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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Evaluation of the offer of flight, train and bus services to and from Brussels

Lennert Vromans

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Transport Policy and Planning

SUPERVISOR :

Prof. dr. Elke HERMANS

MENTOR :

De heer Roeland PAUL

2021
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Preface

I'm Lennert Vromans, a student in the Master of Transportation Sciences at Hasselt University. I have always had a fascination for the railways and the aviation sector, two modes of transport that could complement each other, but now often compete with each other. An example is the flights from Brussels to and from Amsterdam Schiphol Airport, also served by Thalys High-speed rail service, classic international train services and bus services. On these routes, there is a mismatch in the usage of the 'correct' transportation mode.

This study aims to investigate the possibilities to replace aeroplane use for short distances by train and coach use. This is done in several ways: exploring the different travel offers, investigating missing links in the networks and looking at possible policies.

The writing of this thesis was a challenge; the pandemic is still phasing out of our society, and teleworking is now a part of the 'new daily life'. While writing this thesis, I applied objective research methods and knowledge that I have gained over the five years of studying at Hasselt University. I am glad to have received valuable help and feedback during the process of writing this thesis and over the years of studying the Transportation Sciences programme, where I gained valuable knowledge and skills. Therefore I would like to thank Prof. dr. Elke Hermans and Roeland Paul, thank you for being my Promotor and supervisor on this journey; without your valuable feedback, I would not have achieved the same result.

Lennert Vromans
2nd Master in Transportation Sciences
UHasselt – Academic year 2021 – 2022

Summary

This thesis focuses on the available air, train and bus routes that are available to and from Brussels and where one mode can be a good alternative to another, e.g. the train can replace the aeroplane. The research area for this research is a 750 km radius around Brussels, with cities such as London, Paris and Frankfurt, to as far as Prague and Zurich. It wil be researched by means of conducting a literature review, a comparative study between the available travel modes to investigate travel times and cost, and a spatial analysis to identify possible missing links.

All three modes have known a rich development history; although the regional air market has declined, short feeder flights are still operated to neighbouring countries. The world of coaches has a different history. After a decline is Flixbus bringing the transport mode into a new age; Brussels has direct bus services to all neighbouring countries and even much further. The history of high-speed rail started in Japan, where the first operational HST entered service in 1964. Europe followed, with the first service between Paris and Lyon in 1981. Belgium launched the STAR 21 project with the construction of four high-speed lines that connect the country to France, Germany and The Netherlands. Towards the future, the biggest projects are seen in the construction of new railway lines; new high-speed lines and passages through the Alps, ensuring faster travel speeds. For coaches, new driving technologies are being implemented; electric and hydrogen buses are being introduced to have zero-emission travel possible. And for the aeroplane services, Brussels Airport has a 'vision 2040' to increase capacity with new infrastructures like taxiways and piers.

The main findings of this thesis are that several destinations have transportation options, train and coach services, that are faster and have cheaper ticket prices than the aeroplane. Also, the train and coach have significantly less CO_2 emissions, resulting in an overall journey with less monetary and indirect costs. By coach, Amsterdam can be reached faster than by aeroplane, for Paris is the travel time difference 14 minutes. But for both destinations, the train is the faster travel option between the city centres. The train is also quicker to London, Frankfurt and Lyon. To Stuttgart, Birmingham, and Marseille is the difference in travel time less than one hour more than the aeroplane.

Several measures are proposed to ensure better use of the correct transportation mode for each trip. Here is a summary of these measures:

1. Exploring the efficiencies of missing links in the high-speed rail network to better connect Europe by rail and reduce travel time;
2. Enhancing the Air + Rail services:
    a. By Implementation of more early/late train services connecting Brussels to the main Hub airports in the neighbouring countries;
    b. Stimulate relations between airlines and HSR companies;
3. Introducing policies to punish or banish very short flights where alternatives are possible;
4. A unified VAT system on coach tickets, as the VAT can differ vastly between states at the moment, from no VAT to as high as 25%.

The main conclusion of this thesis is that the train or bus can be a good alternative for the aeroplane, depending on the route and distance covered. Amsterdam, Frankfurt, London and Paris are destinations where the train is an excellent alternative to the city centre and where there is great potential to substitute feeder flights with air + rail service. The conditions for each destination are different, so future research is needed to ensure and facilitate this modal shift.

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List of abbreviations

DB	National railway company of Germany
EEA	European Economic Area
ETCS	European Train Controlling System
ERTMS	European Rail Traffic Management System
GHG	Greenhouse Gas
HST	High-Speed train
HSL	High-Speed line
HSR	High-Speed rail
NS	National railway company of The Netherlands
SNCB	National railway company of Belgium
SNCF	National railway company of France
VAT	Value-added tax

1. Introduction

Aeroplane travel often provides the fastest transportation option, but it also has the highest climate impact. On long-haul trips, an aircraft usually represents the only feasible option to tackle the distance and terrain. Nevertheless, aeroplanes are often used on short-haul routes as well, and it is these short-haul flights that produce the highest emissions per distance travelled (Pejovic et al., 2008). As Table 1 shows, there are five cities located closer than 500 km that receive frequent aeroplane service from Brussels. These very short flights are usually the ones that could be replaced the most easily by alternative and land-based transportation modes like (high-speed) train and bus services.

In the literature, high-speed trains are seen as a good alternative mode for trips from around 400 up to about 1000 km, depending on the research. For this research, a radius of 750 km is used around Brussels; this is not the maximum nor the minimum distance used in the relevant literature, due to the present but relatively limited high-speed rail network in and around Belgium. Brussels was chosen as the destination to investigate because it is seen as 'the heart of Europe', and has a broad offer of transport options. Figure 2 shows this on a map, with big cities such as Amsterdam, Paris, London, Frankfurt and Zurich within the radius.

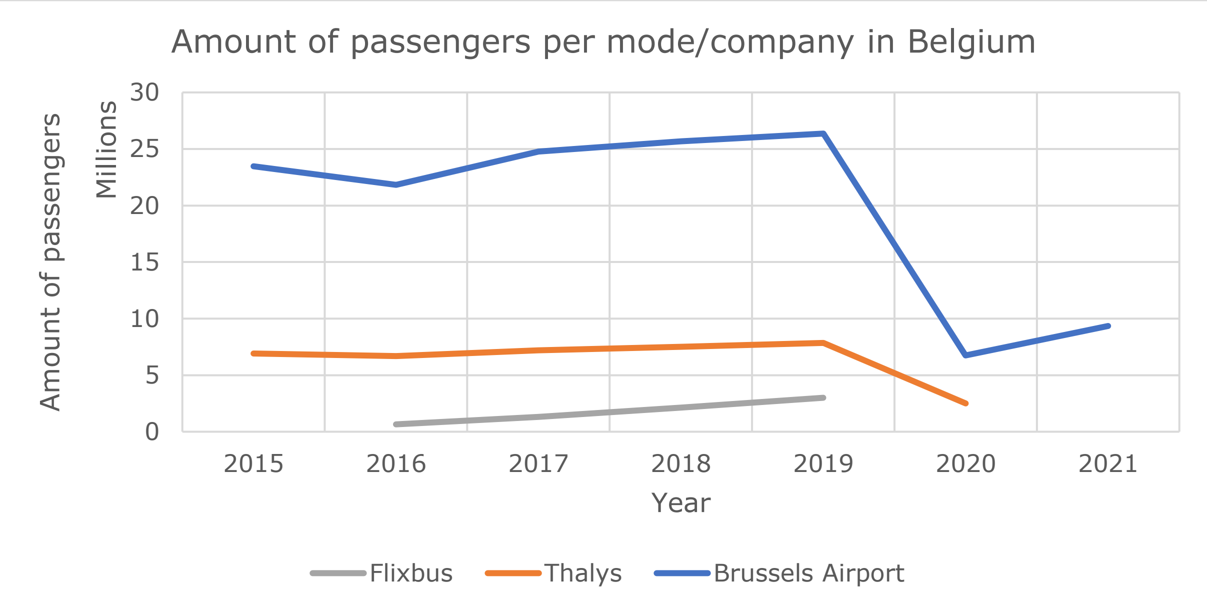
This study investigates the potential of these alternative transport modes, which are possibly able to replace short-haul flights with (high-speed) trains or coaches to and from destinations that are served by aeroplanes to and from Brussels Airport.

Table 1: TOP destinations from BRU in aeroplane movements (2018)
(Brussels Airport Company, 2019)

Ranking	Airport	Number of movements (2018)	Distance from Brussels (km)
1	Madrid	7219	1300
2	Milan	6207	665
3	London (all)	6202	340 (Heathrow)
4	Barcelona	5933	1075
5	Frankfurt	5757	310
6	Geneva	5197	530
7	Rome (FCO, CIA)	5015	1175 (FCO)
8	Lisbon	4956	1705
9	Munich	4505	600
10	Copenhagen	4352	765
…			
14	Amsterdam	3449	165
…			
18	Zurich	3327	485
…			
30	Paris Charles de Gaulle	1928	240

Before the COVID-19 pandemic, the usage of each transportation mode was increasing each year, except for a dip in air travel in 2016, following terrorist attacks at Brussels airport on the 22nd of March 2016. Thalys also shows a steady increase in the number of passengers each year; there only is a slight decrease in 2016, following the terrorist attack onboard a Thalys train in August 2015. Flixbus is a relatively new player in the Belgian market, starting operations in 2015 and taking over its largest competitor Eurolines in 2019, having strong growing results each consecutive year before the pandemic.

Due to the unavailability of general data about the international arrivals and departures, except for Brussels Airport, data was used from the major companies that provide coach and high-speed rail services.



Source: Brussels Airport Company (2022), Thalys (2021) & FLIX (2021)

Figure 1: Amount of international passengers in Belgium (2015 - 2021)

1.1 Context and problem statement

Climate change is a many-sided phenomenon where the transportation sector is one of the main contributors due to the ever-increasing usage of fossil fuels, travel demand and distances. The energy usage of the transportation sector is around 20%, but accountable for about 27% of total greenhouse gas emissions (Dalkic et al., 2017)

The aeroplane is seen as an attractive transportation mode for short distances, while convenient alternatives with less climate impact are available. High-Speed Rail received substantial and increasing attention for its role in climate change mitigation and social welfare, as it can induce a shift towards the use of non-fossil energy usage. (Wan et al., 2016)

1.1.1 Situating

1.1.1.1 Marco-level

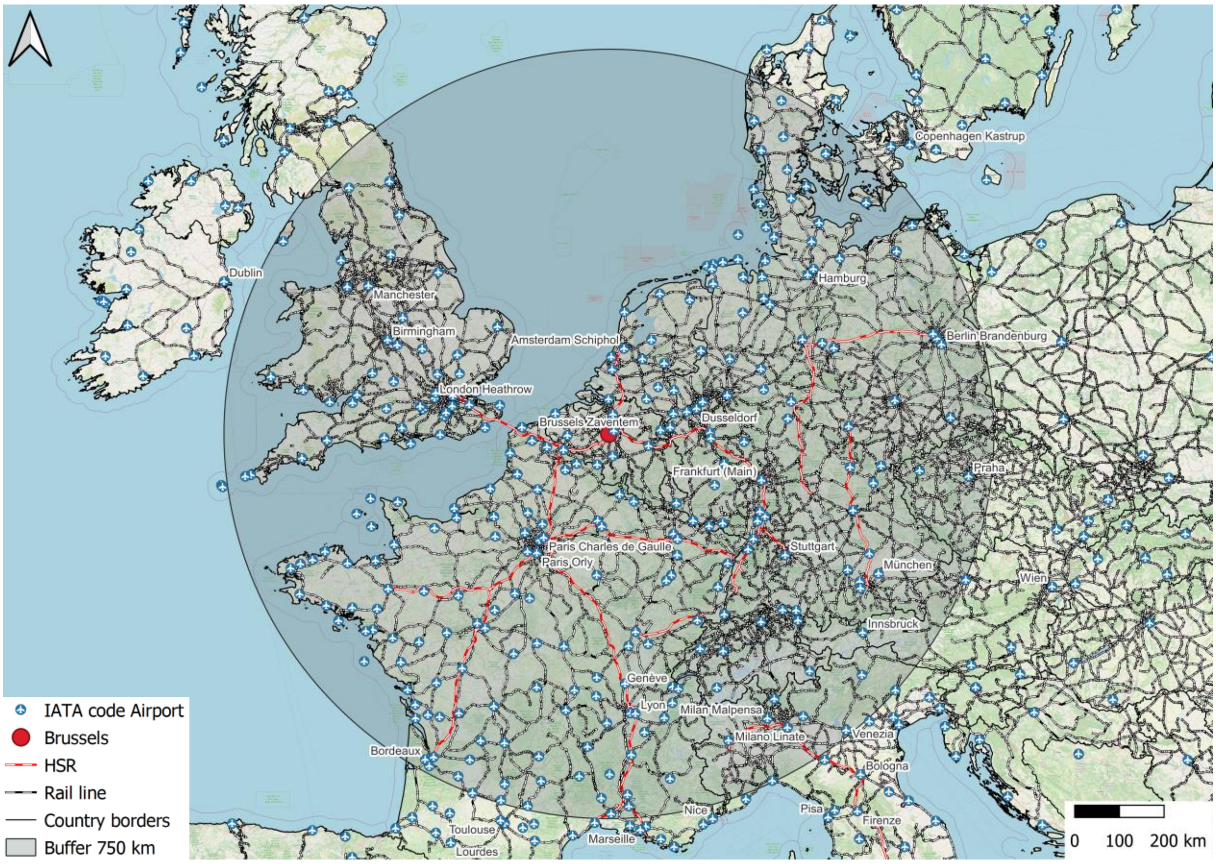


Figure 2: 750 km buffer around Brussels (OpenStreetMap, own adaptations, 2022)

Brussels is the capital city of Belgium and is centrally located within the country. Belgium is located in Western Europe and shares borders with France, Luxembourg, Germany and the Netherlands. The airports with names displayed in Figure 2 are all part of the 20 busiest airports in the European Union for passenger traffic and Londen Heathrow. (Statistics Flanders, 2021)

1.1.1.2 Meso-level

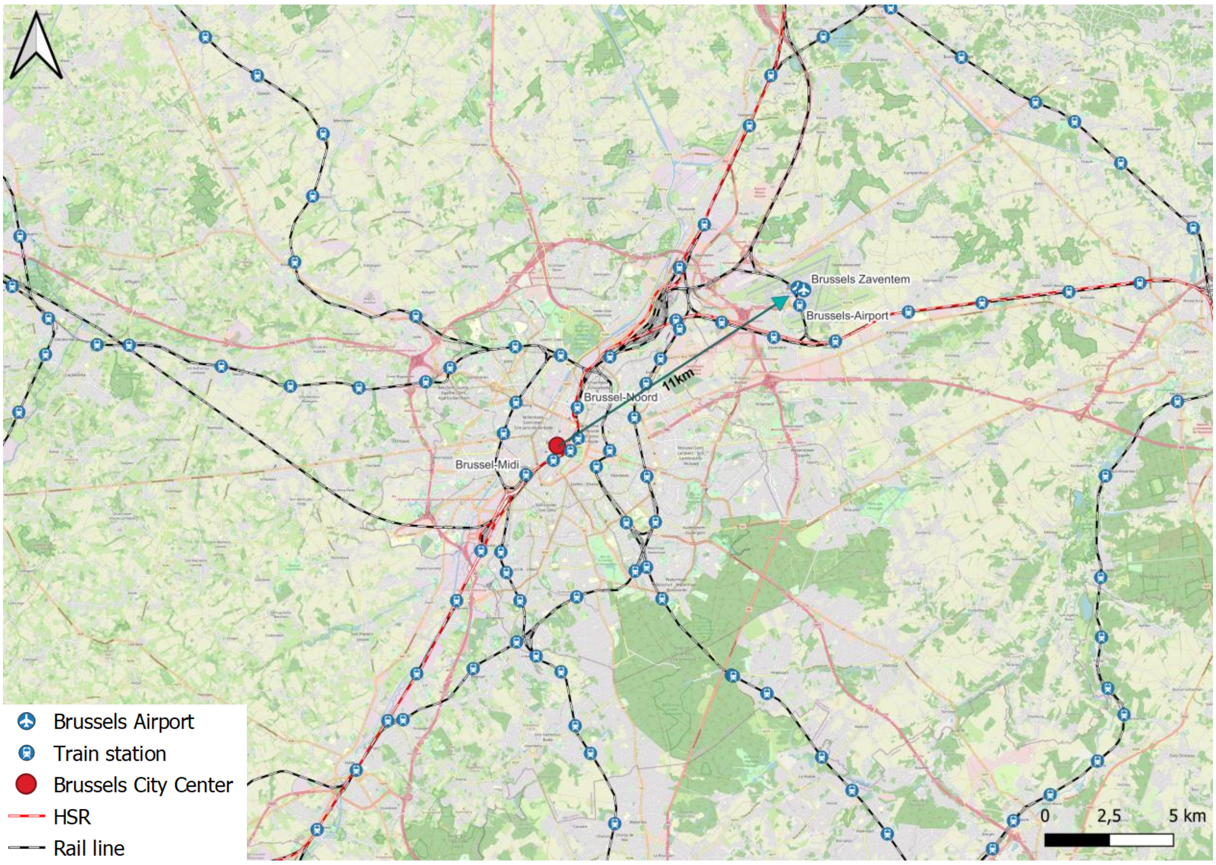


Figure 3: Meso level of Brussels with its transport infrastructure (OpenStreetMap, own adaptations, 2022)

The main airport of Brussels is Brussels Airport (Zaventem), located 11 kilometres northeast of the city centre, in the region of Flanders. The second airport, Brussels South Charleroi Airport, the "low-cost" airport, is located 43 km to the south of the city, in the region of Wallonia, and not taken into account for this research, as the travel times to and from this airport are much higher than the main airport. It takes 55 minutes by shuttle bus from the Brussels-Midi train station to reach the airport (flibco.com, 2022). By train, it takes at least one and a half hours as a connection with a shuttle bus from the train station to the airport is also required. (SNCB, 2022a)

The primary way to travel to and from the city centre to Brussels Airport, by public transport, is by train. There are about six trains per hour in each direction with an average travel time of 19 minutes from Brussels-Central station to the airport. (SNCB, 2022a)

1.1.1.3 Micro-level

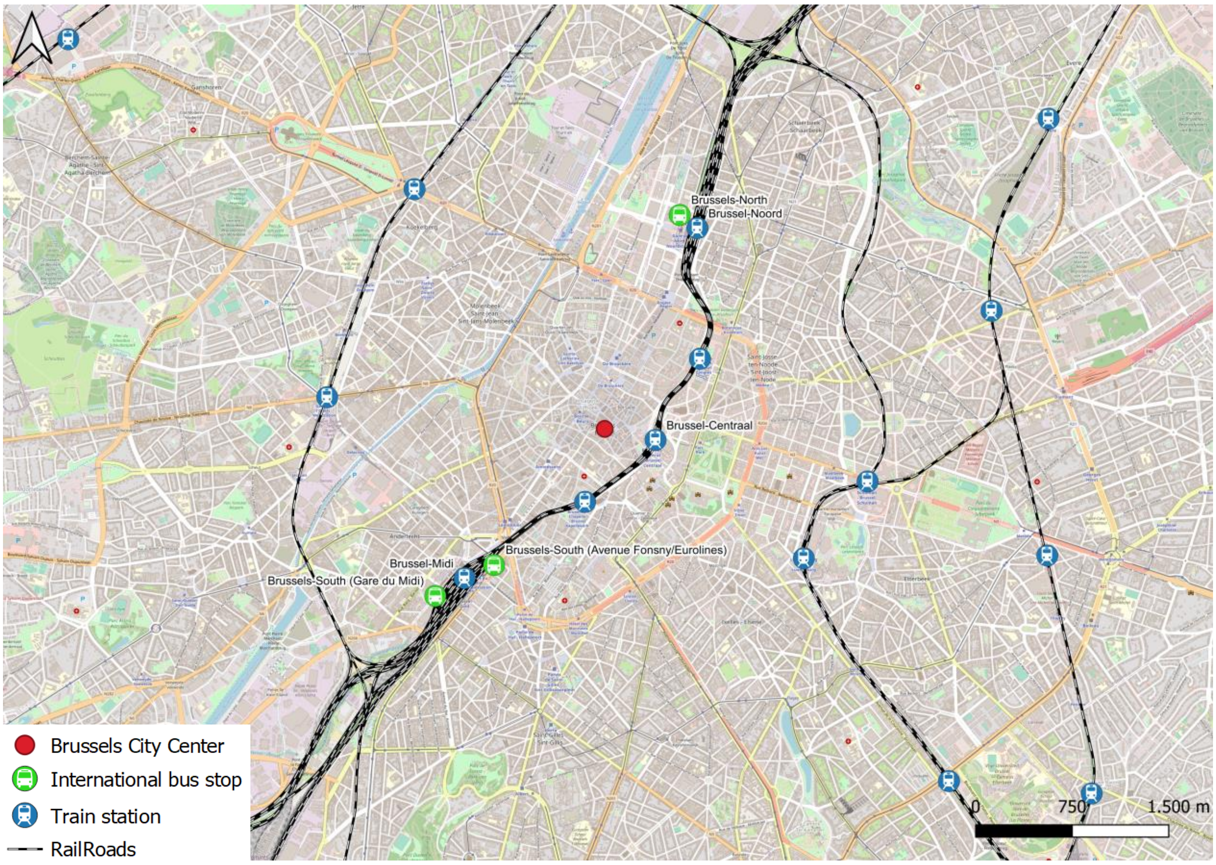


Figure 4: Brussels on a micro-level (OpenStreetMap, own adaptations, 2022)

The city of Brussel has three main train stations; Brussels-North, Brussels-Central and Brussels-Midi (South). The station that is located the most closely to the city centre is Brussels-Central. The main station for international and high-speed train travel is Brussels-Midi. The travel time between Brussels-Central and Brussels-Midi, and Brussels-Central and Brussels-North is about five minutes.

