches serve bus terminals in the centers of larger cities and towns, for which they normally have to exit the highways. Exiting the highway to serve these stops significantly adds to the total travel time. Coaches usually run at top speeds of 100 km/h. For long-distance coach travel, we assumed an average vehicle with a mass of 18 t, a carrying capacity of 5 t, and 50 seats, 14 of which were occupied, as is typical in Finland (VTT, 2017). Coach service in Finland are operated by various bus companies. For this study, timetables and distances were extracted from Matkahuolto's timetable search engine. Matkahuolto is the national service and marketing company promoting bus and coach service in Finland. The company runs all national bus terminals and, through its website, provides timetable information about all long-distance coaches in Finland and also sells tickets for most of the services. We always calculated RTT and distance based on the fastest connection available during a day. However, the durations of distances for different connections did not differ greatly. Non-stop connections were given priority in our selection.

3. Calculations

Following the IPCC's guidelines for the climate impact of local emissions, CO_2-eq emissions per passenger for aircraft, coach, car and ferry were calculated based on the LIBASTO unit emissions database published by VTT (2017). The emissions data provided by VTT are specific to Finland, based on local traffic, weather and geographical circumstances. For these reasons they suit this study well. The time frame chosen for the Global Warming Potential for this study was 100 years (GWP_{100}). Alongside CO_2, we also took CH_4 and N_2O emissions into account. The CO_2-eq emissions were calculated based on IPCC's Fifth Assessment Report (IPCC, 2014):

$$CO2 - eq = CO2 + CH4 * 28 + N2O * 265 \quad (1)$$

The CO_2-eq emissions per passenger for train were calculated based on the emissions released from electricity production. All trains considered in this study are electric and are supplied by electricity produced from hydropower. While the electricity consumption of the three different train types used in this study are based on the LIBASTO unit emissions database (VTT, 2017), the CO_2 and CH_4 emissions per kWh were built based on Hertwich (2013). N_2O emissions from hydropower production were not considered, because they are, according to Hertwich (2013), relatively minor in boreal regions like Finland. Table 1 below provides an overview of all the emissions that have been considered in this study of the different transport modes and specifications per passenger kilometer.

Table 1. Emissions per pkm of the different transport modes (Hertwich, 2013; VTT, 2017).

Mode	Specifications	g CO_2	g CH_4	g N_2O	g CO_2-eq[1]
Aircraft	Turboprop <= 463 km[2]	188.00	0.0013	0.0051	189.61
	Turboprop > 463 km[2]	128.00	0.00087	0.0035	129.10
	Jet engine > 463 km[2]	184.00	0.0013	0.0050	185.58
Train	Electric, Pendolino[3]	9.35	0.33	0	18.59
	Electric, InterCity[3]	4.59	0.162	0	9.13
	Electric, FLIRT (Ring Line)[3]	6.04	0.213	0	12.00
Coach	Highway	39.00	0.00016	0.0015	39.47
Car	Urban driving	155.00	0.0015	0.0046	156.46
	Highway	69.00	0.00058	0.0011	69.35
Ferry	Gas driven	98.00	0.04	0.00057	99.02

[1] g CO_2-eq = g CO_2 + g CH_4 * 28 + g N_2O * 265
[2] Emissions data presented are from 2008
[3] All electric trains in Finland are run on hydropower. The emissions displayed result from energy production.

Train and coach stations in all 16 origin cities are centrally located, while the airports are between 5 and 22 km from the city centers. Only Pori Airport is located within the city center. Therefore, we added 10 minutes to the RTT for train and coach journeys to account for arriving at the station in time to find the right platform and to board the train or coach safely prior to departure. The RTT for cars was calculated starting from the city centers of all 16 origin cities until reaching the city center of Helsinki or the departure terminal at Helsinki Vantaa. For all land-based modes of transportation bound for Helsinki Vantaa Airport, we added a recommended 45 minutes of prior arrival time before check-in closes to the RTT. For the local airports, we added only 30 minutes of prior arrival time to the RTT before check-in closes because these airports are by far less busy and significantly smaller than Helsinki Vantaa and traffic as well as finding the correct check-in counter or baggage drop certainly takes far less time. In all Finnish airports, check-in closes 45 minutes prior to departure, which should allow passengers enough time to clear security and reach the departure gate in time, which usually closes 15 minutes prior to the departure of the flight. For transferring from a domestic flight to the Ring Line train, including claiming baggage, buying a ticket and waiting for the next train, we added 40 minutes to the RTT. Trains run every 8 to 10 minutes, so the maximum waiting time would be 10 minutes. For the ferries from Mariehamn, passengers with cars should be at the harbor 1 hour prior to departure while passengers without cars should report to the terminal 30 minutes prior to departure. For ferry passengers without a car (traveling onwards from Turku Harbor by train), the distance from the ferry to the train station is about 50 meters and takes about 10 minutes, including the safe boarding of the train. Table 2 provides an overview of the calculation method for RTTs for all four transportation modes.

Table 2. Overview of RTTs for all four transportation modes in minutes.

Mode	Aircraft	Train	Coach	Car
Transfer to local airport (car)	8–22			
Transfer to Turku Harbor (ferry)[1]	365	365	385	
Transfer to Rovaniemi (coach)[2]	125–240			
Check-in at local airport	30			
Security control, transfer to gate	45			
Early arrival at station and boarding	10	10		
Scheduled travel time	35–100	90–508	120–1,065	105–756
Baggage claim, transfer to Ring Line[3]	40			
Ring Line airport train to Helsinki City[3]	31			
Early arrival at Helsinki Vantaa Airport[4]	45	45	45	

[1] When traveling on train/coach/car from Mariehamn, the ferry to Turku needs to be used
[2] When traveling on train from Ivalo, Kittilä and Kuusamo, a coach to Rovaniemi needs be used
[3] When traveling by aircraft to Helsinki Vantaa Airport and Helsinki City is final destination
[4] When traveling by train/couch/car to Helsinki Vantaa Airport in order to fly out from Helsinki

4. Results

4.1 Emissions

In terms of CO_2-eq emissions, the train achieves by far the lowest emissions followed by coach, car and aircraft, as shown in Figure 2 below. Depending on the route, the per passenger CO_2-eq emissions of one flight equals 1.6 to 2.6 trips by car, 2.3 to 4.5 trips by coach, and between 2.9 and 17.7 trips by train. Although the aircraft showed the highest emissions figures, the difference between it and car and coach travel was not large. This was probably because flights in Finland have a much higher load factor (62%) while those of coaches are rather low (19%) as is the occupancy of cars on highways, with only 1.9 passengers on average. Furthermore, most of the domestic routes within Finland are operated by aircraft based on their optimal stage lengths. Fuel-efficient ATR 72 turboprop aircrafts are mainly used on the shorter routes up to Kuusamo (667 km) while longer flights to the far northern airports in Lapland are operated by more suitable jet aircraft such as those of the Airbus A320-family or the Boeing 737-800. The only exception is Oulu Airport, which is served by both ATR 72 and jet aircraft due to the high passenger demand. According to Babikian et al. (2002), using turboprop aircrafts on shorter routes can mean significant emissions reductions due to their more efficient operations compared to jet aircraft.

[Figure 2]

Fig. 2. kg CO_2-eq emissions per passenger for all 16 city pairs.

4.2 RTT

In terms of RTT, and as Figure 3 below shows, reaching Helsinki Vantaa Airport from any of the 16 origin cities using an aircraft is the fastest option. Even adding the driving time to the airport, arriving 30 minutes before check-in closes and 45 minutes for security control and boarding did not prevent aircraft from being the fastest option to reach Helsinki Vantaa Airport. For those passengers using aircraft to reach Helsinki Vantaa Airport in order to catch a connecting flight, flying is clearly the fastest option. Only in the case of the Tampere–Helsinki route could trains and cars almost keep up with the aircraft. However, we have added 45 minutes to all land-based modes of transportation for reaching Helsinki Vantaa Airport in order to provide time for check-in and security control at the airport, which passengers arriving to Helsinki by air have already completed at their departure airports.

[Figure 3]

Fig. 3. Comparison of RTTs to reach Helsinki Vantaa Airport for all four modes.