For international bus travel, two main stops are used; next to Brussels-North train station and in the vicinity of the Brussels-South train station, with several stopping positions, as shown in Figure 4. The international busses use different bus stops, separated from the regular public transport.

1.1.2 Environmental impact

In 2018, the transport sector accounted for 25 % of EU greenhouse gas emissions. This sector's emissions come primarily from road-based transportation (72 %), while marine transport and aviation represent 14 % and 13 % of emissions, respectively, and rail has a share of 0,4% (with emissions by diesel trains only). (European Environment Agency, 2021)

As stated in the problem statement, the aeroplane is still seen as an attractive transportation option for short distances. But as seen in Figure 5, these short flights represent a significant carbon output: approximately one-third of passenger CO_2 emissions occurred on short-haul flights of less than 1500 km. Another one-third occurred on medium-haul flights of between 1500 km and 4000 km, and the remaining third is emitted on long-haul flights of greater than 4000 km. As a part of the short-haul flights, the regional flights of less than 500 km, roughly the distance where aircraft compete directly with other passenger transport modes, accounted for about 6% of total passenger CO_2 emissions. (ICCT, 2020)

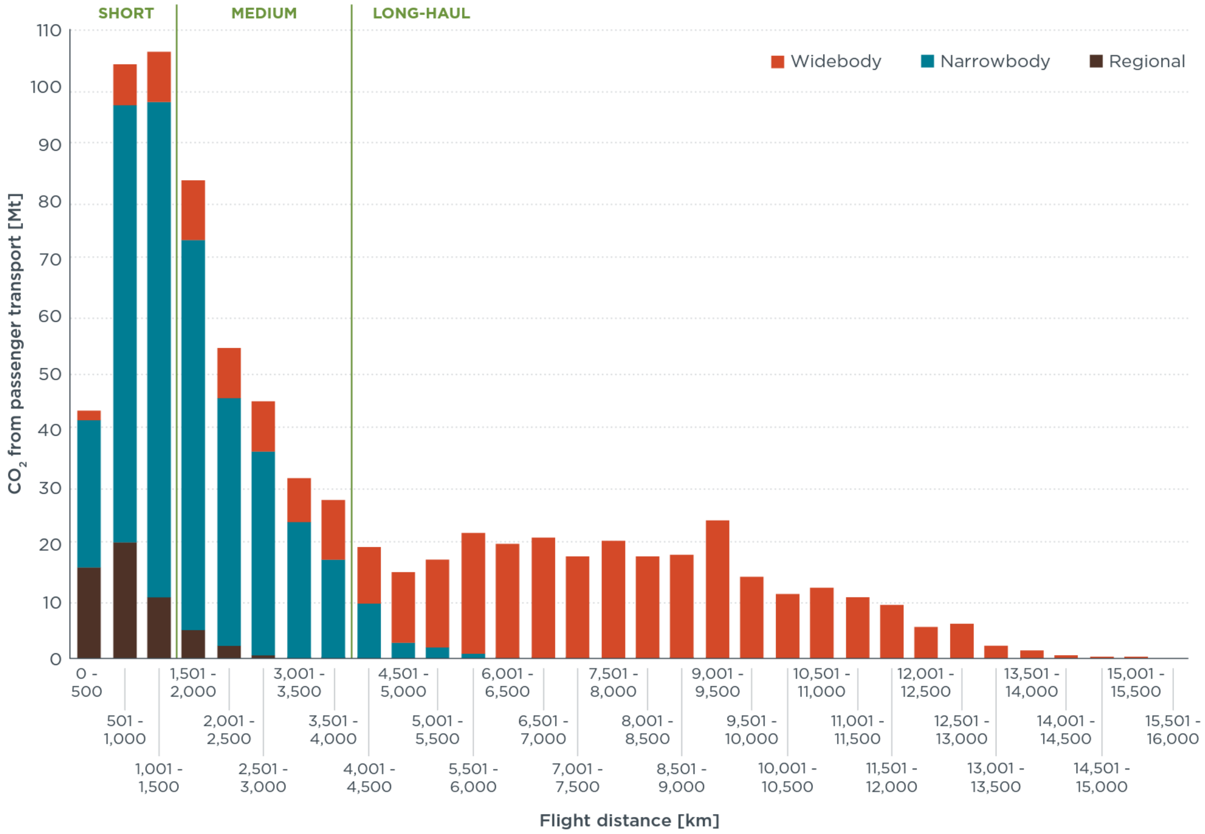
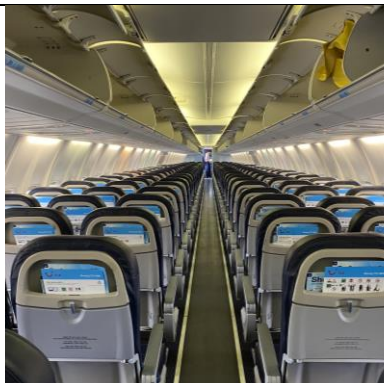
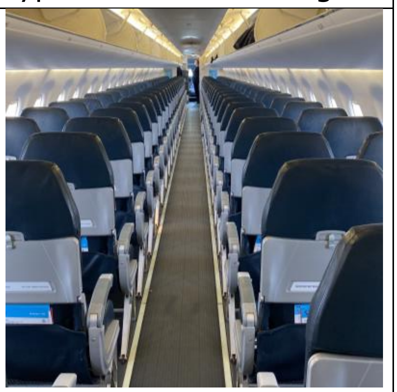


Figure 5: CO_2 output from passenger air transport per flight distance (ICCT, 2020)

Table 2: Aeroplane classifications

Aeroplane classifications		
Widebody = an aeroplane type with two aisles in the cabin	Narrowbody = an aeroplane type with one aisle in the cabin	Regional = a smaller aeroplane type used for short flights
 *Figure 6: Cabin of a Boeing 787 (TUI, 2013)*	 *Figure 7: Cabin of a Boeing 737 (2022)*	 *Figure 8: Cabin of an Embraer E190 (2022)*

1.2 Objectives

The main objective of the thesis is an evaluation of the offer of different public transportation modes to destinations that are served to and from Brussels by airline services and identifying possible missing links in the alternative transportation networks that could make the alternatives more attractive.

This is to achieve the following in the future:

- Awareness of other transport options, so the aeroplane is not always seen as the default option;
- Reducing the number of short-haul flights to improve the environment and reduce the contribution of the airline industry to climate change;
- Contributing to a modal shift from air to rail and coach on short flight (<750 km) routes.

1.3 Research Questions

Main research question:

Which destinations, with airline service to and from Brussels, have the most potential to be substituted by a more sustainable transport service?

Sub research questions:

1. How do the three different modes (aeroplane, train & bus) perform in terms of relevant indicators (e.g. costs, travel time, pollution)?
2. What are the history and future developments of the three transportation modes?
3. What destinations are relevant, where a train and/or bus service could offer an attractive alternative to an airline service?
4. Where are the missing links located in the rail and bus transport networks that could make one of these modes more attractive in comparison to the aeroplane?
5. What policies are needed to boost train and bus use instead of short flights, and which prerequisites should be met before implementing these policies?

1.4 Research Methodology

This thesis focuses on the availabilities of transport options and the attractiveness of more sustainable transport options. The history, development and policies of the transportation networks will be investigated by desk and literature review.

1. A literature review, desk research:
    a. To identify relevant indicators that can compare the three different transportation modes
    b. To research the history and future of the European air, rail and coach services
    c. To identify policies
2. A comparative study between the three different transportation modes; aeroplane, train and bus, utilising a comparison of travel time, costs and other relevant indicators
3. A spatial analysis of the train networks to identify possible missing links

2. Literature review

2.1 Comparison of the transport modes

2.1.1 Transportation modes

In this research, three passenger transportation modes are being compared to each other. Transportation modes are the ways of supporting the mobility of both passengers and freight. Transportation modes are designed to carry passengers or cargo, but most modes can take a combination of both. The technical, operational and commercial features characterise each mode. Technical characteristics relate to attributes such as capacity, speed and drive technology, while operational aspects relate to the context in which modes are used, including speed limits, safety conditions or operating hours. Demand for transport and ownership of transport modes are dominant commercial characteristics as transport modes are used to support economic activities and generate income. (Blauwens et al., 2016)

2.1.1.1 Road transport

Road-based transportation offers a range of motorised and non-motorised options for mobility that occurs primarily over short distances that a user can choose depending on affordability, convenience, availability and comfort. The car has emerged as a preferred form of private passenger road-based transportation because it offers convenience and flexibility but also contributes to congestion, especially in urban areas. However, strategies to promote sustainable transport systems underpin the importance of walking, cycling, and emerging forms of personal mobility (e.g. electric scooters) are essential components of short-distance mobility. On the other hand, road infrastructures are major space consumers with the lowest physical constraints among the modes of transport. However, physiographic constraints are significant in road construction with high additional costs to overcome features such as rivers or rugged terrain. While historical road transport was developed to support non-motorised modes of transportation (walking, pets and cycling in the late 1800s), motorisation has defined most of its development since the early 1900s. Road transport has moderate operational flexibility, as vehicles can serve different purposes but rarely operate off-road. Road transportation systems tend to have high maintenance costs, both for the vehicles and for the infrastructure, which are associated with a short lifespan. They are mainly associated with light industries and freight distribution, where fast movements of freight in small batches are the norm. Containerisation has made road transport a crucial link in the distribution of goods between ports and the commercial hinterland. (Rodrigue, 2020)

2.1.1.2 Rail Transport

Railways consist of a traced path on which wheeled vehicles are attached. Due to recent technological developments, rail transport also includes monorails and magnetic levitation trains (maglev). They have a moderate level of physical limitations, but a low gradient for the infrastructure is required, especially for cargo. Heavy industries have traditionally been linked to rail transport systems, although container transport has improved the flexibility of rail transport by connecting it to road and maritime modes. Rail is by far the highest capacity overland mode of transport, with a fully loaded 23,000-tonne coal train being the heaviest load ever transported. However, gauges vary around the world and are often a challenge for rail system integration. (New World Encyclopedia, n.d.)

Intercity passenger services that have been operating in many parts of the world for a century and a half are expanding through the establishment of high-speed trains between high-density pairs of cities. Another notable form of rail services concerns urban transit systems that rely on specific applications of rail technology. Metro systems are systems that support the densest forms of mobility in large metropolitan areas. Such systems are usually supported by commuter trains connecting a central station to a network of satellite cities. Light rail transit (LRT) systems are also set up in lower density situations. (Rodrigue, 2020)

2.1.1.3 Air Transport

Air transport services are usually provided as scheduled services offered by competing airlines, each within their respective networks. Based on scheduled services posted several months in advance, a traveller (or anyone acting on their behalf) can book an itinerary that may include multiple flight segments. Charter air services are usually offered under specific circumstances, such as seasonal flights to holiday resorts or private jets that cater to the mobility needs of a company or an individual. They are primarily point-to-point services. Air routes are essentially unlimited, but they are denser over the North Atlantic, North America and Europe, and the North Pacific. Air travel restrictions are multidimensional and include a location (a commercial aircraft needs approximately 3,300 meters of runway to land and take off), climate, fog and air currents. Aviation activities are related to the tertiary and quaternary sectors, in particular in the finance and tourism sectors, which rely on the long-distance mobility of people. More recently, air transport has been able to handle increasing amounts of high-value cargo and plays an increasingly important role in global logistics. (Rodrigue, 2020)

2.1.2 Distance, Modal Choice and Transport Cost

Those mobile transport assets fall into three primary types; land (road, rail & pipelines), water (shipping), and air. Each of those transport modes has fundamental operational and commercial advantages and characteristics. However, today’s demand is influenced by integrated transport systems that require flexibility in the respective use of each mode. As a result, modal competition exists in varying degrees and takes on different dimensions. Modes can compete or complement each other in terms of costs, travel times, accessibility, frequency, safety, level of comfort, etc. There are three main conditions that make some modes complement each other (Rodrigue, 2020):

1. <u>Different geographic markets</u>
   When it comes to different markets, the modes ensure continuity within the transport system, especially when it comes to different scale levels, such as

between national and international transport. This requires interconnectivity, made possible by gateways, where it is possible to switch from one mode to another. Intermodal transportation has been particularly relevant in improving the complementarity and connectivity of different geographic markets.

2. Different transport markets
   The nature of what is being carried, such as passengers or goods, often indicates a degree of complementarity. Even if the same market area is served, it may not be equally accessible depending on the mode used. Rail and road transport can thus complement each other in some markets, as one can focus on passengers and the other on freight.
3. Different service levels
   For a comparable market and accessibility, two transport options offering a different level of service will tend to complement one another with niche services. The most common complementarity relates to cost versus time.

Hence, there is modal competition between the different modes when there is an overlap in geography, transport markets and level of service. Cost is one of the most essential attention points when choosing a mode of transport, because each mode has its specific price/performance characteristics. The competition between the modes mainly depends on the distance travelled, the quantities shipped and their value. An essential factor is the terminal cost structure for each of the modes, where the costs of loading and unloading a unit involve fixed costs that are incurred independent of the distance travelled. Figure 9 shows the costs for each of the investigated transport options. It can clearly be seen that land-based transportation options start with the lowest fixed and terminal costs, but the costs over the distance increase more quickly, resulting in different cost functions. (Rodrigue, 2020)

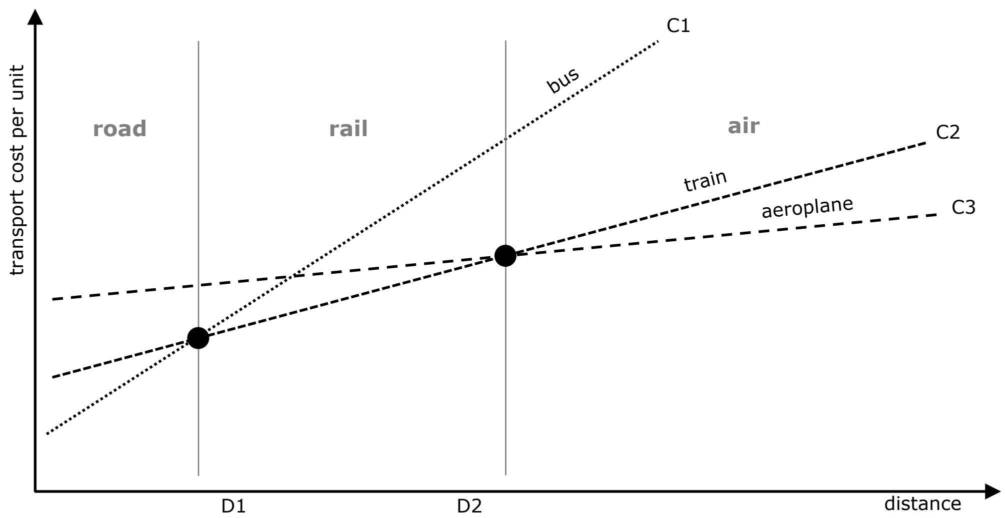


Figure 9: Distance, Modal Choice and Transport Cost (Button, own adaptations, 2014)

Road-based transport has a lower cost for short distances, but it increases faster than rail and air transport. It becomes more profitable at distance D1 to switch from road to rail-based transport options. After the break-even point D2, is it more profitable to use air transportation.

Usually, the estimated threshold for which HSR becomes more attractive is around 500 km, but more recent estimates have shown great attractiveness, up to 1000 km. (Bergantino & Madio, 2020)

This is also translated into Figure 10, where rail, coach and air transport are also shown.

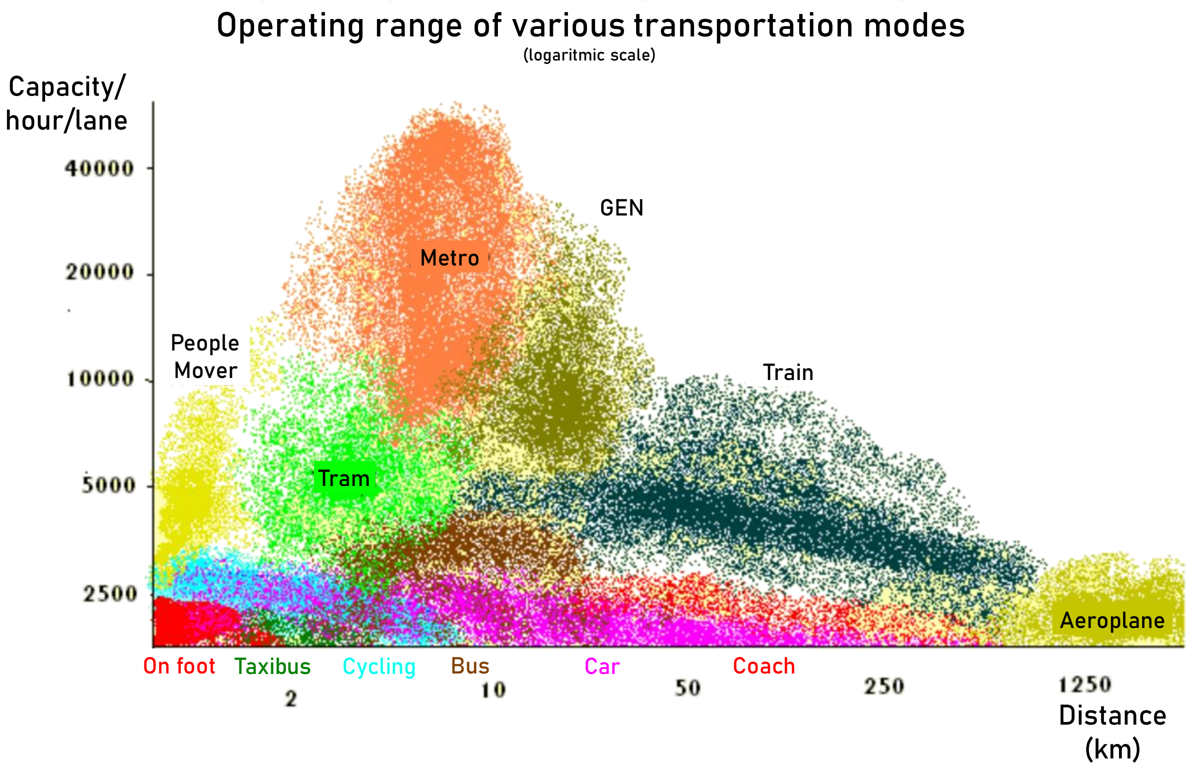


Figure 10: Operating range of various transportation modes (Arien, own adaptations, 2017)

The difference between the various transportation modes is multidimensional; each mode has its operating range by means of distance, which overlaps with other modes. Next to that, all the modes have other specific characteristics, as they are differentiated by capacity per hour in the figure, this difference in capacity will also become clear in the vehicle characteristics, where all the modes have their own capacity depending on the type and manufacturer.

It can be seen that the train has the broadest range by means of distance and capacity. The coach has mainly the same range in terms of distance, but cannot match the capacity of the train. The aeroplane is mixed with the train and coach, but entirely takes over after a distance of about 750-1000 km.

2.2 History and future development

2.2.1 Airline service

2.2.1.1 Sabena

Belgium has a long history in the operation of flight services. The national carrier was Sabena, standing for "Société Anonyme Belge d'Exploitation de la Navigation Aérienne", translated "Belgian Limited Company for the Exploitation of Air Navigation" started operating in 1923 and took over the operation of the first Belgian national airline, SNETA, which began operating in 1919. (Sabena, 2019)

In the 1950s, Sabena introduced a helicopter service, which expanded over the years. The service was intended as a feeder service for its fixed-wing international and European services. By 1960 was this service operational to Antwerp, Rotterdam, Eindhoven, Maastricht, Lille, Liege, Paris, Dortmund, Duisburg, Cologne and Bonn. The service stopped in 1966. (Sabena, 2019)

After an airline recession and the aftermath of the terrorist attacks of 2001, all airlines suffered severely. Furthermore, Sabena was owed 84 million euros by the Swiss airline Swissair. After Swissair ceased operations on October 2, 2001, and refused to refund the money, Sabena was forced to stop flying. On October 3, 2001, they filed for legal protection against their creditors. With most of the major airlines in Europe fighting over passengers in the wake of the attack on the United States and civil aviation, Sabena was not given the necessary support and was liquidated on November 7, 2001. (Sabena, 2019)

As Figure 2 shows, Sabena had an extensive European network; the airline flew to 66 European cities in 1998, just three years before its bankruptcy.