Nevertheless, when the different modes of transportation were compared with the RTT for reaching Helsinki City, the situation looked completely different, as shown in Figure 4 below. The additional time for air passengers to claim their baggage, transfer to the Ring Rail line and the actual driving time of 31 minutes from the airport to downtown Helsinki brought clear advantages to the remaining modes of transportation. Between Tampere and Turku, all land-based modes of transportation were faster than the aircraft. In addition, Helsinki City could be reached faster by train or car from Pori, Jyväskylä, Vaasa and even Kokkola. Only starting from Kuopio and

Joensuu were aircraft passengers able to reach Helsinki City slightly faster than those travelling by train or car. Just from Kajaani and going further north with a growing distance from Helsinki above 400 km, using the aircraft to reach Helsinki City brought an advantage in terms of RTT and would justify its use. This shows that land-based transportation modes can compete with air transportation in terms of RTT on routes up to 400 km even if they are not based on high-speed rail or motorways. The only exception was Mariehamn, which, because reaching Helsinki through land-based transportation modes required the use of a ferry, was reached more quickly by aircraft even though the distance to Helsinki is only 282 km. Coach travel itself gets compared to the other modes of transportation with increasing distance significantly slower. This is probably explained by the increase in intermediate stops in smaller communities typically served by long-distance buses within Finland.

[Figure 4]

Fig. 4. Comparison of RTTs to reach Helsinki City for all four modes.

After comparing CO_2-eq emissions per passenger and RTTs for all four modes on all 16 city pairs, we looked next into the emissions reduction potentials of replacing all domestic flights or parts of them with land-based transportation modes. Table 3 provides an overview of the Great Circle Distance (GCD), flight times, passenger numbers and total CO_2-eq emissions for all 16 city pairs.

Table 3. Overview of total passenger numbers and CO_2-eq emissions for all 16 city pairs (Finavia, 2017).

Route	GCD (km)	Flight time	Passengers 2017	t CO_2-eq
Tampere	143	0:35	85,844	2,552.907
Turku	150	0:35	106,022	3,160.997
Pori	214	0:40	9,645	395.424
Jyväskylä	235	0:45	56,814	2,723.885
Mariehamn	282	0:55	42,488	2,302.369
Kuopio	335	1:00	207,276	13,701.230
Vaasa	348	1:05	162,333	10,977.909
Joensuu	360	1:00	110,666	7,752.682
Kokkola	391	1:05	60,681	4,683.110
Kajaani	464	1:15	84,724	5,188.499
Oulu	514	1:05	851,542	82,994.190
Kemi	609	1:30	95,610	7,598.055
Kuusamo	667	1:20	67,183	5,883.450
Rovaniemi	697	1:40	455,589	59,572.592
Kittilä	823	1:20	183,952	28,234.792
Ivalo	931	1:35	160,906	28,019.217
Total			2,741,275	265,741.308

4.3 Scenarios

In 2017, domestic aviation in Finland carried 2.74 million passengers, which resulted in total emissions of 265,741 t CO2-eq. Table 4 provides an overview of the emissions reduction potential when replacing the aircraft either by train, coach or car. Based on the findings concerning the RTTs to Helsinki City, we have created three scenarios. Scenario 1 considers the replacement of aircraft on all 16 routes, meaning abandoning domestic aviation in Finland entirely. Scenario 2 considers replacing the aircraft on those eight routes where aircraft brings no significant time savings (distance up to 400 km). Scenario 3 considers replacing the aircraft only on the two routes (Tampere and Turku) where all land-based transportation modes are faster than the aircraft (distance up to 200 km). Table 4 also compares the emission reduction potential with the total annual emissions that are released by the transportation sector in Finland, which accounts for 11.1 million t CO_2-eq.

Table 4. Emissions reduction potentials of all 3 scenarios for all land-based transportation modes.

Scenario 1	Scenario 2	Scenario 3	Aircraft	Train	Coach	Car
Tampere	Tampere	Tampere	2,552.907	282.159	593.307	1,017.391
Turku	Turku	Turku	3,160.997	403.167	714.349	1,249.185
Pori	Pori		395.424	27.976	122.570	156.423
Jyväskylä	Jyväskylä		2,723.885	333.549	604.418	1,035.602
Mariehamn			2,302.369	786.088	994.803	1,209.601
Kuopio	Kuopio		13,701.230	822.531	3,242.333	5,415.918
Vaasa	Vaasa		10,977.909	1,236.710	2,756.780	4,657.886
Joensuu	Joensuu		7,752.682	970.644	1,909.881	3,305.774
Kokkola	Kokkola		4,683.110	264.058	1,355.670	2,022.924
Kajaani			5,188.499	939.986	1,902.827	3,200.256
Oulu			82,994.190	5,252.017	20,567.646	35,411.071
Kemi			7,598.055	682.178	2,723.702	4,671.692
Kuusamo			5,883.450	1,054.851	2,205.070	3,683.135
Rovaniemi			59,572.592	3,724.611	15,060.980	25,418.554
Kittilä			28,234.792	2,605.584	7,233.577	12,150.080
Ivalo			28,019.217	3,420.352	7,284.677	12,189.170
Scenario 1: Total t CO_2-eq savings				242,934.848	196,466.538	148,946.646
Scenario 1: Total transport sector emissions savings				2.19%	1.77%	1.34%
Scenario 2: Total t CO_2-eq savings				41,607.350	34,646.656	27,087.039
Scenario 2: Total transport sector emissions savings				0.37%	0.31%	0.24%
Scenario 3: Total t CO_2-eq savings				5,028.578	4,404.248	3,447.328
Scenario 3: Total transport sector emissions savings				0.05%	0.04%	0.03%

As indicated in Table 4, replacing all domestic flights within Finland with land-based modes of transportation could result in a significant reduction of the CO_2-eq emissions that stem from the transportation sector. When replacing all flights (Scenario 1), the total saving of CO_2-eq emissions would be 2.19% in a case where flights would be replaced by trains, 1.77% in the case of replacement by coach and 1.34% if replaced by cars. The saving potential becomes even more significant when one considers the small market share of aircraft in the total transportation volume in Finland, where only 0.1% of the passengers are carried by aircraft (Finnish Transport Agency, 2015). Once flights were replaced on the eight routes where the aircraft does not bring significant time savings (Scenario 2), the CO_2-eq emissions saving potential is rather moderate with 0.37% by train, 0.31% by coach and 0.24% by car. If only the flights to the two closest airports to Helsinki (Tampere and Turku) were replaced by land-based transportation modes (Scenario 3), the CO_2-eq emissions savings would be small with 0.05% by train, 0.04% by coach and 0.03% by car.

5. Discussion and conclusion

Even when domestic aircraft operations are run efficiently, as they are in Finland, aircraft remain the highest CO_2-eq emitters among all modes of transportation. Our study complemented the findings of Borken-Kleefeld et al. (2013) concerning the climate benefits that result from the transition from aircraft to cars, coaches and trains. Trains had a clear advantage in this study because they were all electric and run on hydropower-produced electricity. Yet Dimoula et al. (2016) were able to show that even with diesel trains significantly lower emissions per passenger kilometer can be achieved when compared with the use of passenger cars. In addition to their low emissions, trains also showed, after aircraft, the best performance in RTT. Therefore, due to their low emissions as well as short travel times, trains seem to be the most suitable transportation mode to replace aircraft on short-haul routes. Cars achieve similar RTTs, but their emissions are significantly higher than those of trains. For coach travel, emissions are lower than those for cars, but with increasing distance the RTTs also start to increase significantly.

By taking into account the RTTs from the city centers of the 16 origin cities to reach Helsinki City, we identified three scenarios. Based on our results, we can conclude that for distances up to 200 km using aircraft brings no advantage over any land-based transportation mode in either RTT or emissions. For distances up to 400 km, aircraft show no clear advantage in RTT when compared to trains and cars, and produce significantly higher emissions per passenger than the other two modes. Therefore, shifting passengers from air travel to trains or cars would make sense. For distances greater than 400 km, aircraft have a clear advantage in RTT. Nevertheless, as our study showed, replacing those flights would also result in a significant reduction of CO_2-eq emissions.

Unlike previous research (e.g. D'Alfonso, 2016; Dalkic et al., 2017; Givoni, 2007; Janic, 2003; Jiang and Bracaglia, 2016; Robertson, 2016), the RTTs of our study were based on existing transportation modes. Upgrading the infrastructure to high-speed rail or motorways would, of course, result in shorter RTTs and land-based transportation modes could even compete with aircraft on routes longer than 400 km. Previous studies have actually shown that high-speed rail and aircraft compete on routes ranging from up to 500 km (Prussi and Lonza, 2018), up to 800 km (Chen, 2017) and according to some studies even up to 1000 km (Chiara et al., 2017). However, building a high-speed rail line is expensive and time-consuming and is not feasible in less populated countries such as Finland. Our study, based on RTTs, instead showed that existing transportation modes are able to compete with aircraft on routes of up to 400 km and are even able to outperform aircraft on routes shorter than 200 km. Our findings are hereby in line with Chen and Hall (2011), who found that conventional trains can compete with the travel times of aircrafts for distances up to 400 km.