Figure 11: European network of Sabena (Sabena, 1998)

2.2.1.2 Virgin Express

The history of Virgin Express goes back to 1996 when the parent company Virgin Group acquired the Belgian leisure airline EBA – EuroBelgian Airlines. The airline was transformed into a low-cost airline with scheduled service and charter flights. (Virgin Express, 2006)

In 2005, the airline came under common ownership of the Virgin Group and SN Brussels Airlines (see next section). An Executive Committee was appointed to develop a strategic plan; in March 2006, the SN Airholding, the owner of the two airlines, approved the strategic plan (Virgin Express, 2006):

- The two airlines will come together as one brand in the near future
- The new airline will offer two distinct products:
    - A basic product offered to price-sensitive passengers
    - An upgraded product for time-sensitive customers

In 2007, the new airline Brussels Airlines officially started operations and started competing with low-cost airlines such as EasyJet on popular routes such as Brussels to Vienna, Geneva, Nice and Berlin.

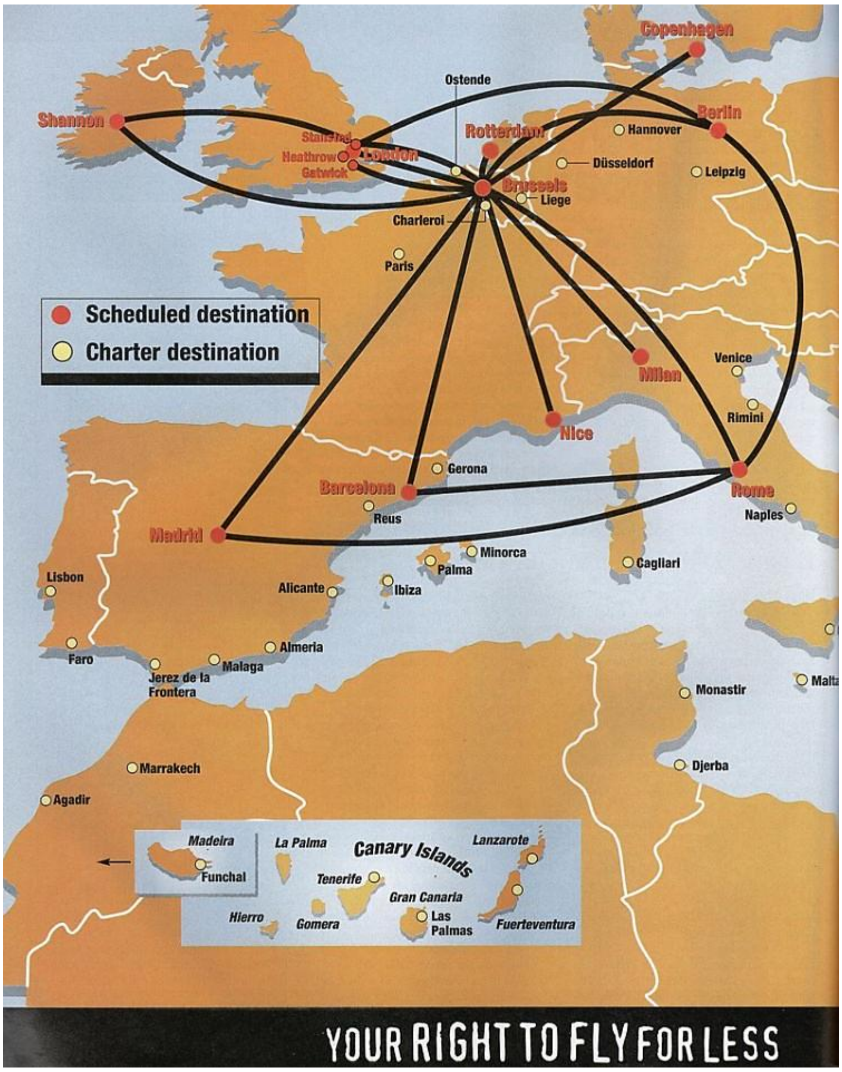


Figure 12: Virgin Express route map (2000)

2.2.1.3 Brussels Airlines

The history of Brussels Airlines goes back to 2002, when the parent company SN Airholding was founded by a group of around 40 investors. The main goal of the shareholders was to ensure a continuum of a reliable air connection to and from Brussels, that is seen as the capital of Europe, in the context of the major disruptions caused by the shutdown of Sabena. The newly founded company was called SN Brussels Airlines and already recorded its first positive results in 2003. (Brussels Airlines, 2021)

In late 2004, it was decided that SN Brussels Airlines and the low-cost carrier Virgin Express would merge under the common ownership of SN Airholding, but each airline would maintain its brand and operational independence in the market. (Brussels Airlines, 2021)

In September 2008, the Lufthansa Group announced the purchase of a stake in the Belgian airline. In June 2009, the European Commission granted regulatory approval for this strategic partnership between Brussels Airlines and Lufthansa. Brussels Airlines has been an official member of Star Alliance since December 2009. The decision paved the way for Lufthansa to acquire an initial 45% stake in SN Airholding SA/NV, the parent company of Brussels Airlines. As of January 2017, SN Airholding is 100% owned by Deutsche Lufthansa AG. (Brussels Airlines, 2021)

As Figure 13 shows, Brussels Airlines operates year-round to 36 destinations in Europe (the Canaries excluded). In the spring and summer seasons, 22 other destinations are added in Europe. All these destinations combined, 58, is still less than the European operation of Sabena, which had 66 cities as destinations. Brussels Airlines also only flies to one airport at each city (except Milan), while Sabena, for example, flew to four different airports in London.

Figure 13: Route network Brussels Airlines (Brussels Airlines, 2022)

2.2.1.4 Brussels Airport

The Brussels Airport Company sees enormous growth opportunities for the airport and the economy, set out in their 'Vision 2040'. More people will travel by air, more people will travel for business, and more products will be transported throughout the world by air. According to forecasts, the number of passengers and cargo volume at Brussels Airport will double, but with fewer aircraft movements than in 2000, thanks to larger aeroplanes that are also quieter. The passenger load factor is also expected to increase further. (Brussels Airport Company, 2015)

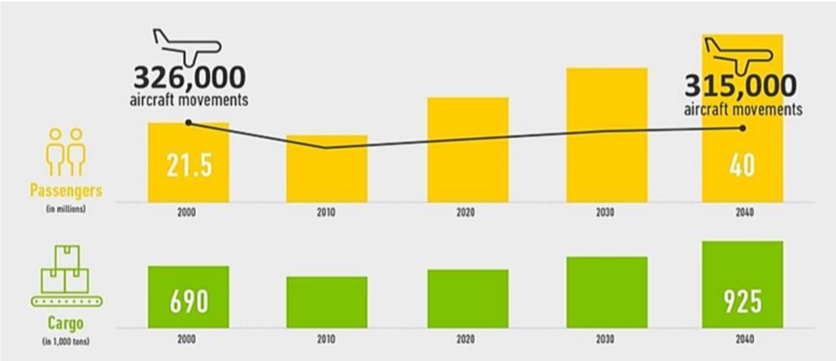


Figure 14: Passenger, Cargo, and Aeroplane movements (Brussels Airport Company, 2015)

According to calculations from the airport operator, more capacity will be needed to meet future market demands. In 2015, there were 74 aeroplane movements per hour; in 2025, this needs to be increased to 84, and in 2040 to 93 movements per hour. These calculations are based on the predicted average European growth.

The capacity increase will be achieved in two stages:

1. Optimising the current runway usage: by means of modernising procedures, deploying new technologies, constructing additional entrances and exits on the runways, and using all available runways for landing;
2. Adapting the existing runway infrastructure with two possibilities:
    a. An extension of a taxiway
    b. An extension of a taxiway and a runway

Next to the runway capacity, new piers will also be constructed. This ensures that most flights can be boarded via an airbridge, giving passengers the best experience possible. (Brussels Airport Company, 2015)

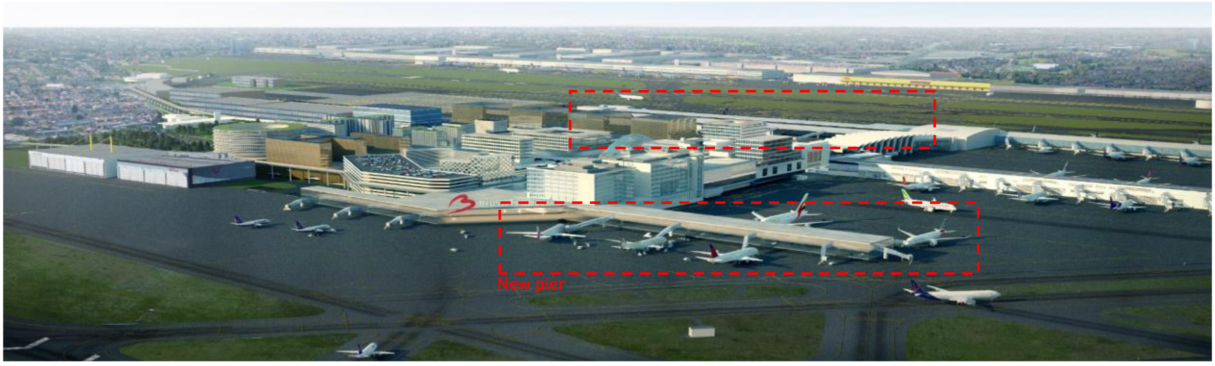


Figure 15: Future impression of Brussels Airport (Brussels Airport Company, 2015)

2.2.2 High-speed rail

2.2.2.1 The early beginnings

In 1959, the Japanese railway company began construction of the Tokaido Shinkansen, the world's first high-speed line, with the first train operational in 1964. Japan shows many similarities with the European continent; a high degree of urbanisation, high population density etc., resulting in a desire to develop a similar system where Japan served as a source of inspiration. France took the lead and presented the TGV 001 in 1972. The first Turbotrain à Grande Vitesse, powered by a gas turbine, was capable of reaching 318 kilometres per hour on the Paris – Lyon line. The original gas turbine did not survive the energy crisis of 1973 and was replaced by a classic and more economical electric motor. That engine still drives today's HSTs. The first operational TGV service was in 1981 between Paris and Lyon. (Infrabel, 2009)

Germany began operating its Inter-City Express (ICE) high-speed trains in 1991 through several German cities. The Eurostar service, which connects London to Paris and Brussels via the Channel Tunnel, was launched in 1994. Due to the early adoption of high-speed trains in France railway and its central location between the Iberian Peninsula, the British Isles and Central Europe, most other high-speed lines in Europe are built to French standards for speeds, voltage and signalling, with the exception of Germany, that were made according to existing German railway standards. (EESI, 2018)

2.2.2.2 An expanding Belgian and European network

It is only on a European scale that the importance of the high-speed network becomes fully clear. The idea of expanding the HST network across the continent, and also in Belgium, was therefore born. The Paris – Brussels line used to be a popular train connection. When the decision was made to build the Channel Tunnel in the early 1980s, the project to extend the HST network became particularly interesting; Brussels, London and Paris would be less than two hours away from each other. (Infrabel, 2009)

To accomplish these goals and prepare the railways for the 21st century, the STAR 21 project was launched in Belgium, that focused on four main topics;

1. Higher speeds: Increasing the maximum speed on important connections;
2. More trains: With the construction of extra tracks on lines to Brussels, a more intensive interurban train service can be developed, and the links with the surrounding area can be improved;
3. Faster and more comfortable equipment: When purchasing new trains, the NMBS will give priority to speed and comfort;
4. Customer-friendly stations: Both the stations themselves and their immediate surroundings are being renovated or embellished. (NMBS, 1995)

The construction of the high-speed network in Belgium was less evident than initially thought; Belgium is in terms of population, road network, rail network and built-up areas denser than the rest of the continent. Moreover, Belgium has been an important hub in the heart of Europe for centuries. Building new high-speed lines, to serve only Brussels, was therefore out of the question; the HST also had to connect our country with our northern neighbours and with Germany while integrating as much as possible into the existing infrastructure, either by upgrading old railway lines or by bundling new railway lines with the existing road and rail network. (Infrabel, 2009)

From this perspective, the Belgian government decided in 1992 to realise three branches of the high-speed rail network:

1. The Western branch: from Brussels to the French border;
2. The Northern branch: from Brussels to the Dutch border – with connection to the Dutch high-speed line to Rotterdam and Amsterdam;
3. The Eastern branch: from Brussels to the German border.

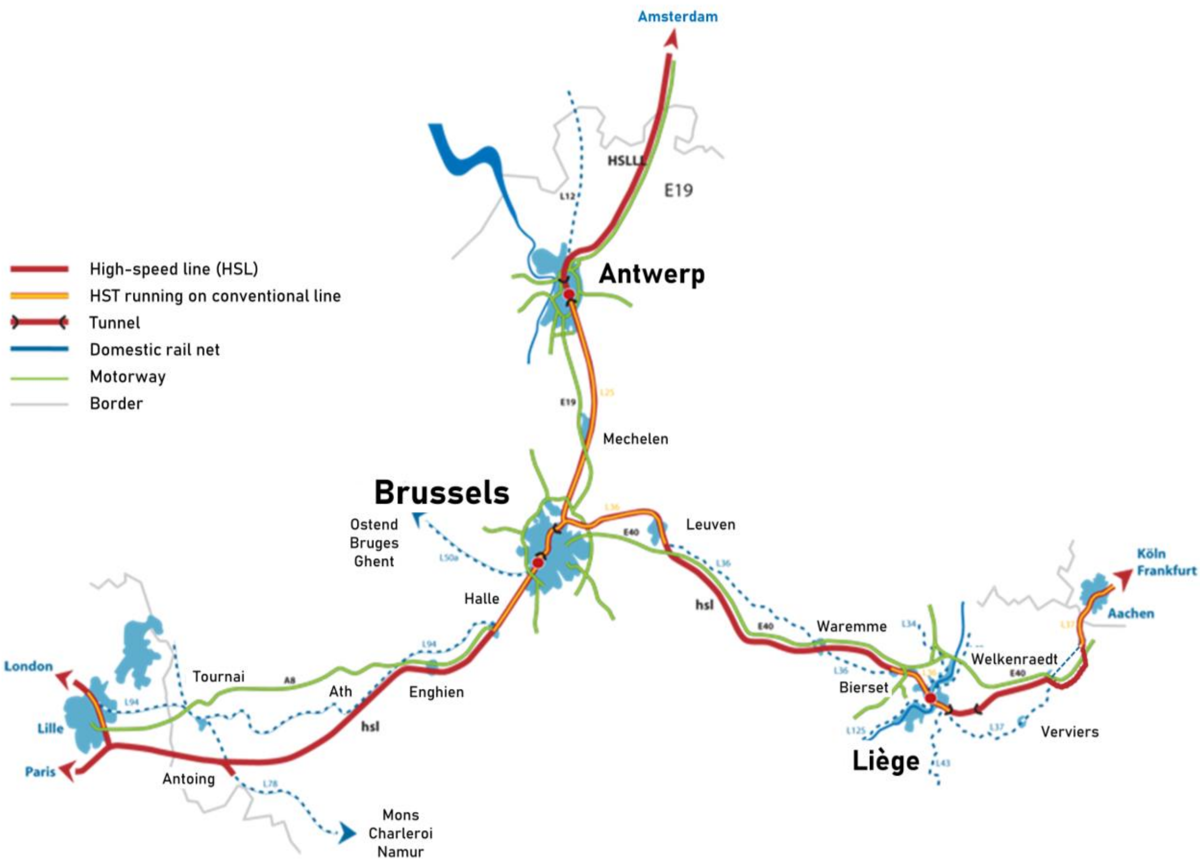


Figure 16: Vision for Belgian High-Speed Rail network (NMBS, own adaptations, 1999)

After completion in 2009, the Belgian high-speed network is 314 kilometres long, out of a total of 35,000 kilometres that the European HST network should eventually count. The total investment for the Belgian high-speed project amounts to almost 5.2 billion euros. An important investment for a small country like Belgium. In this way, Belgium has become an indispensable hub for HST traffic between London, Paris, Lille, Brussels, Antwerp, Amsterdam, Liège, Cologne, Düsseldorf and Frankfurt. Moreover, Belgium is the only European country where domestic train traffic also uses the HST network. Thanks to the HST, the traditional domestic network could thus be significantly improved. (Infrabel, 2009)

After the completion of the high-speed network in 2009, the rest of the rail network is gradually getting ERTMS rolled out to accommodate international trains. ERTMS is a train controlling system that will be implemented throughout the European Union to overcome land-specific safety systems that impede international and a free market operation. Figure 17 shows that the entire network will receive the controlling system by 2025. (ERTMS users group, n.d.)

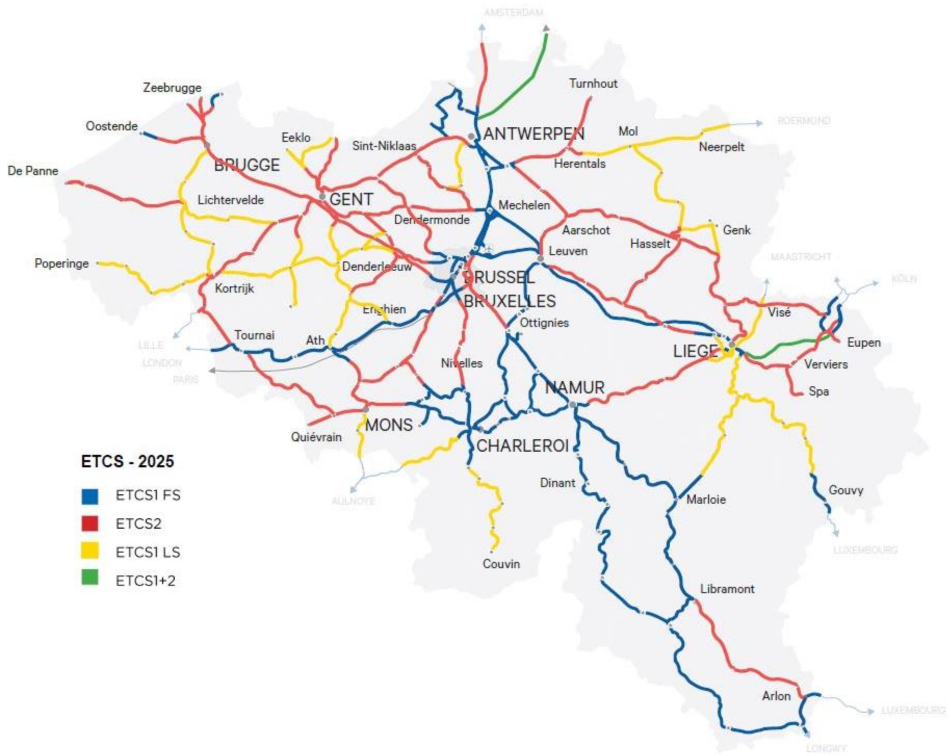


Figure 17: ERTMS implementation goal for 2025 in Belgium (ERTMS users group, n.d.)

Today, France’s high-speed rail network consists of more than 2800 kilometres of Lignes à Grande Vitesse (LGV), capable of speeds of up to 320 km/h, which are served by TGVs (Trains à Grande Vitesse). This high-speed intercity train is operated by SNCF, France’s national railway company. (EESI, 2018)

2.2.2.3 Brussels-South: the high-speed train terminal

All HSTs departing in Belgium depart from Brussels South station. In order to fulfil its new role as an HST pool as efficiently as possible, the South Station underwent a thorough modernisation. (NMBS, 1999)

At the beginning of the 1990s, there was a will to develop the surroundings of the station as a result of the HSTs. The development plan “development scheme for the environment of the South Station” was drafted. The development schedule is in line with the ambition to make a business district in immediate proximity to the station and to create a true gateway to welcome visitors. The schema includes the will to be an “extrovert” station through which the fruits can be reaped from the presence of the HST on a local, regional and international scale. (perspective.brussels, 2021)

In reality, the station was expanded with terminals for Eurostar and Thalys. Those expansions and renovations were finished around 1994. The original vision from SNCB was to upgrade the station to an airport-style building, but after the initial expansion, the rest of the station was not renovated. (perspective.brussels, 2021)

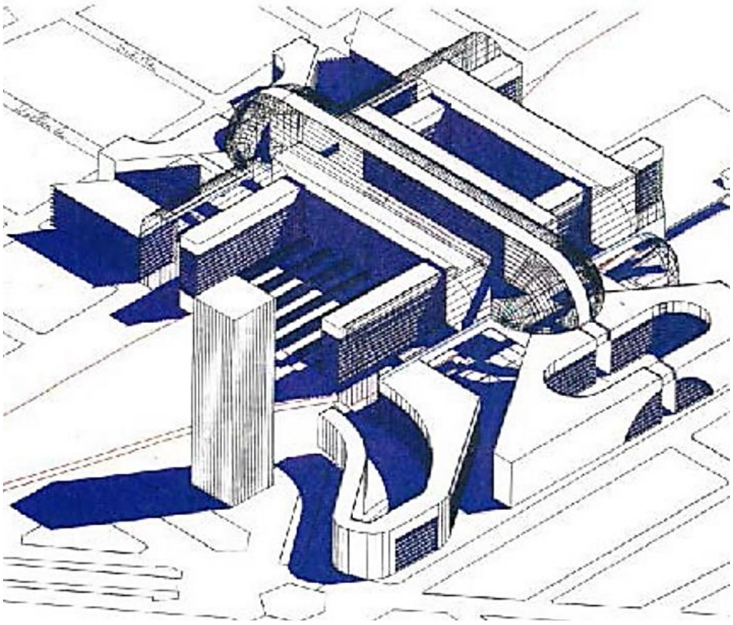


Figure 18: SNCBs vision on Brussels South (perspective.brussels, 2021)

The performed works include the construction of an HST access, and the six platform tracks for high-speed trains (two for Eurostar and 4 for other HSTs) were also renovated. Moreover, the HSTs cross the main tracks and the various track bundles of the station via a 452-meter-long viaduct. The entrance of line 50A to Ghent was also improved, and all existing rail bundles were given a thorough refurbishment. Finally, a new traction substation was built. A traction substation is a station for the transformation and distribution of electrical power required to supply, via the overhead line, a particular section of an electrified line. Brussels South was so ready to fulfil its new function. (NMBS, 1999)

2.2.3 Coach services

2.2.3.1 Europabus

The *Union des Services Routiers des Chemins de Fer Européens* (URF), a long-distance bus transport association, was founded in 1950 by eleven Western European railway companies. This association set up Europabus, an international bus network. Legally, the URF was part of the Swiss Federal Railways, as private companies were not allowed to operate international passenger services. (Schipper, 2008)

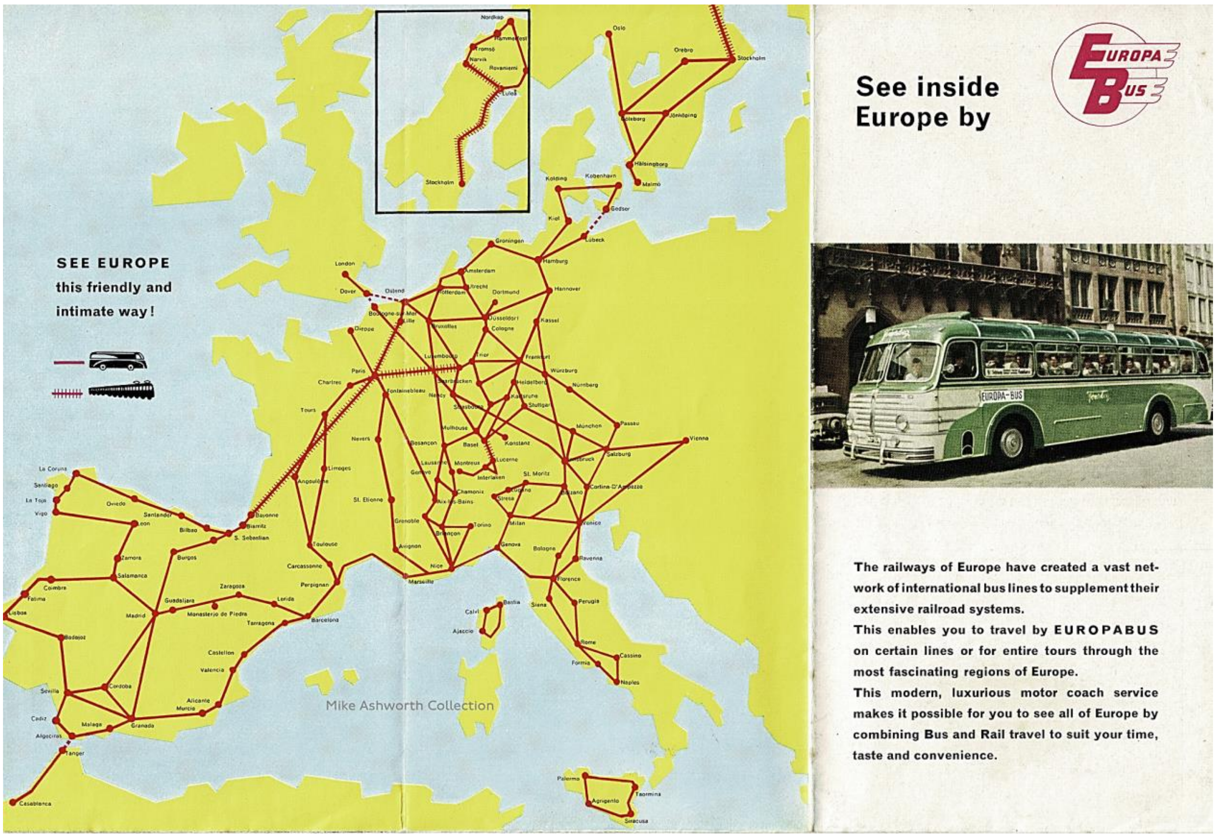


Figure 19: Europabus network 1955 (Ashworth, 2020)

Most lines had a touristic character and ran from late spring to mid-autumn. Services were not exclusively on the road; travellers could include stretches by rail. The operation of Europabus was governed by a number of basic principles. The administrations jointly planned a network of services with harmonised time schematics. They arranged international tickets and organised collective publicity. In the first year, Europabus covered 28 routes with a length of 18500 km, of which 1600 km by rail, mainly on French territory. In contrast to the private long-distance scheduled services, Europabus did not consist of long trans-European connections, but constituted chains of services, usually crossing only one border. For example, Europabus customers had to switch vehicles at different points in their journey when they crossed several borders. (Schipper, 2008)

Towards the end of the last century, the Europabus network increasingly suffered from competition from private long-distance bus services and tourist bus trips. The European road network had become much faster with the construction of many highways and was less suitable for tourist trips. Tour buses to tourist destinations drive if they can through beautiful regions, but when it comes to transportation alone, there are alternatives such as charter airlines and cheap long-distance buses.

2.2.3.2 Eurolines

There was a need among the participating bus companies and tour operators to set up a new European bus network without the influence of the railway companies. The Eurolines regular service organisation was founded in 1985. However, Eurolines continued to use the brand name 'Europabus'. Eurolines is less tourism-oriented and also offers fast long-distance services that do not make stops along the way. (OECD, 2010)

The company was organised as a joint venture of European coach operators; there were 35 independent coach companies operating in 32 countries, operating Europe's largest regular coach network. Common quality standards were developed for all members, including harmonised sales and travel conditions. The organisation was based in Brussels and ran as a non-profit that was open to companies that operated international scheduled passenger services. (OECD, 2010)

In 2019, Eurolines was acquired by its German competitor Flixbus, which resulted in the disappearance of the brand name Eurolines and its network. (Schoofs, 2019)

Figure 20: Eurolines route network to and from Belgium (Wikitravel, 2007)

2.2.3.3 Flixbus

FlixBus was founded in Munich by three young entrepreneurs to make sustainable travel comfortable and affordable. At the same time, “MeinFernbus” in Berlin started the same concept with green buses running all over Germany. After the German railway monopoly was lifted in 2013, the two startups established themselves as the leading providers in the bus market and gained the upper hand among the major international transport companies. Since the merger of the teams in Munich and Berlin, FLIX has been the market leader in Germany. (FLIX, 2022)

Since 2015, FlixBus has also expanded internationally, with bus networks in the Netherlands, France, Austria, Italy and Croatia, as well as cross-border buses to Scandinavia, Spain, England and Eastern Europe – operating the most extensive range of long-distance buses in Europe. In this expansion, Flixbus also took over its competitor Europlines. (FLIX, 2022)

Towards the future, FLIX mobility is introducing more and more electric buses. In 2024, the company wants to start operating long-distance hydrogen buses that can cover 450 km stretches without refilling. The hydrogen HyFleet project focuses on developing a high-performance fuel cell system for long-distance buses to bring sustainable and CO_2-free mobility to life. After creating this technology, FlixMobility plans to test and launch fuel cell-powered buses. (Sustainable BUS, 2021)

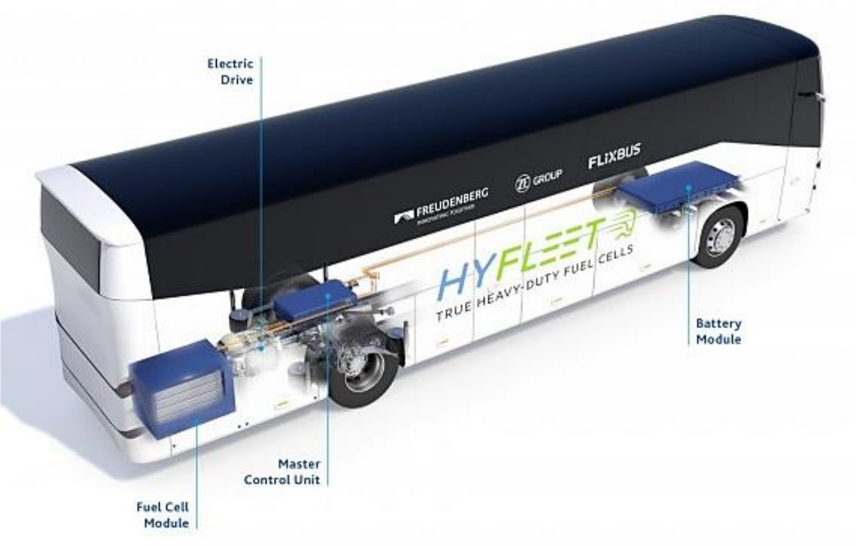


Figure 21: HyFleet bus scheme (Sustainable BUS, 2021)

The challenge with these hydrogen-powered buses is that FlixBuses drive around 200.000 km yearly with distances up to more than 1000 km per day with usually only short stops during the ride. Depending on the number of drivers involved during a trip, the bus will legally have to take a break after driving 4,5 hours, which is reached after approximately 450 km. For this reason, any alternative to a diesel bus must be able to travel at least about 500 kilometres before refuelling, the main goal of the bus that is getting developed. (Sustainable BUS, 2021)

2.3 Pollution

The transportation sector emits 24% of total CO_2 emissions globally. In greenhouse gasses is transportation the fastest-growing cause. From 1990 to 2015, the CO_2 grew by 68%, caused mainly by road transportation. Nevertheless, air transportation shows the highest growth rates, despite the fact that its share of the transportation sector's total CO_2 emissions remains at 12% of the total emissions. In terms of CO_2-eq emissions, the train achieves the lowest emissions, followed by coach, car and aircraft. (Baumeister, 2019)

2.3.1 Hidden costs

Since 1999, the EU has been trying to calculate the exact costs of transport, which arise in society or in nature and are not financed by road users. These "externalised" costs arise from congestion and accidents, air and noise pollution, soil and water pollution, climate change and soil sealing. It is based on what can be expressed in monetary terms, including on the basis of questions of what it would cost to eliminate or prevent this damage. For example, how strongly an economy is burdened by passivity, disease and premature death, by crop failures and a decline in biodiversity. (Heinrich Böll Foundation & Airbus Group, 2016)

The calculations for 2014 were very accurate. EU experts estimate that the externalized costs of aircraft noise caused by an aircraft landing and taking off in Luxembourg amounted to 285 euros. In Warsaw, it was only 27 euros. However, significant uncertainties remain about the impact that climate change will have. Accurate calculations about what proportion of the flood or storm damage can be attributed to global warming are difficult to perform. In an EU comparison of modes of transport for 2008, these uncertainties are particularly pronounced in air traffic because it emits the most greenhouse gases. However, it can already be concluded that assuming the maximum harmfulness of emissions, air and road traffic are approximately on the same page when it comes to externalized costs. (Heinrich Böll Foundation & Airbus Group, 2016)

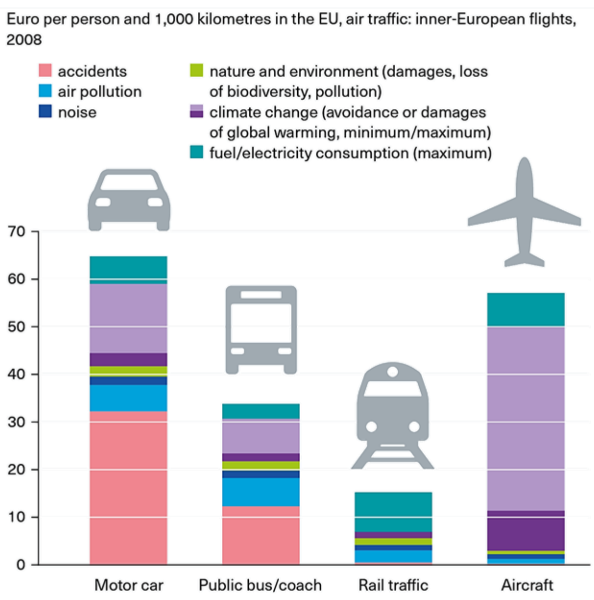


Figure 22: Hidden costs from transportation modes (Heinrich Böll Foundation & Airbus Group, 2016)

2.3.2 Carbon emissions

The transport sector is one of the most significant contributors to greenhouse gas (GHG) emissions. Unless there is a shift toward low-carbon transport, technology that emits fewer greenhouse gases, and less transport usage, it will continue to be so. Whether it can meet its emissions targets depends on technical opportunities, user behaviour and infrastructure investments. Continuing business as usual in the face of global climate change could lead to higher overall costs, less mobility, less transport support for the development and more disruption, not only of transport services but also production that depends on these services. (Kopp et al., 2013)

Within the sector, road transport accounts for the largest share of emissions; 72 per cent, followed by air transport and water transport with both around 13,5 per cent of emissions. Behind these figures are drastic differences between countries in absolute and per capita energy consumption. The per capita energy usage differs between different European countries, and the type of transportation mode usage also varies vastly, with a much higher water transport usage in Belgium and The Netherlands than in the rest of Europe. (European Environment Agency, 2019)

Figure 23: Total Transport CO_2 emissions by transport mode in the European Union in 2016 (European Environment Agency, 2019)

2.3.3 Air transport

Air transport is considered the most energy-intensive mode of transportation and one of the leading causes of climate change. Currently, aviation emissions account for about 2% to 2,5% of total anthropogenic carbon dioxide emissions and about 12% of global carbon dioxide emissions from transportation. Multiple sources claim that aviation is the mode with the highest CO_2 emissions measured per passenger-kilometre. For example, data from the European Environment Agency for Europe in 2014 shows that aviation emitted 244 g CO_2 per passenger-kilometre, while road transport emitted an average of 102 g and rail only 28 g CO_2. Unlike other modes of transportation, aviation remains heavily dependent on petroleum-based fuels for the time being. Although various efforts are being made to use synthetic fuels from renewable raw materials in aviation, it is questionable whether the amount of energy needed in aviation can be supplied in the short term from alternative sources. One of the most promising routes to generate drop-in fuels for aviation is power-to-liquid processes, which use excess electricity from renewable sources. However, large-scale, affordable generation capacity is probably years, if not decades, away. (Grimme & Jung, 2018)

2.4 Comparison of vehicle characteristics

Each transportation mode (coach, rail & aeroplane) is characterised by its own set of characteristics, which contributes to the travel time of the transportation mode and to the emissions that are emitted from the vehicle or the power plant that feeds the transport mode. There is a broad selection available of different vehicles from different manufacturers; a popular selection is discussed in the tables below.

2.4.1 Coach

Flixbus is the largest bus operator in Europe and Belgium for regulated transportation; therefore, two popular bus options are discussed below. Flix mobility offers general numbers of the carbon emissions for each of their transport modes; for the coaches with combustion engines, is this 23 g CO_2 equivalent for each passenger kilometre. (FLIX, 2019)

In Europe, there are regulations regarding the maximum speed that certain types of vehicles may drive. For coaches, this is set at a maximum of 100 km/h, with some member states having lower speed limits. Therefore, all coaches have the same top speed, maintained by a speed limiter in the vehicle. (European Commission, 2022)

Table 3: Bus vehicle characteristics

Transport mode	**Specific type**	**Characteristics**
Coach	 *Figure 24: Setra S531 DT (Flixbus, 2015)* Flixbus Setra S531 DT	83 passengers Max. 100 km/h 23 g CO_2 eq per passenger-km (Flixbus, 2019)
Coach	 *Figure 25: VDL Futura FHD 2 (VDL, n.d.)* Flixbus VDL Futura FHD 2	63 passengers Max. 100 km/h 23 g CO_2 eq per passenger-km (Flixbus, 2019)

2.4.2 Rail

There are four high-speed railway operators active to and from Belgium: Thalys, SNCF (with the TGV), Deutsche Bahn (with the ICE) and Eurostar. In the number of services is Thalys the largest operator, followed by Eurostar.

For Thalys, the carbon footprint is calculated for the average CO_2 eq emissions per passenger travelling 1 km on board Thalys. These numbers were calculated by SNCF, based on internal Thalys data for 2019 and for the whole Thalys network (annual consumption of traction electricity, number of passengers transported, number of kilometres travelled by these passengers) and on the other hand based on the CO_2 eq emission factors, which are assigned to the traction electricity used in the respective countries, where Thalys operates, was produced. (Thalys, 2020)

Deutsche Bahn is operating its electric trains within Germany with entirely green energy, resulting in a carbon footprint of 1,4 grams per passenger kilometre. (Deutsche Bahn, 2021b)

Eurostar calculated the carbon footprint of a one-way journey based on the energy consumption of their trains, together with the occupancy rates and energy mix of the countries it operates in. For the journey between Brussels and London is, 4,3 kg CO_2 eq emitted, resulting in an output of 15,6 g CO_2 per travelled kilometre. Other routes have lower output per kilometre, as the energy mix is different in those countries. (Eurostar, 2020)

Table 4: Train type characteristics

Transport mode	Specific type	Characteristics
Train	 *Figure 26: Thalys PBKA (2009)* Thalys PBKA Alstom	373 passengers Max. 300 km/h 6,7 g CO_2 eq per passenger-km (Thalys, 2019) The TGV from the SNCF uses similar trainsets as Thalys, with similar characteristics.
Train	 *Figure 27: Siemens Velaro* Eurostar Siemens Velaro	900 passengers Max. 320 km/h 15,6 g CO_2 eq per passenger-km (London – Brussels) (Eurostar, 2017)

Train	 *Figure 28: ICE 3 (2007)* Deutsche Bahn Siemens ICE 3	441 passengers Max. 320 km/h in service 1,4 g CO_2 eq per passenger-km (Deutsche Bahn, 2021a)

2.4.3 Air

Each different aeroplane type has its own set of characteristics; the passenger capacity, operating range, engine type, etc. For short-haul routes are generally smaller aircraft used, with a maximum seating capacity of around 180 passengers. Brussels Airlines, the primary carrier at Brussels Airport, uses the Airbus A319 and A320 for its short-haul operation, with seating capacities of 141 and 180, respectively.

Ryanair claims to be the greenest airline, with a claimed average of 66 grams of CO_2 per passenger-kilometre before the pandemic and setting 60 grams as a target to achieve in 2030. The most significant contributing factor to the lower emissions than its competitors is the higher load factor and its modern fleet with less polluting older planes. (Ryanair, 2022)

Table 5: Aeroplane type characteristics

Transport mode	Specific type	Characteristics
Aeroplane	 *Figure 29: Brussels Airlines A320 (AirTeamImages, 2022)* Brussels Airlines Airbus A319 – A320	A319: 141 passengers A320: 180 passengers Cruising speed 840 km/h 182 g CO_2 eq per passenger-km (Brussels – Frankfurt, 304 km) (ICAO, 2016)

Aeroplane	 *Figure 30: KLM Embraer E190 (2009)* KLM Embraer E190	100 passengers Cruising speed 850 km/h 262 g CO_2 eq per passenger-km (Brussels – Amsterdam, 156 km) (ICAO, 2016)
Aeroplane	 *Figure 31: Ryanair Boeing 737-800 (2006)* Ryanair Boeing 737-800	189 passengers Cruising speed 842 km/h 125 g CO_2 eq per passenger-km (Brussels – Berlin, 640 km)(ICAO, 2016)

3. Transportation networks

3.1 Air network

The main airline operating at Brussels Airport Zaventem is Brussels Airlines, followed by TUI Airlines Belgium (TUI fly). Brussels Airlines is owned by Lufthansa and a part of Star Alliance. The airline offers a selection of both business and leisure destinations. The amount of leisure destinations increases significantly in the summer; 30 destinations are added in the Spring or Summer. Most of those destinations are located in Greece, the only seasonal destination within the 750 km radius is Bordeaux. (Brussels Airlines, 2022)

TUI fly does not offer (seasonal) destinations closer than 750 km from Brussels Airport. The other seasonal destination within the radius, Innsbruck, is served in the winter season by Transavia Airlines. (Flightradar24, 2022)

Figure 32: Flight services to and from Brussels (2022)

Table 6: Destination scheme from Brussels Airport

Destination	# flights per weekday (one way)							# flights per week (one way)	Airline	Travel time
	M	T	W	T	F	S	S			
Amsterdam	4	4	4	4	4	4	4	28	KLM	60
Berlin	4	4	4	4	4	3	4	27	Brussels Airlines, Ryanair	80
Birmingham	1	0	1	0	1	0	0	3	Brussels Airlines	75
Bologna	1	1	1	1	1	0	1	6	Brussels Airlines	100
Bordeaux	1	0	1	0	1	0	1	4	Brussels Airlines	90
Firenze	1	1	1	1	1	1	1	7	Brussels Airlines	110
Frankfurt	8	8	8	8	8	6	6	52	Brussels Airlines, Lufthansa (CityLine)	60
Genève	6	5	5	6	6	3	6	37	Brussels Airlines, easyJet, Swiss	75
Hamburg	2	2	2	2	2	1	1	12	Brussels Airlines	75
Innsbruck	0	0	0	1	0	0	1	2	Transavia	85
London	5	5	5	5	5	5	5	35	British Airways, Brussels Airlines	75
Lourdes	1	0	0	0	1	0	0	2	TUI fly	120
Lyon	2	2	2	2	2	1	2	13	Brussels Airlines	80
Manchester	2	2	2	2	2	1	1	12	Brussels Airlines	80
Marseille	1	2	1	2	2	1	2	11	Brussels Airlines	105
Milano M	3	3	3	3	3	2	2	19	Brussels Airlines, Ryanair	90
Milano L	6	6	6	6	6	3	4	37	Brussels Airlines, ITA Airways	85
München	7	7	7	7	7	6	5	46	Brussels Airlines, Lufthansa	75
Nice	3	3	3	3	3	2	3	20	Brussels Airlines, easyJet	105
Paris	2	2	2	2	2	2	2	14	Brussels Airlines	55
Pisa	1	0	0	1	0	0	0	2	Ryanair	105
Praha	2	2	2	2	2	0	2	12	Brussels Airlines	85
Stuttgart	2	2	2	2	2	0	0	10	Eurowings	65
Toulouse	2	2	2	2	2	1	1	12	Brussels Airlines	100
Venezia	2	2	2	2	3	1	2	14	Brussels Airlines	95
Wien	6	6	6	6	7	4	5	40	Austrian Airlines, Brussels Airlines	100
Zürich	3	3	3	3	3	3	3	21	Swiss	75

Table 6 shows all the destinations that are shown in Figure 32; these are both flights to destinations further and closer than 750 km from Brussels. The destinations further than 750 km have a smaller fond than the closer destinations. The table shows the number of flights per weekday to a specific destination; this is not the same for every week. The most common flight pattern in April – May 2022 is shown in the table.