Replacing all domestic flights of a country with train travel could result in significant emissions reduction potential, especially when the trains are run on renewable energy sources. Nevertheless, when observing the current trends of the aviation sector, abandoning all domestic flights in a country might first appear to be an unrealistic scenario. However, following IPCC's latest special report (Rogelj et al., 2018), which calls for drastic reductions of greenhouse gas emissions by 2030 in order to limit warming to 1.5 degrees above pre-industrial levels, this scenario would offer a fast and simple solution. Domestic flights are the most polluting but also the ones that could be replaced the most easily by alternative transportation modes. In Finland alone, aircraft have only a 0.1% market share but replacing flights with train travel could result in a 2.19% emissions reduction for the entire transportation sector and a 0.44% emissions reduction of the country's entire CO_2-eq emissions. In countries where aircraft have a larger market share than they do in Finland, the emissions savings could be even larger. Shifting all or part of the air passengers of a country to land-based modes would require, however, that those modes provide enough room to accommodate those additional passengers. On the basis of current load factors, in Finland this transition would not be a problem. In addition, the infrastructure of land-based transportation modes need 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.

Because the study took a very narrow focus of investigating the greenhouse gas emissions reduction potential of replacing short-haul flights with land-based transportation modes in Finland only, it also shows certain limitations. The study in its current form will not justify any policy recommendations. In order to provide a more holistic viewpoint and to allow for policy recommendations, a number of other aspects have to be considered as well. These include land use and land fragmentation of the transport infrastructure; the financing of the transportation modes, including subsidies; and the question of whether travel and flight plans are redundant from a demand perspective regarding departure and arrival times and connection frequencies. In addition, a customer's choice of transportation mode could have been a further criteria as well as the loss of compensation for missed connections, delays and cancellations, which are usually not covered on intermodal trips. Future research could cover these aspects in order to provide a more holistic picture and to allow for policy recommendations regarding a modal shift.

As a further limitation, the study did not discuss the actual reasons for having all transportation modes available in Finland. While the study only addresses the replacement of short-haul flights for reducing greenhouse gas emissions, it fails to address the effects such a replacement would have on all relevant stakeholders. For example, the study neglects the importance of short-haul flights as part of a larger hub-and-spoke network that feeds Helsinki Vantaa Airport with domestic passengers. Future research could more deeply address the effects of replacing short-haul flights within a country by going beyond reductions in greenhouse gas emissions.

Finally, the paper did not take into account the effects of the EU Emissions Trading Scheme (EU-ETS), which already provides incentives for emissions reductions of flights within Europe, or the next level of aviation policy, CORSIA. Future research with a more policy-driven focus could also look into these effects.

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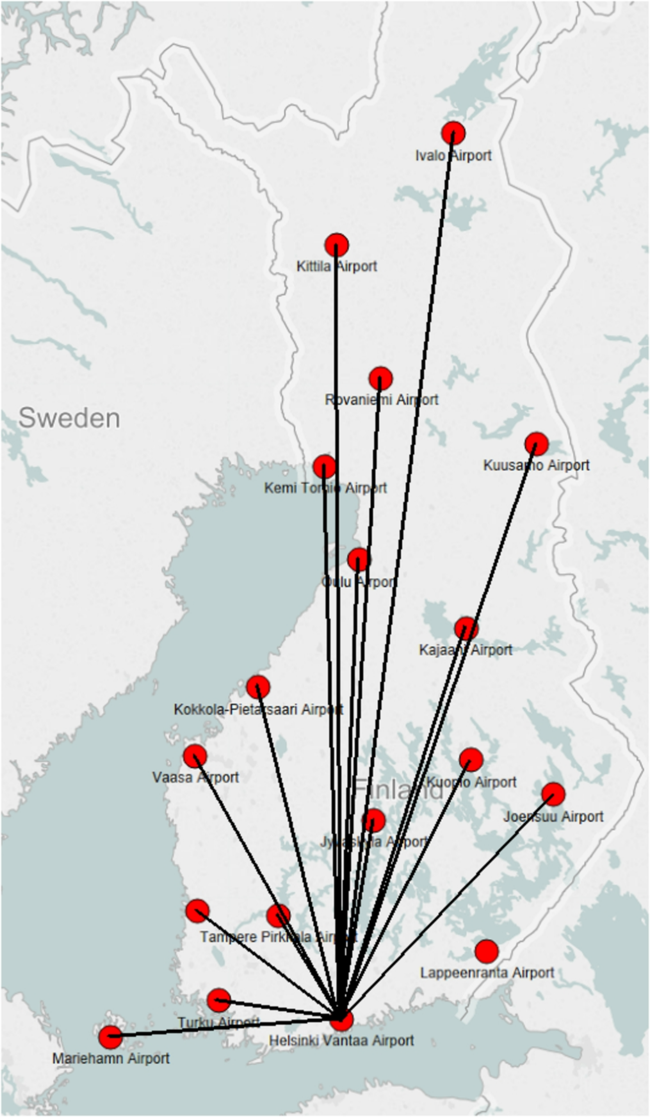
Replacing short-haul flights with land-based transportation modes to reduce greenhouse gas emissions: the case of Finland

Highlights

- Domestic flights are the least efficient but the easiest replaceable by other modes
- Substituting all domestic flights in Finland with land-based modes was studied
- Carbon dioxide emissions and door to door travel time were taken into account
- Replacing domestic flights could reduce a country's climate impact significantly
- Train, car and coach can keep up with air travel times on routes up to 400 km


Ivalo Airport
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Rovaniemi Airport
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Kuusamo Airport
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Oulu Airport
Kajaani Airport
Kokkola-Pietarsaari Airport
Vaasa Airport
Kuopio Airport
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Joensuu Airport
Jyvaskyla Airport
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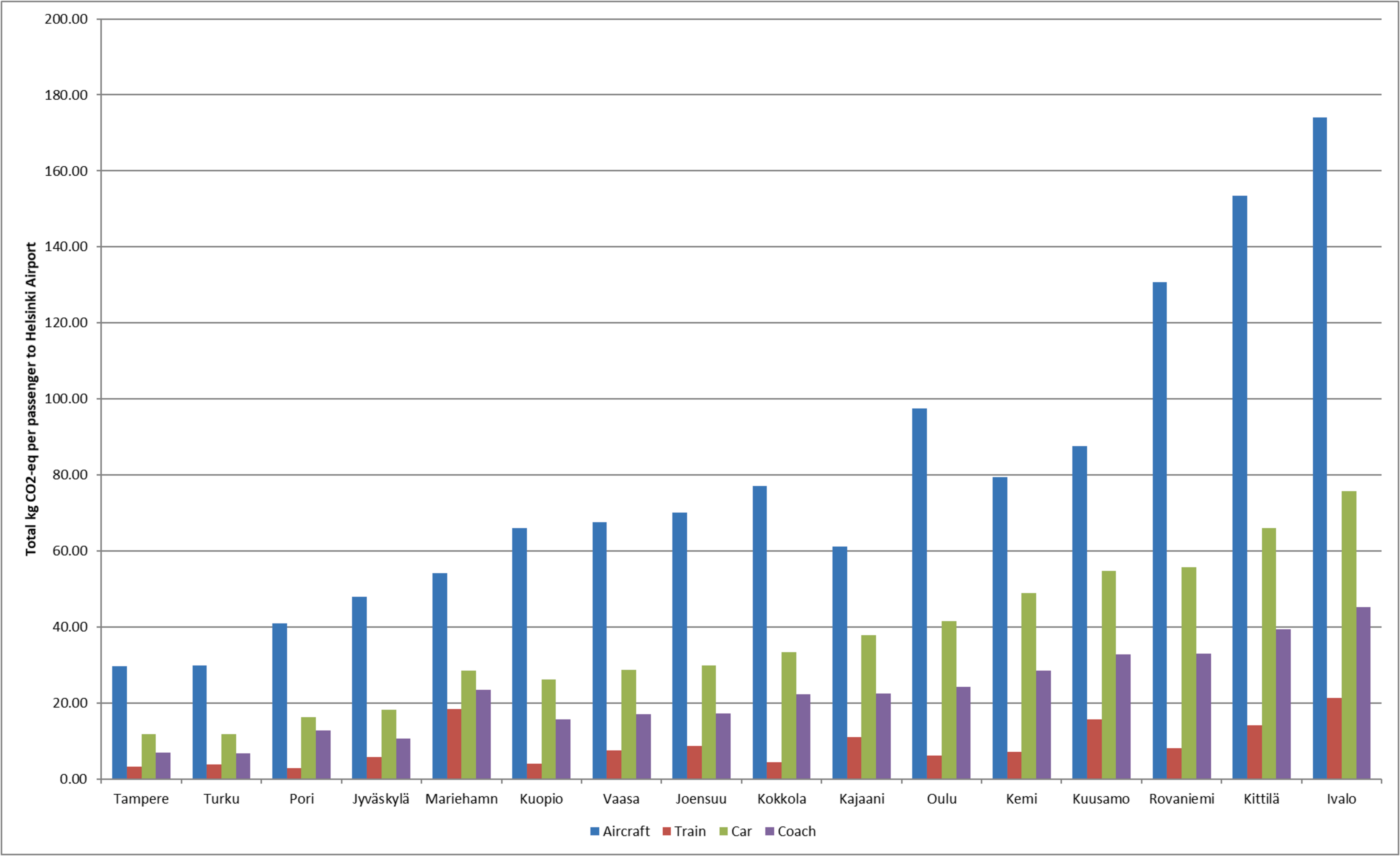
Lappeenranta Airport
Turku Airport
Helsinki Vantaa Airport
Mariehamn Airport