The most frequently served destinations are Frankfurt and Munich; both destinations are the main hubs of Lufthansa, the mother company of Brussels Airlines. This ensures a convenient connection without long waiting times at those airports on Star Alliance flights.

The other major alliance, Skyteam, operates from both Amsterdam Schiphol Airport with KLM and Paris with AirFrance. AirFrance does not offer feeder flights to and from Paris, as KLM does to Schiphol, but instead uses AirRail service from Brussels Midi train station. KLM also offers this, next to the feeder flights. AirRail is a combined flight and train ticketing experience. (SNCB, 2022b)

3.2 Train network

Brussels has a variety of international train services; classic, sleeper, and high-speed train services run out of the city. There are high-speed services to all neighbouring countries, except towards the Grand Duchy of Luxembourg. These high-speed train services are enabled by the high-speed rail lines that were constructed towards the French border (Line 1), the German border (Line 2 & 3) and the Dutch border (Line 4). There is no high-speed train line towards the Grand Duchy of Luxembourg. (Infrabel, 2009)

There is a newly planned sleeper train to Berlin and Prague that would first run three times per week (From Brussels on Monday, Wednesday & Friday) in each direction. Afterwards, the service would change to a daily operation. Confirmation still needs to be given by the railway company. The line is visualised differently in Figure 33. (European Sleeper, 2021)

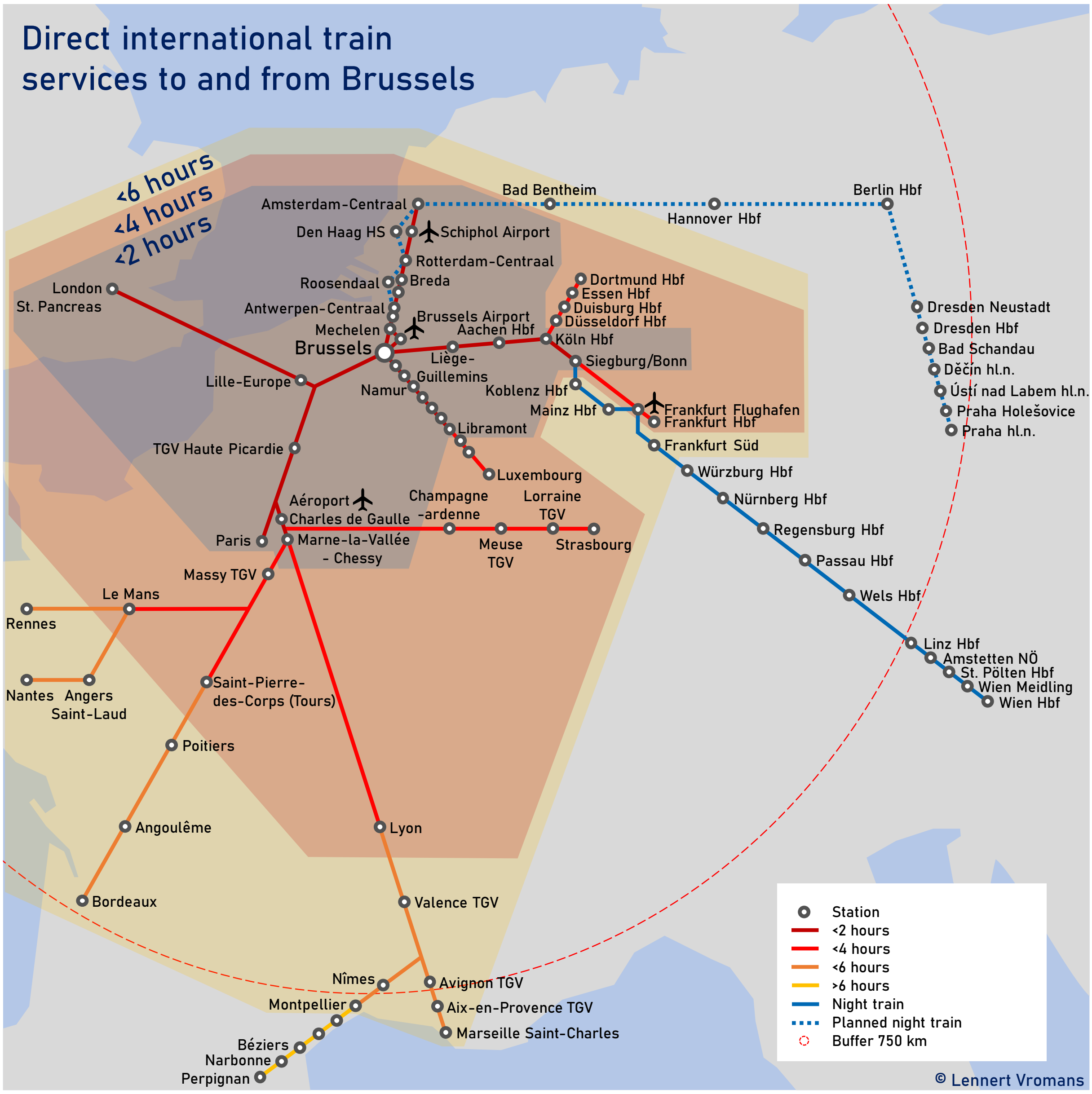


Figure 33: International train services running from Brussels (HAFAS, 2022)

Table 7: Destination Scheme for Brussels-Midi

Destination	# trains per weekday (one way)							# trains per week (one way)	Company	Type C-Classic HS-High-Speed S-Sleeper
	M	T	W	T	F	S	S			
Amsterdam	14	14	14	14	14	9	10	89	Thalys	HS
Amsterdam	3	3	3	3	3	2	2	19	Eurostar	HS
Amsterdam	16	16	16	16	16	16	16	112	NS-SNCB	C
Bordeaux	1	1	1	1	1	1	1	7	SNCF	HS
Dortmund	2	2	2	2	2	0	0	10	Thalys	HS
» Essen	1	1	1	1	1	1	1	7	Thalys	HS
» Köln	2	2	2	2	2	4	3	17	Thalys	HS
Frankfurt	7	7	7	7	7	7	5	47	DB	HS
London	7	7	7	7	7	5	6	46	Eurostar	HS
Luxembourg	12	12	12	12	12	13	9	82	SNCB	C
Marseille	2	2	2	2	2	3	2	15	SNCF	HS
Nantes/Rennes	1	1	1	1	1	1	1	7	SNCF	HS
Paris	18	18	18	18	20	12	16	120	Thalys	HS
Perpignan	0	0	0	0	1	1	0	2	SNCF	HS
» Montpellier	3	3	3	3	2	2	3	19	SNCF	HS
Praha	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*7*	*European Sleeper*	*S*
Strasbourg	2	2	2	2	2	2	2	14	SNCF	HS
Wien	1	0	1	0	1	0	0	3	ÖBB	S

Table 7 shows all the direct international train services that run out of Brussels-Midi train station. Most services are high-speed services; 14 out of 18. Not all trains run every ride towards the end destination; when the train runs only to an intermediate stop, it is shown with the "»" symbol in the table. The sleeper train towards Prague is displayed differently, as this service is not official in the timetables yet, but should start running from the summer of 2022. Firstly three times a week, and afterwards, the other days of the week, shown with an underline. (European Sleeper, 2021)

The leading high-speed railway operator that runs services from Brussels is Thalys, with 243[1] trains that can be taken on a weekly basis from Brussels to an international destination. The next competitor is Eurostar with 65[1] services and SNCF with 64[1] TGV services.

THI Factory, with trade name Thalys, is a company set up to provide international high-speed train services out of Brussels. The company is owned mainly (60%) by SNCF – the French railways, and SNCB (40%) – the Belgian railways. (Thalys, 2015)

[1] This is not the same for every week, the most recurring pattern in April – May 2022 is used.

3.3 Air + Rail network in Belgium

3.3.1 Accesrail

By implementing AccesRail, airlines can offer more destinations to their customers within a single booking process. AccesRail is a platform acting on behalf of more than 25 train, coach and ferry operators worldwide, using the airline code 9B. (Delta Airlines, 2021)

In Belgium, Air France, Brussels Airlines and KLM offer Air + Rail products with AccesRail technology for the routes, as shown in Figure 34. The trains used are trains in regular service; there are no additional trains to replace flights. When a booking is made, a reservation is made on the train that gives the best connection to the flight. When a train is planned after a flight, passengers can usually take the earliest train possible. (Brussels Airlines, n.d.)

Figure 34: Air + Rail services in Belgium

3.3.2 Airfrance–KLM & Thalys

In 2011, the airline KLM entered into a partnership with the high-speed train operator Thalys to offer passengers an alternative to feeder flights between Brussels Airport and Amsterdam Airport Schiphol. The easy accessibility and higher comfort of Brussels South station are the main reasons why travellers prefer a train ride over a flight between Brussels and Schiphol. In addition, Thalys trains connect the city of Antwerp with Schiphol Airport. KLM states that the costs of providing train services by Thalys are higher than the costs of a feeder flight, but passengers pay the same ticket price regardless of their choice. One of the main reasons why KLM offers this alternative is that climate responsibility is becoming more critical. For passengers travelling to Paris Charles de Gaulle, Air France has a relationship with high-speed train operator, TGV, to provide an alternative to feeder flights between Brussels and Charles de Gaulle airport. (Boulet, 2020)

3.3.3 Brussels Airlines & BeNe Rail

When travelling to and from the Netherlands via Brussels Airport, it is possible to take the train and enjoy a smooth journey thanks to a collaboration between Brussels Airlines and BeNe Rail[2]. The booking can be made from the Brussels Airlines website when travelling to and from Amsterdam-Centraal, Schiphol Airport, Rotterdam-Centraal and Breda. The train service is not the high-speed Thalys train but the regular intercity service between Brussels and Amsterdam. Therefore, no transfer between trains is needed, as the train has a stop at Brussels Airport. (Brussels Airlines, n.d.)

3.3.4 Challenges

Feeding air passengers by train has many advantages, but there are also some disadvantages. For example, if there is a problem on the rail network, people may miss their connecting flight or connecting train on the return journey. When this happens, the airline or train company will have to replace the traveller on the next available service, which may lead to overbookings. The same issue occurs when a feeder flight is delayed. Another challenge for the passenger is luggage; while Air France passengers travelling with the TGV to Charles de Gaulle Airport can already check-in their luggage at the Brussels-South station, passengers travelling with Thalys to Amsterdam cannot, as Thalys trains have no luggage space. Another problem is the lack of train services in the morning; the first intercontinental flights leave as early as 6.30 am while the first Thalys trains from Brussels arrive at Amsterdam Schiphol Airport at 8.30 am. (Boulet, 2020)

[2] BeNe Rail = The intercity service between Brussels and Amsterdam.
This service is a joint operation between SNCB and NS.

3.4 Coach network

Brussels has a wide variety of destinations to go to by long-distance bus. By far, the leading operator is FlixBus, operating buses to all neighbouring countries. Other operators are BlaBlaBus (formerly iDbus and Ouibus) which focuses on France, RegioJet with service to Prague, Arda Tur to Bulgaria, Sidbad with service to Poland and Unibus. However, FlixBus has such an extensive network that FlixBus serves almost all stops that the other operators make within the 750 km radius. Because of this reason, Figure 35 only shows the network of FlixBus.

As Figure 35 shows, FlixBus operates services to all neighbouring countries of Belgium, including service via the Channel Tunnel Shuttle to London. Several services run even further; towards Croatia, Italy, Poland, Portugal, Romania, Slovakia, and Spain.

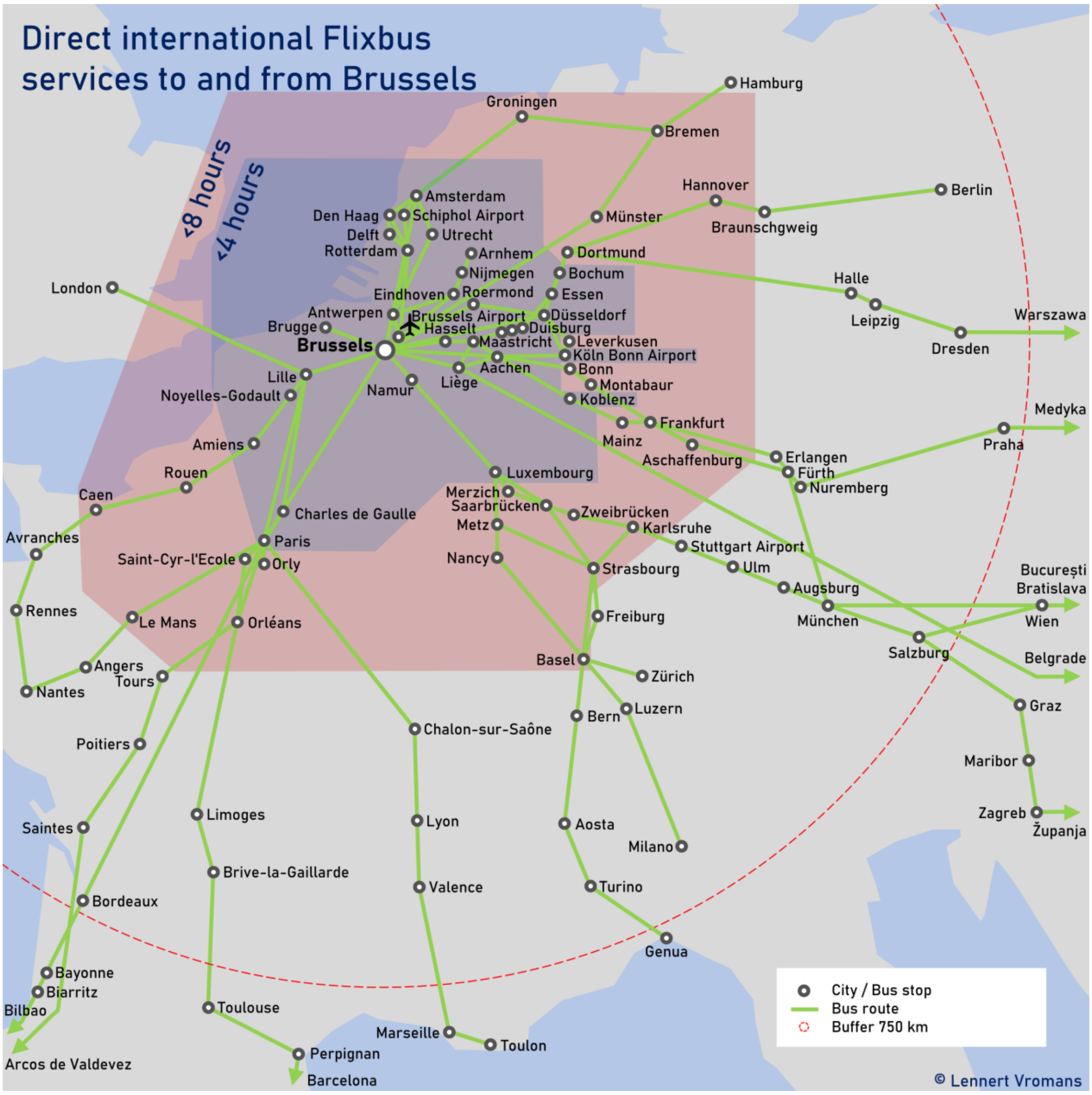


Figure 35: International Flixbus services from Brussels (2022)

Table 8: FlixBus lines that serve Brussels

N°	Departure	Arrival	# buses per weekday (passing, arriving or departing)							Intermediate stops
			M	T	W	T	F	S	S	
N71	Hamburg	Paris	2	2	1	0	1	2	2	Bremen, Münster, Bru-South
N79	Dortmund	Paris	2	2	1	0	1	2	2	Bochum, Essen, Dusseldorf, Leverkusen, Köln Bonn Airport, Aachen, Liège, Bru-South
081	Bru-North	Hannover	2	1	1	2	2	2	2	Roermond, Dusseldorf, Essen, Bochum, Dortmund
N81	Bru-North	Berlin	1	1	1	1	1	1	1	Dusseldorf, Essen, Bochum, Dortmund, Hannover, Brunswijk
N136	Antwerpen	Bratislava	2	2	0	2	2	2	2	Bru-North, Luxembourg, Metz, Strasbourg, Karlsruhe, Stuttgart, Ulm, Augsburg, Munchen, Wien, Bratislava Most
299	Antwerpen	Zürich	2	2	2	1	2	2	2	Bru-North, Luxenbourg, Saarbrücken, Strasbourg, Freiburg, Basel
328	Darmstadt	Lille	2	2	2	1	2	2	2	Frankfurt, Frankfurt Flughaven, Köln Bonn Airport, Aachen, Bru-North
N506	Bru-North	Genova	1	0	0	0	1	1	1	Luxembourg, Saarbrücken, Strasbourg, Basel, Bern, Aosta, Turino
N712	Bru-Airport	Nantes	2	2	2	2	2	2	2	Bru-North, Lille, Paris CdG, Paris, Le Mans, Angers
712	Bru-North	Nantes	0	0	0	1	2	1	1	Lille, Noyelles-Godault, Amiens, Rouen, Caen, Avranches, Rennes
713	Bru-North	Caen	0	0	0	1	1	1	1	Lille, Amiens, Rouen
N743	Bru-North	Bilbao	1	1	1	1	1	1	1	Lille, Paris, Bordeaux, Bayonne, Biarritz, San Sebastiàn
N769	Bru-Midi	Toulon	1	1	1	1	1	1	1	Lille, Paris CdG, Paris, Chalon-sur-Saône, Lyon, Valence, Marseille
N781	Bru-Airport	Barcelona	2	2	2	2	3	2	2	Bru-North, Lille, Paris CdG, Paris, Orléans, Limoges, Brive-la-Gaillarde, Toulouse, Perpignan
782	Lille	Bru-Airport	2	2	2	2	2	2	2	Bru-North
N800	Amsterdam	Paris	2	0	0	0	2	2	2	Amsterdam, Utrecht, Antwerpen, Brussels-Airport, Bru-South, Lille
801	Bru-North	Paris	2	2	2	2	2	2	2	
N803	Den Haag	Paris	2	2	2	2	2	2	2	Delft, Rotterdam, Brussels-Airport, Bru-North, Lille, Paris CdG
806	Bru-Midi	Paris	5	3	3	5	6	6	6	
807	Bru-Midi	Paris	5	3	3	4	6	5	6	Paris CdG
810	Bru-North	Amsterdam	7	5	5	8	11	11	11	
B810	Bru-North	Amsterdam	1	1	1	1	1	1	0	
811	Bru-North	Amsterdam	0	0	0	1	1	1	1	Bru-Heizel, Antwerpen, Tilburg, Efteling, Vianen
813	Bru-North	Amsterdam	3	3	3	3	4	4	4	Antwerpen, Rotterdam, Delft, Den Haag
815	London	Köln Airport	3	2	2	3	5	4	4	Folkestone, Calais, Lille, Bru-North, Aachen
N815	London	Maastricht	3	3	3	3	1	3	1	Folkestone, Calais, Lille, Bru-North, Liège
817	Bru-North	Amsterdam	5	2	2	2	5	4	5	Bru-Airport, Antwerpen, Utrecht
818	Bru-North	Amsterdam	1	0	0	0	1	1	1	Bru-Airport, Rotterdam, Den Haag, Schiphol
N818	Bru-North	Hamburg	2	1	1	1	1	2	2	Bru-Airport, Rotterdam, Schiphol, Amsterdam, Groningen, Bremen
819	Amsterdam	Brugge	3	2	2	3	4	4	4	Schiphol, Rotterdam, Rotterdam, Antwerpen, Brussels-Airport, Bru-North
821	Bru-North	Eindhoven	2	0	0	0	1	2	2	Antwerpen
822	Arnhem	Orly Airport	2	1	0	1	2	2	2	Nijmegen, Eindhoven, Bru-North, Paris
823	Eindhoven	Paris	4	4	4	4	4	4	4	Antwerpen, Bru-North
834	Bru-North	Den Haag	2	0	0	2	2	2	2	Antwerpen, Rotterdam
N836	Amsterdam	Milano	2	2	2	2	2	2	2	Bru-North, Luxembourg, Metz, Nancy, Basel, Luzern
N884	Antwerpen	Županja	2	2	2	2	2	2	2	Bru-North, Hasselt, Maastricht, Aachen, Bonn, Montabaur, Frankfurt, Aschaffenburg, Fürth ,

										Munchen, Salzburg, Graz, Maribor, Zagreb, Kutina, Nova Gradiška, Slavonski Brod
K901	Belgrade	Amsterdam	0	0	0	1	0	1	0	Novi Sad, Subotica, Liège, Bru-North, Antwerpen, Rotterdam, Den Haag
N1153	Dortmund	Arcos de Valdevez	0	1	1	1	1	1	1	Essen, Dusseldorf, Köln Bonn Airport, Aachen, Bru-North, Bru-South, Lille, Paris, Paris, Saint-Cyr-l'Ecole, Orléans, Tours, Poitiers, Saintes, Vitoria-Gasteiz, Int Hub, Palencia, Benavente, Verin, Chaves, Vidago, Pedras Salgadas, Vila Pouca de Aguiar, Arco de Baulhe, Fafe, Guimaraes, Braga, Ponte de Lima, Ponte da Barca
1304	Bru-North	Warszawa	1	1	1	1	1	1	1	Maastricht, Mönchengladbach , Krefeld , Duisburg , Essen , Dortmund, Halle, Leipzich, Dresden, Görlitz, Zgorzelec, Bolesławiec, Wrocław , Wrocław, Sieradz Dworzec Autobusowy
N1310	Rotterdam	Przemyśl Główny	2	2	2	2	2	2	2	Antwerpen, Bru-North, Aachen, Koblenz, Mainz, Frankfurt, Erlangen, Fürth, Nürmberg, Praha, Praha, Olomouc, Ostrava, Jastrzębie-Zdrój, Żory, Katowice, Kraków, Tarnów, Rzeszów
1770	Lille	Brussels Airport	0	0	0	2	4	4	4	Bru-South
1929	Bru-North	București	0	0	0	0	1	0	1	Namur, Luxembourg, Merzig, Saarbrücken, Zweibrücken, Karlsruhe, Stuttgart Airport, Ulm, Augsburg, Munich, Salzburg, Wien, Arad, Lipova, Deva, Orăștie, Sebeș, Sibiu, Făgăraș, Brașov, Sinaia, Ploiești

Table 8 shows 36 different bus lines from FlixBus that depart, arrive or pass Brussels. Some lines have a daytime and a nighttime (N) service, where the lines can have different routes. Other bus lines, like 806 and 807, have the same departure and arrival station but take different routes to and from their destination with various intermediate stops.

The busiest axis is Paris – Brussels – Amsterdam, with services running the whole day at all hours. There are services that run directly from Brussels to Paris or Amsterdam. And there are services that make intermediate stops like Lille and Charles de Gaulle Airport to Paris and Rotterdam and The Hague towards Amsterdam.

The further-destination routes run less frequently but overlap with each other on the first part of the route, so the medium-distance destinations are served more often. Examples of those cities that receive several lines from Brussels are Colone, Frankfurt, Strasbourg and Munich. The routes toward these cities are not always the same, as can be seen in Figure 35.

4. Relevant destinations

In this section, all destinations that are served by aeroplane service to and from Brussels are investigated. The different transport options (aeroplane, train and coach) are compared to each other with relevant indicators such as travel time, ticket price etc. The ticket prices are the lowest price that is available on the day for a trip in 14 and 60 days. This is the price for non-stop service, if it exists, and only for the main travel mode (aeroplane, train or coach). The ticket price is taken from the carrier's website. Sources travel times; Air: Skyscanner (2022), Rail: HAFAS (2022) & Bus: FLIX (2022). Before/After transport: Google Maps (2022).

The routes are calculated from the town hall of Brussels to the town hall or central place of the other city, to represent relevant travel routes and times from the city centre to the other city centre. When the main transport option needs before- and/or after-transport, the fastest public transport option is used.

For the carbon emissions, the Ecopassenger.org calculator was used. The website does not offer a possibility to calculate coach emissions, so a Euro 6 car with an occupancy of five passengers was selected. The carbon emissions of the aeroplane also include the transport to and from the airport by train. (EcoPassenger, 2022)

4.1 Travel times

To make sure that relevant and credible times are used, the times from this table are used in the analysis.

Table 9: Travel time elements

Time		Carrier/Place	Element
	x minutes	Walking	Walking to/from a station
	x minutes	Metro/Tram	After transport or a transfer
	5 minutes	Station/Stop	Transfer walking time in the same station
	5 minutes	Regular train	Time on the platform before the train
	10 minutes	High-Speed train	Time on the platform before the train
	30 minutes	Eurostar	Time on the platform before the train
	5 minutes	All trains	Time needed in the station after a train ride
	120 minutes	Brussels Airport	Time needed in the airport before the flight
	30 minutes	Destination Airport	Time needed in the airport after a flight
	15 minutes	Flixbus	Time on the platform before the bus ride
	5 minutes	Flixbus	Time needed after the busride

4.1.1 Amsterdam

Amsterdam is the closest city to Brussels that receives regular air service. Next to this, Thalys operates high-speed trains and has a partnership with airline KLM to replace some of these flights. Next to that, Flixbus operates frequent buses that are direct express services that cover the stretch in 3h20.

Table 10: Route Brussels – Amsterdam

Aeroplane		Train		Coach	
	7 minutes		7 minutes		7 minutes
	5 minutes Brussels Central		5 minutes Brussels Central		5 minutes Brussels Central
	17 minutes SNCB		5 minutes SNCB		5 minutes SNCB
	120 minutes Brussels Airport		15 minutes Brussels South		20 minutes Brussels North
	60 minutes KLM		112 minutes Thalys		200 minutes Flixbus
	30 minutes Schiphol Airport		10 minutes		10 minutes
	29 minutes Train + Metro		3 minutes Metro		14 minutes Metro
	5 minutes		5 minutes		5 minutes
273 minutes, 4h33 Price 14 days: 236 Price 60 days: 148 84,6 kg CO_2 eq		162 minutes, 2h42 Price 14 days: 29 Price 60 days: 29 6 kg CO_2 eq		266 minutes, 4h26 Price 14 days: 10 Price 60 days: 10 6,8 kg CO_2 eq	

4.1.2 Berlin

Travelling to and from the capital of Germany is possible with a direct flight or coach, but not possible with a direct train; a connection in Cologne is required. Due to the competition of low-cost carrier Ryanair, low ticket prices are offered on flights, certainly if booked in the future.

Table 11: Route Brussels – Berlin

Aeroplane		Train		Coach	
	7 minutes		7 minutes		7 minutes
	5 minutes Brussels Central		5 minutes Brussels Central		5 minutes Brussels Central
	17 minutes SNCB		5 minutes SNCB		5 minutes SNCB
	120 minutes Brussels Airport		15 minutes Brussels North		20 minutes Brussels North

80 minutes Ryanair/Brussels Airl.	6h38 **Transfer** in Köln Hbf ICE Deutsche Bahn	12 hours Flixbus
30 minutes Brandenburg Airport	10 minutes	10 minutes Zentraler busbahnhof
25 minutes Deutsche Bahn	7 minutes Metro	28 minutes Metro
7 minutes	2 minutes	7 minutes
291 minutes, 4h51 Price 14 days: 101 Price 60 days: 23 117,6 kg CO_2 eq	449 minutes, 7h29 Price 14 days: 82 Price 60 days: 82 23,7 kg CO_2 eq	802 minutes, 13h22 Price 14 days: 20 Price 60 days: 20 23,4 kg CO_2 eq

4.1.3 Birmingham

Birmingham is located in the United Kingdom, so it is necessary to cross the English Channel. The Flixbus uses the Channel Tunnel train shuttle. For rail passengers, a transfer in London is required from St-Pancras to Euston train station, where the trip can be continued. It is also necessary to book the train tickets separately. Flixbus only operates a direct service to London, so a transfer in London is also required.

Table 12: Route Brussels – Birmingham

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	35 minutes Brussels North	20 minutes Brussels North
75 minutes Brussels Airlines	124 minutes Eurostar	12h55 **Transfer** in London Flixbus
30 minutes Birmingham Airport	15 minutes Border Control	10 minutes Dudley Street
15 minutes West Midland trains	10 minutes **Transfer** to Euston	10 minutes
7 minutes	10 minutes Euston	
	84 minutes Avanti West Coast	
	7 minutes	

276 minutes, 4h36 Price 14 days: 170 Price 60 days: 72 110,9 kg CO_2 eq	302 minutes, 5h02 Price 14 days: 103 + 28 Price 60 days: 69 + 21 17,9 kg CO_2 eq	832 minutes, 13h52 Price 14 days: 20 Price 60 days: 20 17,6 kg CO_2 eq

4.1.4 Bordeaux

This is a seasonal destination from Brussels Airlines; in the winter season, there is no flight service. Every day, there is a direct TGV high-speed rail service directly from Brussels to Bordeaux. For a faster travel time, a train journey with a transfer in Paris is also an option. Flixbus operates a direct service, with the service to Bilbao, that has a stop in the city.

Table 13: Route Brussels – Bordeaux

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels South	20 minutes Brussels North
90 minutes Brussels Airlines	5h47 TGV SNCF	11h50 Flixbus
30 minutes Bordeaux Airport	10 minutes Bordeaux St-Jean	15 minutes
30 minutes Bus	14 minutes Bus	14 minutes Bus
5 minutes	5 minutes	5 minutes
304 minutes, 5h04 Price 14 days: 134 Price 60 days: 134 141,1 kg CO_2 eq	408 minutes, 6h48 Price 14 days: 130 Price 60 days: 130 6,4 kg CO_2 eq	781 minutes, 13h01 Price 14 days: 40 Price 60 days: 50 27,4 kg CO_2 eq

4.1.5 Frankfurt

Frankfurt is one of the biggest cities in Germany and one of the hub airports of Lufthansa, the parent company of Brussels Airlines. Therefore, there are frequent flight services to the city, which are mainly intended for connecting passengers to Lufthansa's worldwide network. The travel time by train is shorter than by aeroplane, with a difference of about 30 minutes. The coach can compete on the level of price, as the train and plane have ticket prices that are at least three times higher.

Table 14: Route Brussels – Frankfurt

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels North	20 minutes Brussels North
60 minutes Lufthansa, Brussels A	2h59 ICE Deutsche Bahn	6h25 Flixbus
30 minutes Frankfurt Airport	10 minutes Frankfurt Hbf	10 minutes Frankfurt Hbf
17 minutes Suburban train	3 minutes Metro	3 minutes Metro
7 minutes	7 minutes	7 minutes
263 minutes, 4h23 Price 14 days: 200 Price 60 days: 133 114,2 kg CO_2 eq	231 minutes, 3h51 Price 14 days: 68 Price 60 days: 68 11,5 kg CO_2 eq	442 minutes, 7h22 Price 14 days: 20 Price 60 days: 20 12,3 kg CO_2 eq

4.1.6 Genève

The city of Geneva is located near the French border in Switzerland. There is no direct train or bus service, so a transfer in Paris is required. For the train, a transfer between train stations is also necessary from Gare du Nord to Gare de Lyon. Three airlines offer flights to and from Geneva, resulting in competitive ticket prices in the near and distant future.

Table 15: Route Brussels – Genève

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels South	20 minutes Brussels South
75 minutes Swiss, Easyjet, Brussels Airlines	82 minutes Thalys	12h20 **Transfer** in Paris Flixbus

30 minutes Geneva Airport	10 minutes Paris Nord	10 minutes Frankfurt Hbf
7 minutes SBB CFF FFS	15 minutes Metro – 1 **Transfer**	7 minutes
10 minutes	15 minutes	
	3h29 TGV	
	10 minutes	
271 minutes, 4h31 Price 14 days: 52 Price 60 days: 50 112,9 kg CO_2 eq	373 minutes, 6h13 Price 14 days: 143 Price 60 days: 90 7,3 kg CO_2 eq	794 minutes, 13h14 Price 14 days: 34 Price 60 days: 34 19,1 kg CO_2 eq

4.1.7 Hamburg

The route to Hamburg is possible with a direct flight or Flixbus. To travel by train, at least one transfer is required; on a regular IC train or another high-speed train. The flight has no competition from other airlines, resulting in high ticket prices for a departure within two weeks. For Flixbus and the train, the prices are about the same for a near or distant departure.

Table 16: Route Brussels – Hamburg

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels North	20 minutes Brussels South
75 minutes Brussels Airlines	104 minutes ICE Deutsche Bahn	8h20 Flixbus
30 minutes Hamburg Airport	53 minutes Köln Hbf	10 minutes Hamburg Hbf
28 minutes Suburban train	4h05 Deutsche Bahn	12 minutes
7 minutes	12 minutes	
289 minutes, 4h49 Price 14 days: 192 Price 60 days: 65 115 kg CO_2 eq	446 minutes, 7h26 Price 14 days: 70 Price 60 days: 68 18,8 kg CO_2 eq	559 minutes, 9h19 Price 14 days: 35 Price 60 days: 35 18,6 kg CO_2 eq

4.1.8 Innsbruck

Innsbruck is a seasonal destination from Transavia Airlines, getting service in the winter season. To travel by rail or coach, there are no direct services. By train, two transfers are at least required, and by bus at least one. It is not possible to have an entire train journey on a high-speed train; classic trains are required to be taken.

Table 17: Route Brussels – Innsbruck

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels North	20 minutes Brussels North
85 minutes Transavia Airlines	6h34 **Transfer** in Frankfurt ICE Deutsche Bahn	16h00 **Transfer** in München Flixbus
30 minutes Innsbruck Airport	27 minutes München Hbf	10 minutes Südbahnstraße
15 minutes Bus	105 minutes Eurocity Brenner	15 minutes
2 minutes	10 minutes	
196 minutes, 3h16 Price 14 days: / Price 60 days: / 133,9 kg CO_2 eq	568 minutes, 9h28 Price 14 days: 90 Price 60 days: 80 27,6 kg CO_2 eq	1022 minutes, 17h02 Price 14 days: 42 Price 60 days: 47 23,3 kg CO_2 eq

4.1.9 London

To travel to London, it is necessary to cross the street of Dover, requiring the coach service to use the shuttle service under the sea. London is serviced by direct Flixbus services from Brussels, resulting in a convenient travel option. By train, the Eurostar brings passengers in two hours from city to city, resulting in the fastest travel option between the two cities. For aeroplane passengers in London, a 47 minutes metro ride is needed from the airport to the city centre.

Table 18: Route Brussels – London

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central

17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	35 minutes Brussels North	20 minutes Brussels North
75 minutes British A, Brussels A	124 minutes Eurostar	8h30 Flixbus
30 minutes Heathrow Airport	15 minutes Border Control	10 minutes Victoria Coach Station
47 minutes London Underground	7 minutes London Underground	9 minutes
2 minutes	2 minutes Piccadilly Circus	2 minutes London Underground
		11 minutes
303 minutes, 5h03 Price 14 days: 87 Price 60 days: 67 118,4 kg CO_2 eq	200 minutes, 3h20 Price 14 days: 103 Price 60 days: 69 9,2 kg CO_2 eq	568 minutes, 9h28 Price 14 days: 25 Price 60 days: 15 12,5 kg CO_2 eq

4.1.10 Lyon

Travelling to the city of Lyon is possible by direct train and bus connections from TGV and Flixbus. Due to the direct high-speed train, the total travel time by train is less than the travel time by aeroplane. The Flixbus offers an alternative with steady ticket pricing, but a travel time that is more than double the travel time of the other options.

Table 19: Route Brussels - Lyon

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels South	20 minutes Brussels South
80 minutes Brussels Airlines	3h28 TGV SNCF	10h45 Flixbus
30 minutes Lyon Airport	10 minutes Lyon Part-Dieu	10 minutes Lyon Perrache
35 minutes Train + Metro	10 minutes TCL	6 minutes Metro
3 minutes	3 minutes	3 minutes

297 minutes, 4h57 Price 14 days: 198 Price 60 days: 55 121,6 kg CO_2 eq	263 minutes, 4h23 Price 14 days: 108 Price 60 days: 108 5,9 kg CO_2 eq	701 minutes, 11h41 Price 14 days: 50 Price 60 days: 50 20,4 kg CO_2 eq

4.1.11 Manchester

Manchester is located in the United Kingdom, so it is necessary to cross the English Channel. The Flixbus uses the Channel Tunnel train shuttle. For rail passengers, a transfer in London is required from St-Pancras to Euston train station, where the trip can be continued. It is also necessary to book the train tickets for the Eurostar and British railways separately. Flixbus only operates a direct service to London, so a transfer in London is also required for bus passengers.

Table 20: Route Brussels - Manchester

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	35 minutes Brussels North	20 minutes Brussels North
80 minutes Brussels Airlines	124 minutes Eurostar	14h36 **Transfer** in London Flixbus
30 minutes Manchester Airport	15 minutes Border Control	10 minutes Shudehill Interchange
18 minutes Transpennine Exp	10 minutes **Transfer** to Euston	12 minutes
12 minutes	10 minutes Euston	
	129 minutes Avanti West Coast	
	10 minutes Manchester Piccadilly	
	5 minutes Go North West	
	5 minutes	
289 minutes, 4h49 Price 14 days: 187 Price 60 days: 100 114,5 kg CO_2 eq	360 minutes, 6h00 Price 14 days: 103 + 46 Price 60 days: 69 + 41 26,8 kg CO_2 eq	935 minutes, 15h35 Price 14 days: 32 Price 60 days: 30 19,2 kg CO_2 eq

4.1.12 Marseille

Marseille is not located within the 750 km radius, but has direct high-speed rail service that operates daily. The TGV connects Brussels to Marseille in 5h21, resulting in a total travel time by train that is 39 minutes longer than the travel time by aeroplane. The bus has a total travel time of 16h18, but can compete with its stable ticket pricing.

Table 21: Route Brussels – Marseille

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels South	20 minutes Brussels South
105 minutes Brussels Airlines	5h21 TGV SNCF	15h20 Flixbus
30 minutes Marseille Airport	10 minutes Marseille St-Charles	10 minutes Marseille St-Charles
45 minutes Bus + Metro	5 minutes Metro	5 minutes Metro
6 minutes	6 minutes	6 minutes
335 minutes, 5h35 Price 14 days: 128 Price 60 days: 95 138,7 kg CO_2 eq	374 minutes, 6h14 Price 14 days: 138 Price 60 days: 138 7,9 kg CO_2 eq	978 minutes, 16h18 Price 14 days: 80 Price 60 days: 80 30,2 kg CO_2 eq

4.1.13 Milano

On the route from Brussels to Milan is a lot of competition between airlines; Brussels Airlines, ITA, and Ryanair offer flights towards the Italian city. Ryanair offers flights to Malpensa Airport, ITA to Linate Airport and Brussels Airlines to both. Linate Airport is located the most closely to the city centre, and is therefore used in the comparison between the different transportation modes.

A direct train service does not exist; at least one transfer is required. The example in the comparison is a transfer onto a recently introduced service from the Italian Railways that runs two times each day in each direction. Flixbus offers direct service to Milan on a daily basis.

Table 22: Route Brussels – Milano

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels South	20 minutes Brussels North
85 minutes ITA, Ryanair, Brussels Airlines	8h50 **Transfer** in Lyon TGV, Frecciarossa	13h10 Flixbus
30 minutes Linate Airport	10 minutes Milano Centrale	10 minutes Lampugnano
29 minutes Bus	6 minutes Metro	15 minutes Metro
6 minutes	2 minutes	2 minutes
299 minutes, 4h59 Price 14 days: 102 Price 60 days: 53 128,4 kg CO_2 eq	580 minutes, 9h40 Price 14 days: 194 Price 60 days: 167 20 kg CO_2 eq	844 minutes, 14h04 Price 14 days: 48 Price 60 days: 48 25 kg CO_2 eq

4.1.14 München

Munich is one of Germany's largest cities and is one of Lufthansa’s hub airports; therefore, are there several scheduled flights each day to connect passengers to Lufthansa’s worldwide network. By train, there is no direct option; one transfer in Frankfurt is needed. Flixbus, on the other hand, offers direct bus services.

Table 23: Route Brussels – München

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels North	20 minutes Brussels North
75 minutes Lufthansa, Brussels Airlines	6h34 **Transfer** in Frankfurt ICE Deutsche Bahn	12h00 Flixbus

⌛	30 minutes München Airport	⌛	10 minutes München Hbf	⌛	10 minutes Central Bus station
🚆	38 minutes Suburban train	🚆	5 minutes Suburban train	🚆	5 minutes Suburban train
🚶	2 minutes	🚶	2 minutes	🚶	2 minutes
294 minutes, 4h54 Price 14 days: 129 Price 60 days: 96 127,3 kg CO_2 eq		443 minutes, 7h23 Price 14 days: 92 Price 60 days: 92 20,7 kg CO_2 eq		774 minutes, 12h54 Price 14 days: 30 Price 60 days: 30 21,6 kg CO_2 eq	

4.1.15 Paris

The high-speed train between Paris and Brussels was the world's first international high-speed train service. It connects the two cities in 1h22, with an operating speed of 300 km/h. The flying time between the cities is 55 minutes, and the travel time by bus is 3h55. When the total travel times are compared from city centre to city centre, the train is by far the fastest option. The travel time by bus and aeroplane is less than a quarter different.