Total kg CO2-eq per passenger to Helsinki Airport
200.00
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Tampere
Turku
Pori
Jyväskylä
Mariehamn
Kuopio
Vaasa
Joensuu
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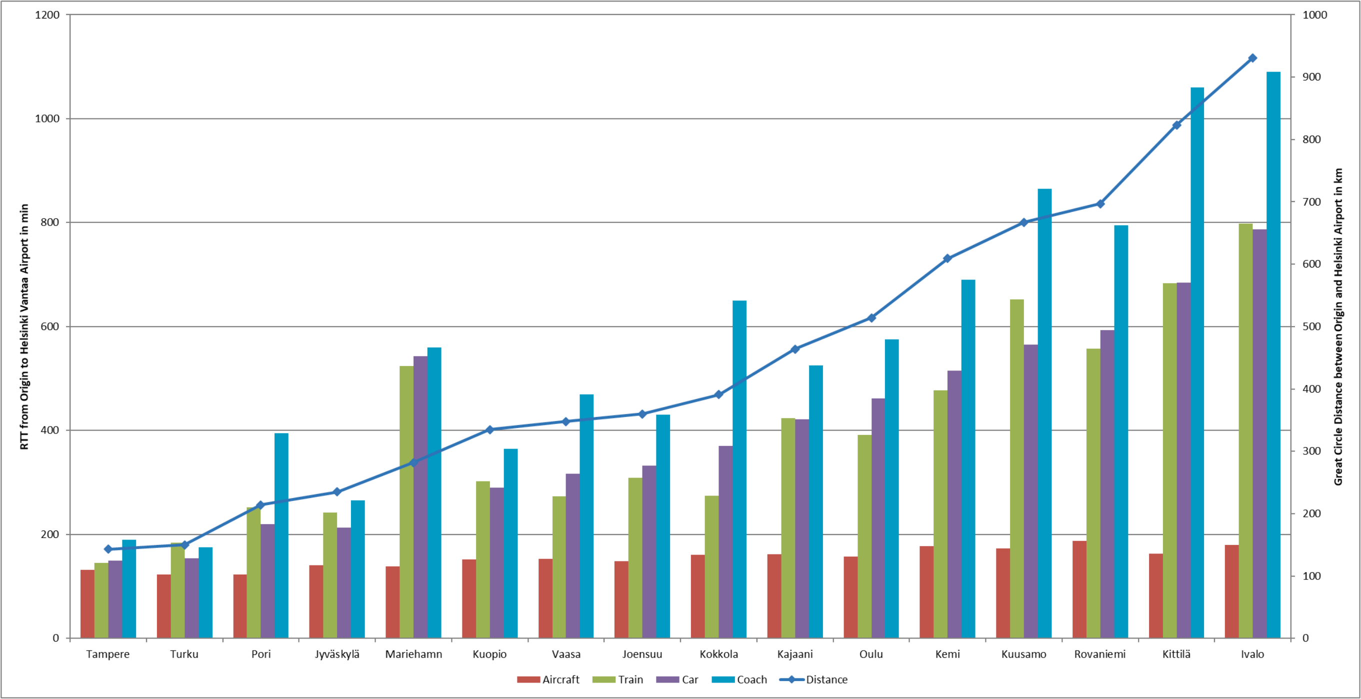
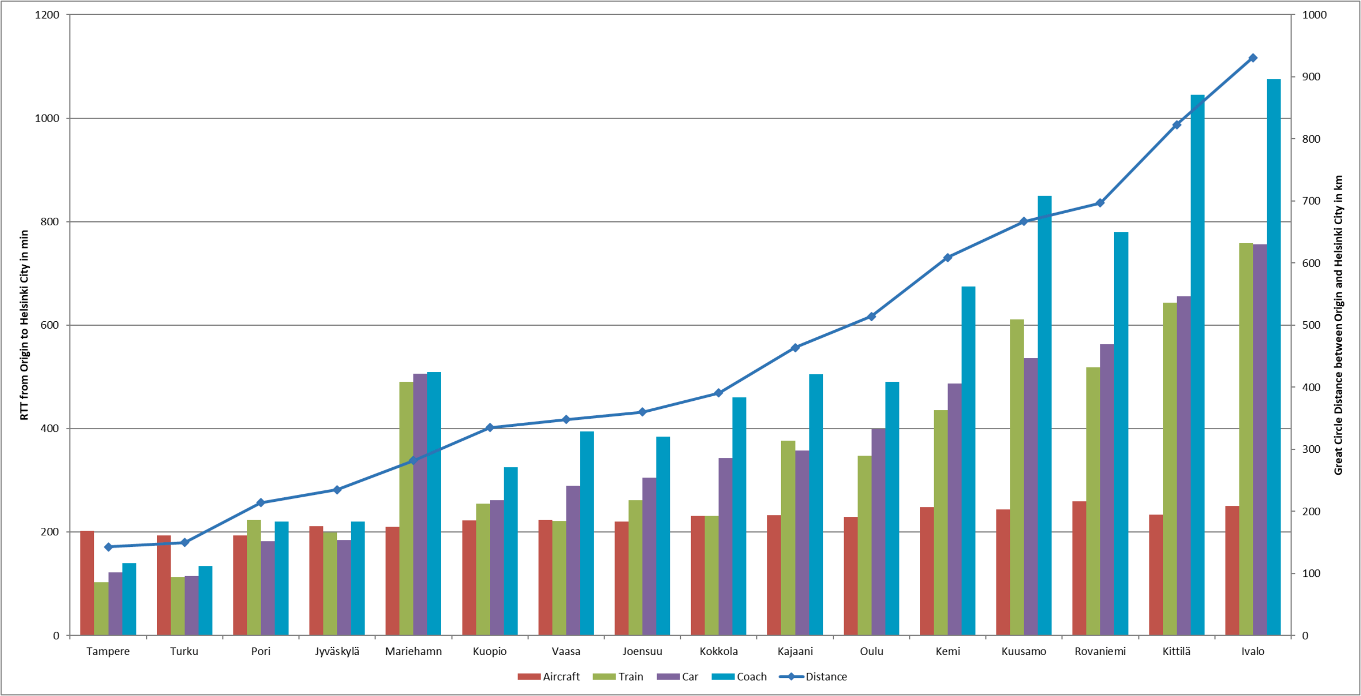
Oulu
Kemi
Kuusamo
Rovaniemi
Kittilä
Ivalo
Aircraft
Train
Car
Coach



RTT from Origin to Helsinki Vantaa Airport in min
Great Circle Distance between Origin and Helsinki Airport in km
0
200
400
600
800
1000
1200
0
100
200
300
400
500
600
700
800
900
1000
Tampere
Turku
Pori
Jyväskylä
Mariehamn
Kuopio
Vaasa
Joensuu
Kokkola
Kajaani
Oulu
Kemi
Kuusamo
Rovaniemi
Kittilä
Ivalo
Aircraft
Train
Car
Coach
Distance



1200
1000
800
600
400
200
0
RTT from Origin to Helsinki City in min
Great Circle Distance between Origin and Helsinki City in km
900
700
500
300
100
Tampere
Turku
Pori
Jyväskylä
Mariehamn
Kuopio
Vaasa
Joensuu
Kokkola
Kajaani
Oulu
Kemi
Kuusamo
Rovaniemi
Kittilä
Ivalo
Aircraft
Train
Car
Coach
Distance