Table 24: Route Brussels – Paris

Aeroplane		**Train**		**Coach**	
🚶	7 minutes	🚶	7 minutes	🚶	7 minutes
⌛	5 minutes Brussels Central	⌛	5 minutes Brussels Central	⌛	5 minutes Brussels Central
🚆	17 minutes SNCB	🚆	5 minutes SNCB	🚆	5 minutes SNCB
⌛	120 minutes Brussels Airport	⌛	15 minutes Brussels South	⌛	20 minutes Brussels North
✈	55 minutes Brussels Airlines	🚆	82 minutes Thalys	🚌	3h55 Flixbus
⌛	35 minutes CdG terminal 1 » 3	⌛	10 minutes Paris Nord	⌛	15 minutes Paris Bercy
🚆	36 minutes Suburban train	🚆	10 minutes Metro	🚆	6 minutes Metro
🚶	12 minutes	🚶	8 minutes	🚶	8 minutes
287 minutes, 4h47 Price 14 days: 180 Price 60 days: 180 122,1 kg CO_2 eq		142 minutes, 2h22 Price 14 days: 79 Price 60 days: 37 3,3 kg CO_2 eq		301 minutes, 5h01 Price 14 days: 8 Price 60 days: 10 10,1 kg CO_2 eq	

4.1.16 Praha

The route from Brussels to Prague is possible to make with a direct flight or Flixbus service. When taking the train, at least two transfers are required, except when taking the night train with destination Vienna, and changing trains in Regensburg Hbf.

Table 25: Route Brussels – Prague

Aeroplane		Train		Coach	
	7 minutes		7 minutes		7 minutes
	5 minutes Brussels Central		5 minutes Brussels Central		5 minutes Brussels Central
	17 minutes SNCB		5 minutes SNCB		5 minutes SNCB
	120 minutes Brussels Airport		15 minutes Brussels North		20 minutes Brussels North
	85 minutes Brussels Airlines		6h34 **Transfer** in Frankfurt ICE Deutsche Bahn		14h00 Flixbus
	30 minutes Prague Airport		51 minutes Regensburg Hbf		10 minutes Prague Roztyly
	34 minutes Bus + Metro		4h06 DPN		12 minutes Metro
	8 minutes		18 minutes		16 minutes
306 minutes, 5h06 Price 14 days: 295 Price 60 days: 133 128,2 kg CO_2 eq		741 minutes, 12h21 Price 14 days: 100 Price 60 days: 90 41,4 kg CO_2 eq		915 minutes, 15h15 Price 14 days: 60 Price 60 days: 35 25,8 kg CO_2 eq	

4.1.17 Stuttgart

Travelling to Stuttgart is possible by a direct flight and bus, or by train with one transfer in Frankfurt. The Buses from Brussels have their stop at the airport of Stuttgart, resulting in the same after transport that needs to be taken. Flights are operated by Eurowings, the low-cost carrier of Lufthansa group, with a minimum ticket price of €39,99 for the route for a one-way ticket. (EuroWings, 2022)

Table 26: Route Brussels – Stuttgart

Aeroplane		Train		Coach	
	7 minutes		7 minutes		7 minutes
	5 minutes Brussels Central		5 minutes Brussels Central		5 minutes Brussels Central
	17 minutes SNCB		5 minutes SNCB		5 minutes SNCB

120 minutes Brussels Airport	15 minutes Brussels North	20 minutes Brussels North
65 minutes Eurowings	4h07 **Transfer** in Frankfurt ICE Deutsche Bahn	8h45 Flixbus
30 minutes Stuttgart Airport	10 minutes Stuttgart Hbf	10 minutes Stuttgart Airport
25 minutes Suburban train	5 minutes Metro	25 minutes Suburban train
10 minutes	5 minutes	10 minutes
279 minutes, 4h39 Price 14 days: 159 Price 60 days: 50 101,7 kg CO_2 eq	299 minutes, 4h59 Price 14 days: 70 Price 60 days: 70 15,9 kg CO_2 eq	607 minutes, 10h07 Price 14 days: 26 Price 60 days: 26 16,1 kg CO_2 eq

4.1.18 Zürich

Travelling to Zurich, the largest city in Switzerland, is possible with a direct flight or Flixbus. Train passengers need to transfer at least one time between high-speed trains. Flights are only operated by Swiss, the national carrier of Switzerland that is also part of the Lufthansa group.

Table 27: Route Brussels – Zürich

Aeroplane	Train	Coach
7 minutes	7 minutes	7 minutes
5 minutes Brussels Central	5 minutes Brussels Central	5 minutes Brussels Central
17 minutes SNCB	5 minutes SNCB	5 minutes SNCB
120 minutes Brussels Airport	15 minutes Brussels North	20 minutes Brussels North
75 minutes Swiss	7h26 **Transfer** in Frankfurt ICE Deutsche Bahn	10h30 Flixbus
30 minutes Zürich Airport	10 minutes Zürich HB	10 minutes Zürich HB
16 minutes Suburban train	5 minutes Tram	8 minutes Tram
12 minutes	2 minutes	2 minutes
282 minutes, 4h42 Price 14 days: 312 Price 60 days: 108 115 kg CO_2 eq	495 minutes, 8h15 Price 14 days: 80 Price 60 days: 80 21,3 kg CO_2 eq	687 minutes, 11h27 Price 14 days: 36 Price 60 days: 30 19 kg CO_2 eq

4.2 Discussion

4.2.1 Travel time

When travelling by aeroplane, the travel times are relatively stable; the flight time is between 55 and 90 minutes for all destinations within the 750 km radius. This and the after transport is the only variable when taking the plane towards a destination, resulting in a relatively flat curve in Figure 36.

When travelling by high-speed train, competitive travel times are usually achieved. For Amsterdam, Frankfurt, London, Lyon and Paris is the travel time shorter by train than by aeroplane. These destinations have in common that they are all located on a high-speed rail line that is connected by direct service from Brussels.

The Flixbus has overall the longest travel time. But, the long travel times are usually night buses that leave Brussels in the evening to arrive the following day at their destination. Only two destinations show competitive travel times in comparison to the aeroplane; Amsterdam and Paris can be reached faster than the plane. But in these cases is the train even quicker than the bus.

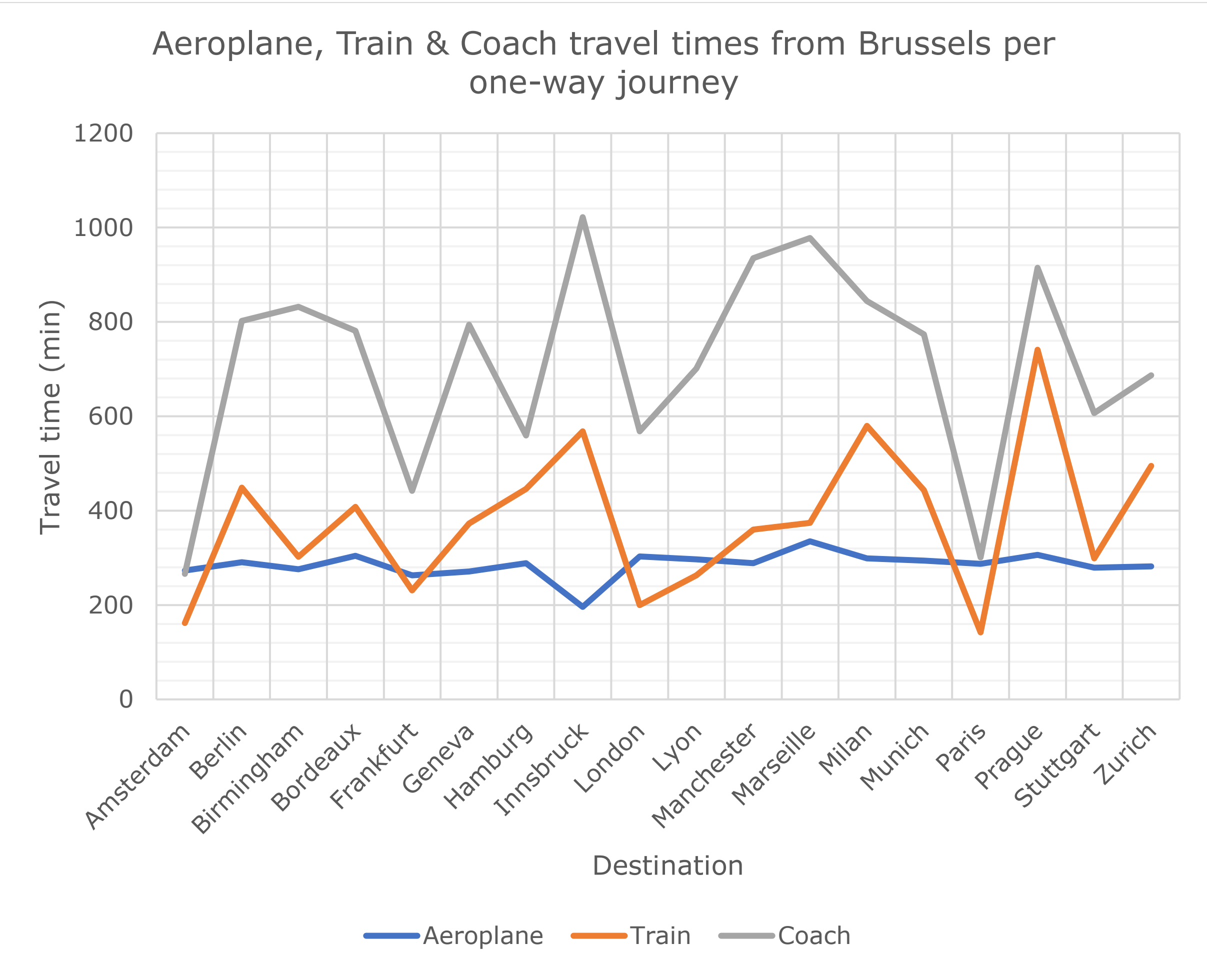


Figure 36: Aeroplane, train & coach travel times from Brussels

In the next chapter, missing links will be investigated to make the high-speed train more competitive with the aeroplane by reducing its travel time on specific routes.

4.2.2 Ticket prices

The overall cheapest way of travelling is by Flixbus; both when purchasing the ticket two months in advance, as buying it just two weeks in advance. This mode also does not have a significant difference in prices between those buying points in time, making it a much more attractive mode to travel with in terms of ticket price when travelling last minute.

The train and aeroplane compete more on ticket prices; for some destinations, it is cheaper to fly, and for others, it is cheaper to take the train. For cities where there is competition between the high-speed train and aeroplane, ticket prices tend to be similar; Bordeaux, London, and Marseille have similarly priced tickets for the 14 and 60 booking period. These are more leisure-oriented destinations, for the more business-oriented destinations such as Frankfurt or Paris is this not the case.

The aeroplane ticket prices to Innsbruck are not for the direct flight with Transavia Airlines because these tickets could not be booked anymore while conducting this research, as the winter season was already coming to an end. The ticket prices are for a flight with a transfer in Vienna, operated by Austrian Airlines (Lufthansa Group).

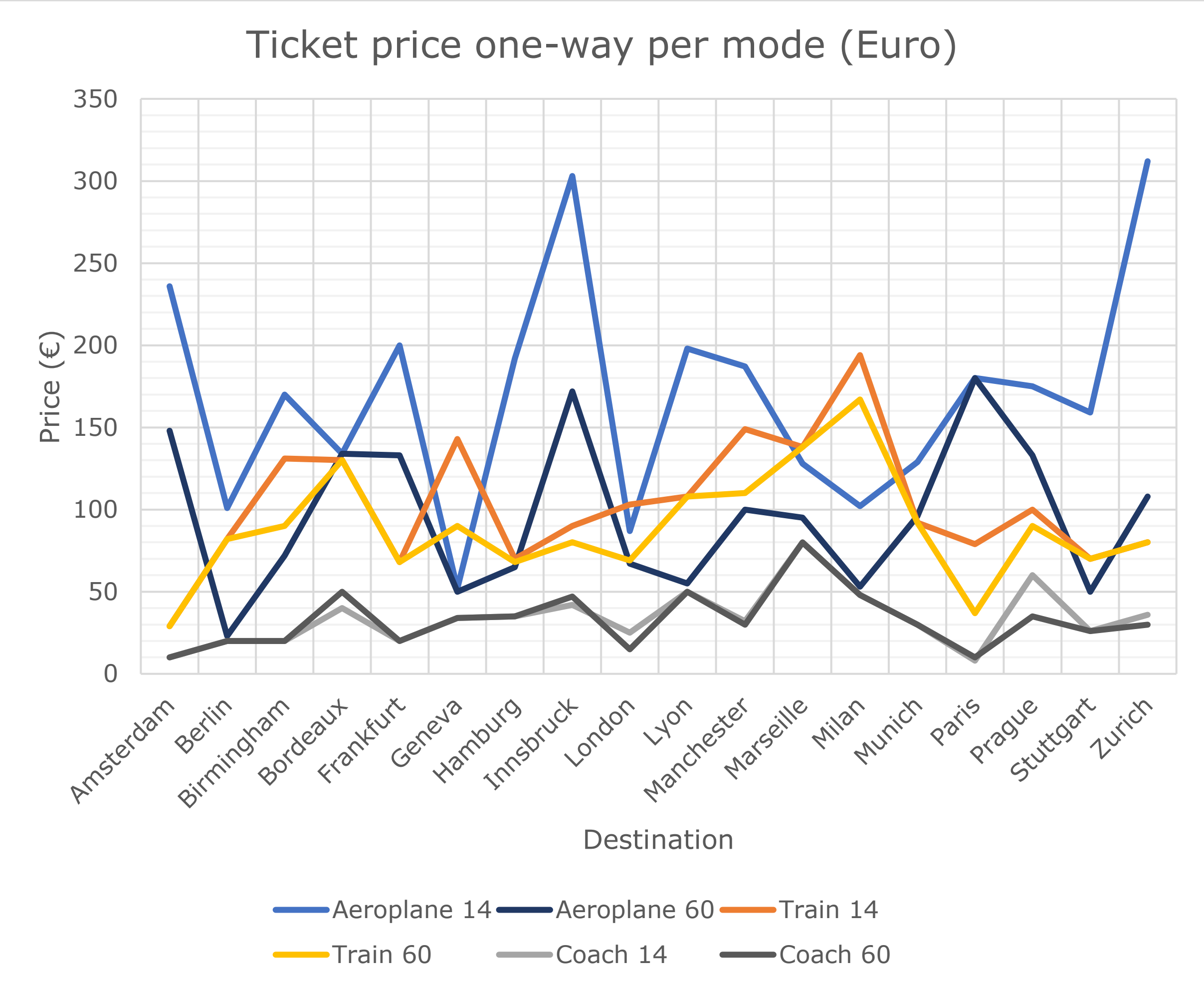


Figure 37: Ticket price per travel mode; ticket price of 14 and 60 days in advance

4.2.3 Emissions

On the emissions level, it can clearly be seen that the aeroplane journeys emit the most amount of CO_2, and that the train is in most cases the cleanest way to travel.

The calculator uses the national energy mix of the respective country to calculate the emissions for the train because they run on electricity. When trains run through France, they emit less CO_2 than other countries. This is due to the way France produces its electricity; about 70% is made with nuclear power, and about 22% is made with renewable powers such as hydropower, wind or solar. This results in an energy mix that produces meagre amounts of greenhouse gases. This a big contrast with Germany that produces about 47% of its electricity with fossil fuels such as coal (28,82%), gas (14,68%) and oil (3,85%), resulting in higher CO_2 emissions. (Ritchie et al., 2020)

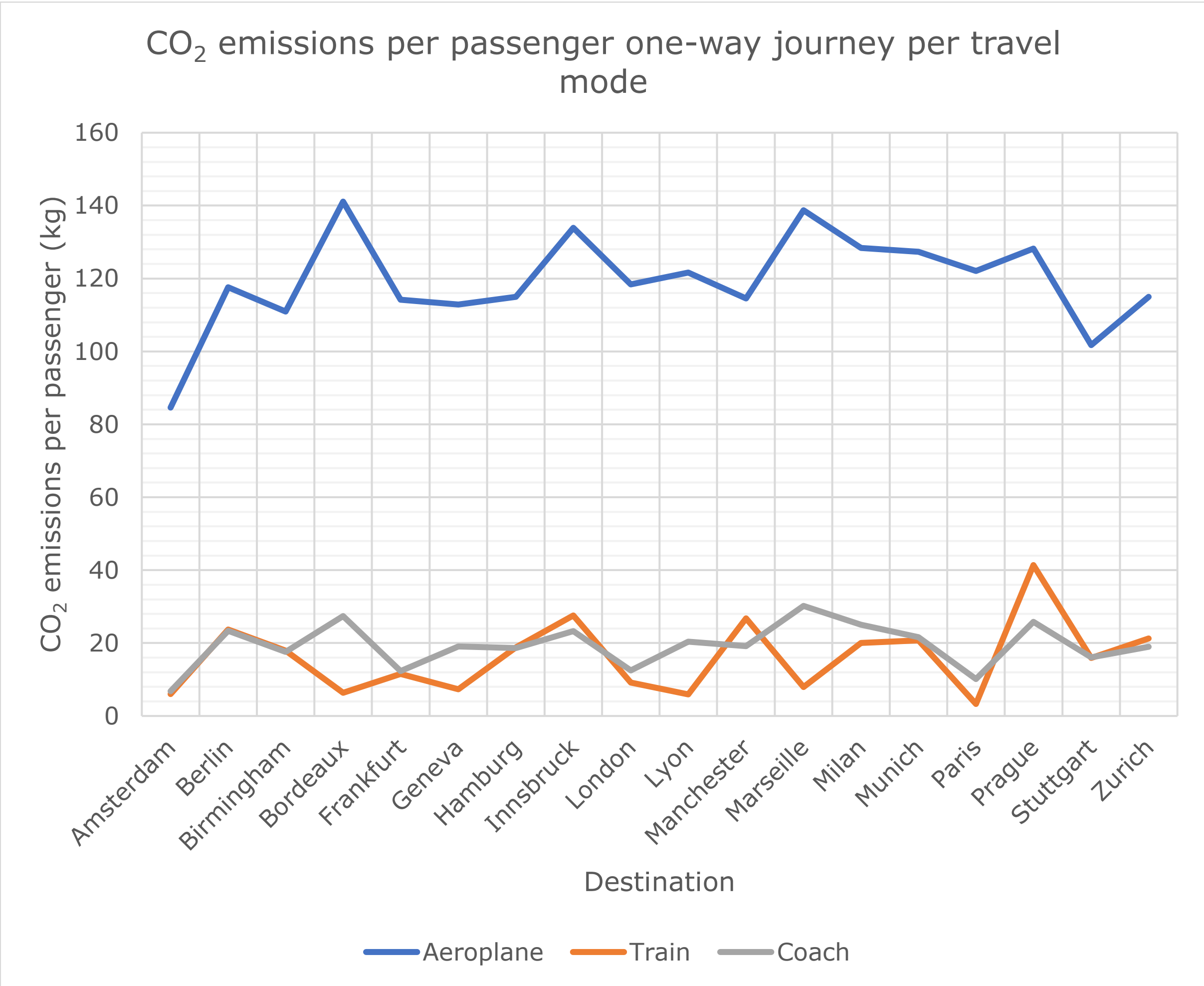


Figure 38: CO_2 emissions per passenger one-way trip per travel mode

5. Missing links

5.1 Comparison between air and rail

The high-speed train has proven itself to be an excellent alternative to flying where the infrastructure exists. Several destinations have a faster city centre to city centre travel time than the aeroplane. The difference in travel time can be seen in the table below.

Table 28: Travel time comparison between aeroplane and train

Destination	Travel time (min) (centre – centre)		Time profit by train (%)	Direct train service
	Aeroplane	Train		
Paris	287	142	50,52	YES
Amsterdam	273	162	40,66	YES
London	303	200	33,99	YES
Frankfurt	263	231	12,17	YES
Lyon	297	263	11,45	YES
Stuttgart	279	299	-7,17	NO
Birmingham	276	302	-9,42	NO
Marseille	335	374	-11,64	YES
Manchester	289	360	-24,57	NO
Bordeaux	304	408	-34,21	YES
Geneva	271	373	-37,64	NO
Munich	294	443	-50,68	NO
Berlin	291	449	-54,30	NO
Hamburg	289	446	-54,33	NO
Zurich	282	495	-75,53	NO
Milan	299	580	-93,98	NO
Prague	306	741	-142,16	NO
Innsbruck	196	568	-189,80	NO

Most destinations with a direct high-speed service have a faster travel time by train. Only Bordeaux, which is located on the 750 km border of the research area, has a travel time that is 34% longer than the aeroplane but is only served during the summer season by plane. Marseille, which is located 845 km from Brussels in a straight line, has a 12% longer travel time by train, proving that when the infrastructure is available, an attractive train offer is possible, even when the distance is further than 750 km.

5.2 Attractive destinations

To select relevant missing links, it is necessary to know what destinations are popular and frequently travelled to. Brussels Airport reports statistics about passenger numbers and destinations annually; the latest data is from 2018 and can be found in Table 29. The destinations in this table are filtered from the original table to only show cities within the 750-kilometre radius.

Table 29: Destinations out of TOP 30 passenger destinations at Brussels Airport

Rank	Destination	Amount of passengers in 2018	Direct train service
5	London	688333	YES
6	Milan	639346	NO
7	Geneva	608377	NO
8	Frankfurt	589109	YES
10	Berlin	497362	NO
15	Munich	414558	NO
19	Prague	329194	NO
22	Zurich	304032	NO
25	Amsterdam	277787	YES
29	Lyon	259606	YES

Source: Brussels Airport Company, 2019

5.2.1 Destinations with existing non-stop service

The first destination on the list is London, which already receives direct high-speed train service with Eurostar, resulting in an attractive service with a ride time of two hours. The second destination with non-stop service is Frankfurt, which is reached after a riding time of about three hours. Amsterdam is the third city on the list of TOP 30 destinations that receive non-stop train service. The city is reached after 1h52 driving time on the Thalys. The last city in the TOP 30 is Lyon, located in southeast France, with about 260 thousand passengers travelling by aeroplane in 2018. The city is reached after a TGV ride of 3h28, making the total city centre to city centre time about 13% faster than by aeroplane.

Table 30: Non-stop train services

Destination	Operator	Distance over rail	Time	Commercial speed
London	Eurostar	369 km	2h01	183 km/h
Frankfurt	Deutsche Bahn	402 km	3h06	130 km/h
Amsterdam	Thalys	213 km	1h52	114 km/h
Lyon	SNCF	731 km	3h28	211 km/h

The commercial speed is the average travel speed of public transport between two points, including any delays at stops. (Fernandez & Valenzuela, 2003)

5.2.2 Destinations without non-stop service

5.2.2.1 Milan

Milan is second in terms of the amount of commercial passenger flight movements and sixth in terms of the number of passengers. It is, therefore, a city with a high potential for a direct train connection. (Brussels Airport Company, 2019)

Currently, a project is underway to connect Lyon and Milan by a new tunnel for passenger and freight traffic through the Alps. The maximum allowed speed in the tunnel will be 220 km/h for passenger trains, resulting in a new travel time of about 2h30 between Lyon and Milan. Hypothetically, when adding 2h30 to the current travel time of 3h28 from Brussels to Lyon would result in a high-speed train service from Brussels to Milan in about 6 hours. The hypothetical service is described in Table 31. (Liaison Europénne Lyon - Turin, 2022)

Table 31: Hypothetical Brussels – Milan passenger service timetable

Station	Riding time	Cumulative time
Brussels South	+00h00	00h00
Charles de Gaulle Airport	+01h19	01h19 – 01h25
Marne la Vallée-Chessy	+00h09	01h34 – 01h39
Lyon Part-Dieu	+01h49	03h28 – 03h34
Turino Porta Susa	+01h47	05h21 – 05h26
Milano Centrale	+00h47	06h13

Table 32: Hypothetical travel time comparison between aeroplane and train to Milan

Destination	Travel time (min) (centre – centre)		Time profit by train (%)	Direct train service
	Aeroplane	Train		
Milan (with new infrastructure)	299	423	-41,47	YES

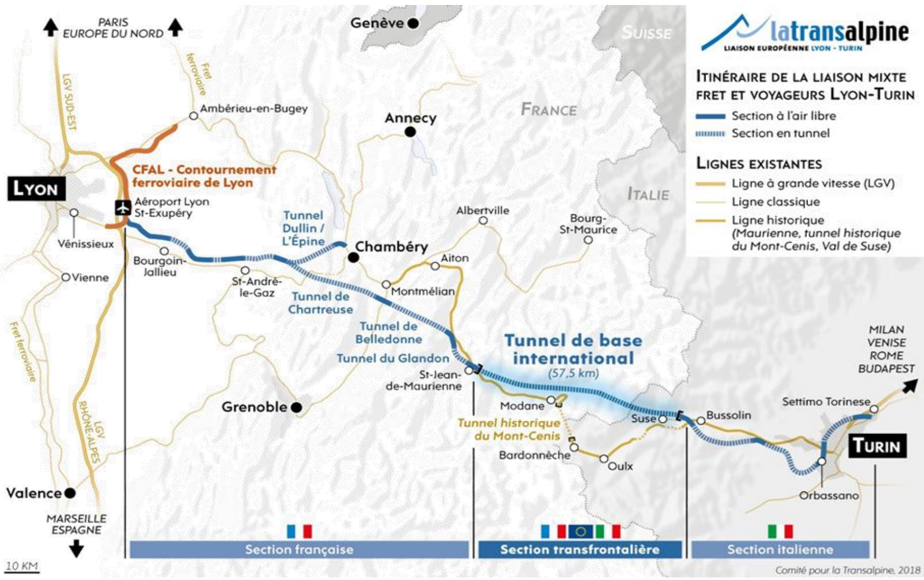


Figure 39: New Lyon – Turin rail corridor (latransalpine, 2018)

5.2.2.2 Geneva

In 2018, Geneva had more than 600 thousand passengers flying to and from Brussels, the seventh busiest route from Brussels Airport in terms of passenger numbers. This is an indicator that the route has the potential for direct high-speed rail service. (Brussels Airport Company, 2019)

Currently, there is an HSR service every two hours from Paris gare de Lyon to Geneva, from 06h15 until 18h17, departing every two hours. The ride has a travel time of three and a half hours, with the most distance covered on the LGV Sud-Est, the HSL that connects Paris with Lyon. The last 132 km is on classic lines, with stops in Bourg-en-Bresse and Bellegarde. From Bourg-en-Bresse to Geneva is the route over rail 97 km, with a travel time of 1h38, resulting in a commercial speed of 59 km/h in the mountain area. When the commercial speed on this part of the route is increased to 150 km/h, the travel time would be decreased by precisely one hour.

Implementing a new service from Brussels to Geneva also benefits Charles de Gaulle Airport, as the service passes and stops at the airport and Disneyland Paris. Table 33 shows an example of how the service could operate in the future.

Table 33: Hypothetical Brussels – Geneva passenger service timetable

Station	**Without** new infrastructure		**With** new infrastructure	
	Riding time	**Cumulative time**	**Riding time**	**Cumulative time**
Brussels South	+00h00	00h00	+00h00	00h00
Charles de Gaulle Airport	+01h19	01h19 – 01h25	+01h19	01h19 – 01h25
Marne la Vallée-Chessy	+00h09	01h34 – 01h39	+00h09	01h34 – 01h39
Bourg-en-Bresse	+01h50	03h29 – 03h32	+01h50	03h29 – 03h32
Bellegarde(Ain)	+01h06	04h38 – 04h40	+00h24	03h56 – 03h58
Genève	+00h30	05h10	+00h12	04h10

Table 34: Hypothetical travel time comparison between aeroplane and train to Geneva

Destination	**Travel time (min) (centre – centre)**		**Time profit by train (%)**	**Direct train service**
	Aeroplane	**Train**		
Geneva	271	352	-29,89	YES
Geneva (with new infrastructure)	271	292	-7,75	YES

5.2.2.3 Berlin

Berlin had about 497 thousand passengers travelling by aeroplane to and from Brussels in 2018, the tenth busiest route at Brussels Airport in terms of passenger numbers. (Brussels Airport Company, 2019)

One transfer between high-speed trains is currently needed when travelling by train to Berlin, with a usual transfer time of 32 – 33 minutes in Cologne, resulting in a total travel time of about 6h45.

When a direct service is implemented, the travel time can be decreased by 30 minutes, or when the commercial speed between Cologne and Hannover is increased from 111 km/h to 180 km/h, the travel time would be reduced by another 61 minutes, resulting in an overall reduction of travel time of 1h30.

Table 35: Hypothetical Brussels – Berlin passenger service timetable

Station	**Without new infrastructure**		**With new infrastructure**	
	Riding time	**Cumulative time**	**Riding time**	**Cumulative time**
Brussels South	+00h00	00h00	+00h00	00h00
Brussels North	+00h06	00h06 – 00h07	+00h06	00h06 – 00h07
Liège-Guillemins	+00h38	00h45 – 00h47	+00h38	00h45 – 00h47
Aachen	+00h24	01h11 – 01h14	+00h24	01h11 – 01h14
Cologne Hbf	+00h37	01h51 – 01h55	+00h37	01h51 – 01h55
Hannover	+02h26	04h21 – 04h24	+01h39	03h34 – 03h37
Berlin Hbf	+01h39	06h03	+01h39	05h16

Table 36: Hypothetical travel time comparison between aeroplane and train to Berlin

Destination	**Travel time (min) (centre – centre)**		**Time profit by train (%)**	**Direct train service**
	Aeroplane	**Train**		
Berlin	291	357	-22,68	YES
Berlin (with new infrastructure)	291	310	-6,53	YES

Figure 40: Missing link Cologne – Hannover (International Union of Railways, own adaptations, 2021)

5.2.2.4 Munich (and Stuttgart)

The route between Munich and Brussels was the 15th busiest route in terms of passenger numbers in 2018. Almost 415 thousand passengers travelled by air between the two cities, resulting in an attractive connection between the two cities. However, as Munich is one of the central hub airports for Lufthansa, many of the passengers might be connecting passengers instead of going to the city of Munich itself.

One transfer between high-speed trains is currently needed when travelling by train to Munich, with a usual transfer time of 23 minutes in Frankfurt, resulting in a total travel time of about 6h45.

When a direct service is implemented, the travel time can be decreased by 20 minutes, or when the commercial speed between Frankfurt and Munich is increased from 125 km/h to 180 km/h, the travel time would be reduced by another 54 minutes, resulting in an overall reduction of travel time of 1h14.

The currently fastest ICE that travels from Frankfurt to Munich travels via Würzburg and Nürnberg, with a route of exactly 400 km. The proposed route for the new infrastructure is via Mannheim and Stuttgart. Between Stuttgart and Ulm is the construction of a new HSL already underway; with a new station, tunnels and a new trajectory next to the highway. Between Frankfurt and Mannheim is the construction of a new HSL in the planning phase. This trajectory from Frankfurt to Munich is 413 km long.

Table 37: Hypothetical Brussels – Munich passenger service timetable

Station	Without new infrastructure		Station	With new infrastructure	
	Riding time	Cumulative time		Riding time	Cumulative time
Brussels South	+00h00	00h00	Brussels South	+00h00	00h00
Brusselt North	+00h06	00h06 – 00h07	Brusselt North	+00h06	00h06 – 00h07
Liège-Guillemins	+00h38	00h45 – 00h47	Liège-Guillemins	+00h38	00h45 – 00h47
Aachen	+00h24	01h11 – 01h14	Aachen	+00h24	01h11 – 01h14
Cologne Hbf	+00h37	01h51 – 01h54	Cologne Hbf	+00h37	01h51 – 01h54
Siegburg/ Bonn	+00h13	02h07 – 02h08	Siegburg/ Bonn	+00h13	02h07 – 02h08
Frankfurt Flughaven	+00h45	02h53 – 02h54	Frankfurt Flughaven	+00h45	02h53 – 02h54
Frankfurt Hbf	+00h13	03h07 – 03h13	Frankfurt Hbf	+00h13	03h07 – 03h13
Aschaffen burg	+00h28	03h41 – 03h42	Mannheim	+00h25	03h38 – 03h40
Würzburg	+00h38	04h20 – 04h23	Stuttgart	+00h34	04h14 – 04h16
Nürnberg	+00h55	05h18 – 05h22	Ulm	+00h26	04h42 – 04h44

München	+01h03	06h25	Augsburg	+00h24	05h08 – 05h10
			München	+00h21	05h31

Table 38: Hypothetical travel time comparison between aeroplane and train to Stuttgart and Munich

Destination	**Travel time (min) (centre – centre)**		**Time profit by train (%)**	**Direct train service**
	Aeroplane	**Train**		
Stuttgart (with new infrastructure)	279	300	-7,53	YES
Munich	294	428	-45,58	YES
Munich (with new infrastructure)	294	374	-27,21	YES

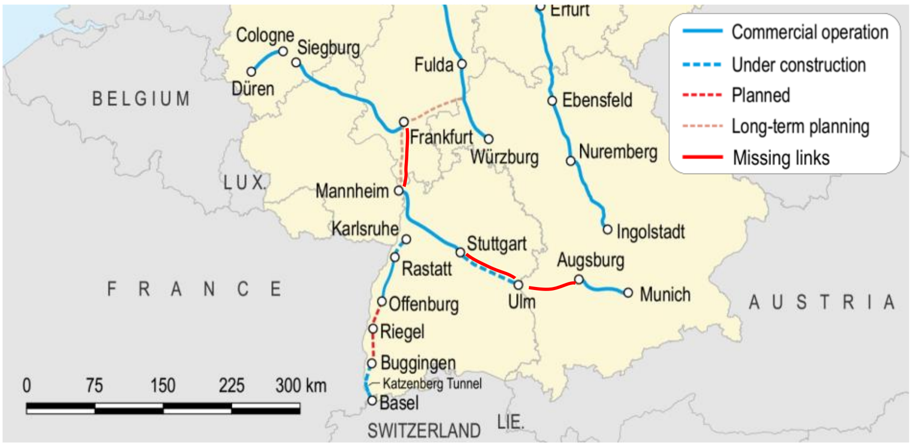


Figure 41: Missing links Frankfurt – Munich (International Union of Railways, own adaptations, 2021)

5.2.2.5 Prague

Prague had about 329 thousand passengers travelling by aeroplane to and from Brussels in 2018, the 19th busiest route at Brussels Airport in terms of passenger numbers. (Brussels Airport Company, 2019)

Germany is the country that lies between Belgium and the Czech Republic. The high-speed rail network in Germany is mainly laid out from one city centre to the next city centre, not as in France, where the HSL passes next to most city centres, except the large cities.

The Czech Republic has plans to implement its own high-speed line network in the future, with lines from Prague to Munich and Dresden (on the line to Berlin), creating large detours when coming from Brussels. The shortest route from Brussels would be an east-going high-speed line from Frankfurt. (Geerts, n.d.)

A more direct route via Nuremberg, as indicated in Figure 42, will significantly reduce the travel time. The route, with new infrastructure, will be 496 km long. When a commercial speed of 180 km/h is reached, the travel time from Frankfurt to Prague would be 2h45, reducing the total travel time by 5h38.

Table 39: Hypothetical Brussels – Prague passenger service timetable

Station	With new infrastructure	
	Riding time	Cumulative time
Brussels South	+00h00	00h00
Brusselt North	+00h06	00h06 – 00h07
Liège-Guillemins	+00h38	00h45 – 00h47
Aachen	+00h24	01h11 – 01h14
Cologne Hbf	+00h37	01h51 – 01h54
Siegburg/Bonn	+00h13	02h07 – 02h08
Frankfurt Flughaven	+00h45	02h53 – 02h54
Frankfurt Hbf	+00h13	03h07 – 03h13
Aschaffenburg	+00h15	03h28 – 03h30
Würzburg	+00h23	03h53 – 03h55
Nürnberg	+00h30	04h25 – 04h27
Domažlice	+00h45	05h12 – 05h14
Plzeň	+00h15	05h29 – 05h31
Praha Hlavní Nádraží	+00h28	05h59

Table 40: Hypothetical travel time comparison between aeroplane and train to Prague

Destination	Travel time (min) (centre – centre)		Time profit by train (%)	Direct train service
	Aeroplane	Train		
Praha	306	741	-58,70	NO
Praha (with new infrastructure)	306	403	-24,07	YES

Figure 42: Missing links Frankfurt – Prague

5.2.2.6 Zurich

The route between Zurich and Brussels was the 22nd busiest route in terms of passenger numbers in 2018. About 304 thousand passengers travelled by air between the two cities, a route with three daily flights in each direction in 2022.

One transfer between high-speed trains is currently needed when travelling by train to Zurich, with a usual transfer time of 35 minutes in Frankfurt, resulting in a total travel time of about 7h35. Or with a transfer between train stations in Paris; arriving from Brussels in Gare du Nord and needing to travel to Gare de Lyon, with a travel time of 6h43.

When a direct service via Paris CdG is implemented, the travel time can be decreased by 66 minutes, or when the commercial speed between Paris and Zurich is increased, by implementing new infrastructure, the travel time would be reduced by another 44 minutes, resulting in an overall reduction of travel time of 1h50.

Table 41: Travel time comparison between two hypothetical routes to Zurich

Station	**Without** new infrastructure		Station	**With** new infrastructure	
	Riding time	**Cumulative time**		**Riding time**	**Cumulative time**
Brussels South	+00h00	00h00	Brussels South	+00h00	00h00
Charles de Gaulle Airport	+01h19	01h19 – 01h25	Charles de Gaulle Airport	+01h19	01h19 – 01h25
Marne la Vallée-Chessy	+00h09	01h34 – 01h39	Marne la Vallée-Chessy	+00h09	01h34 – 01h39
Dijon	+01h36	03h15 – 03h18	Dijon	+01h20	02h59 – 03h02
Mulhouse	+01h02	04h20 – 04h22	Mulhouse	+01h00	04h02 – 04h04
Basel	+00h20	04h42 – 04h44	Basel	+00h20	04h24 – 04h26
Zürich	+00h53	05h37	Zürich	+00h27	04h53

Table 42: Hypothetical travel time comparison between aeroplane and train to Zurich

Destination	Travel time (min) (centre – centre)		Time profit by train (%)	Direct train service
	Aeroplane	**Train**		
Zurich	282	386	-36,88	YES
Zurich (with new infrastructure)	282	342	-21,28	YES

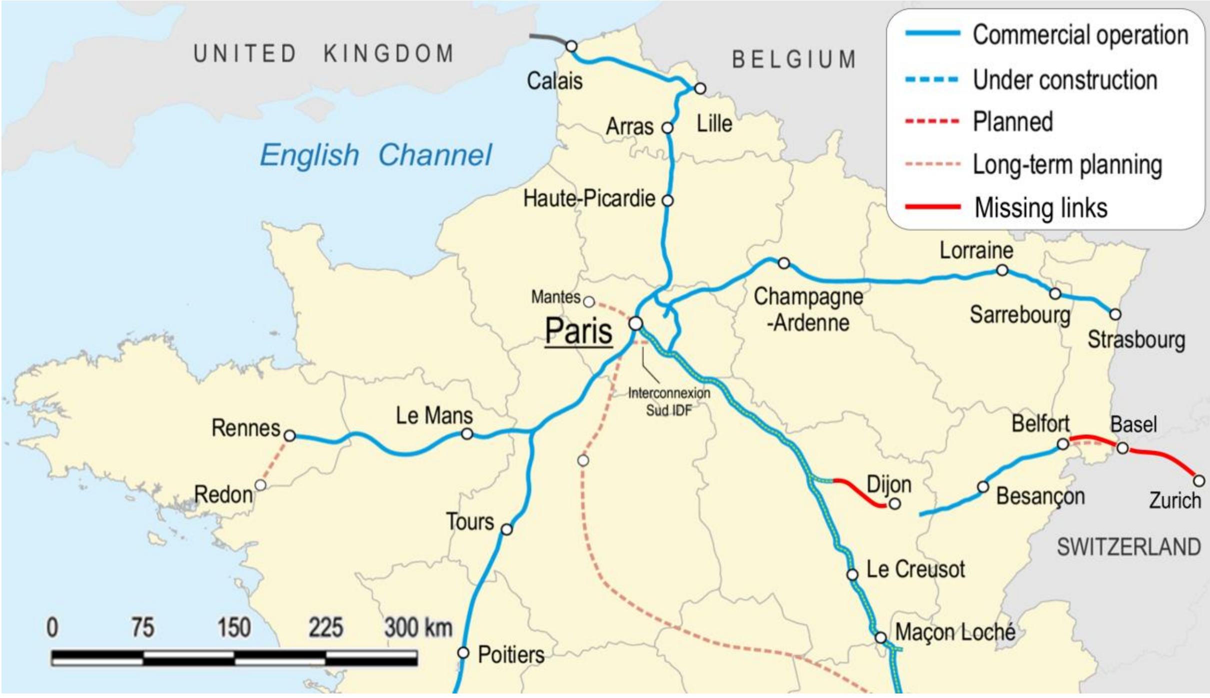


Figure 43: Missing links Paris – Zurich

5.2.3 Discussion

There are still many missing links in the European high-speed rail network. Also, the way that a high-speed rail network is set up can vastly influence the commercial speed of a train service; the French network has much higher commercial speeds in comparison to the German network. Figure 44 shows that the commercial speed between Paris and other French cities is as fast as 277 km/h, while the commercial speed between Frankfurt and Berlin, the fastest reported German commercial speed, is 149 km/h. This is mainly because of the German high-speed lines that do not bypass most cities, so the train needs to slow down often and have more scheduled stops per kilometre than their French counterpart.

When the commercial speed is increased, the train shows itself as a real alternative for the aeroplane on some routes:

- Berlin could be reached with 6,5% more travelling time than the aeroplane
- Geneva could be reached with 7,75% more travelling time than the aeroplane
- Stuttgart could be reached with 7,5% more travelling time than the aeroplane

For the other routes, the plane is always the clear winner in travel time between the city centres. For the most popular air route, from Brussels to Milan, there is still an additional two hours extra travel time by train via the future rail tunnel.

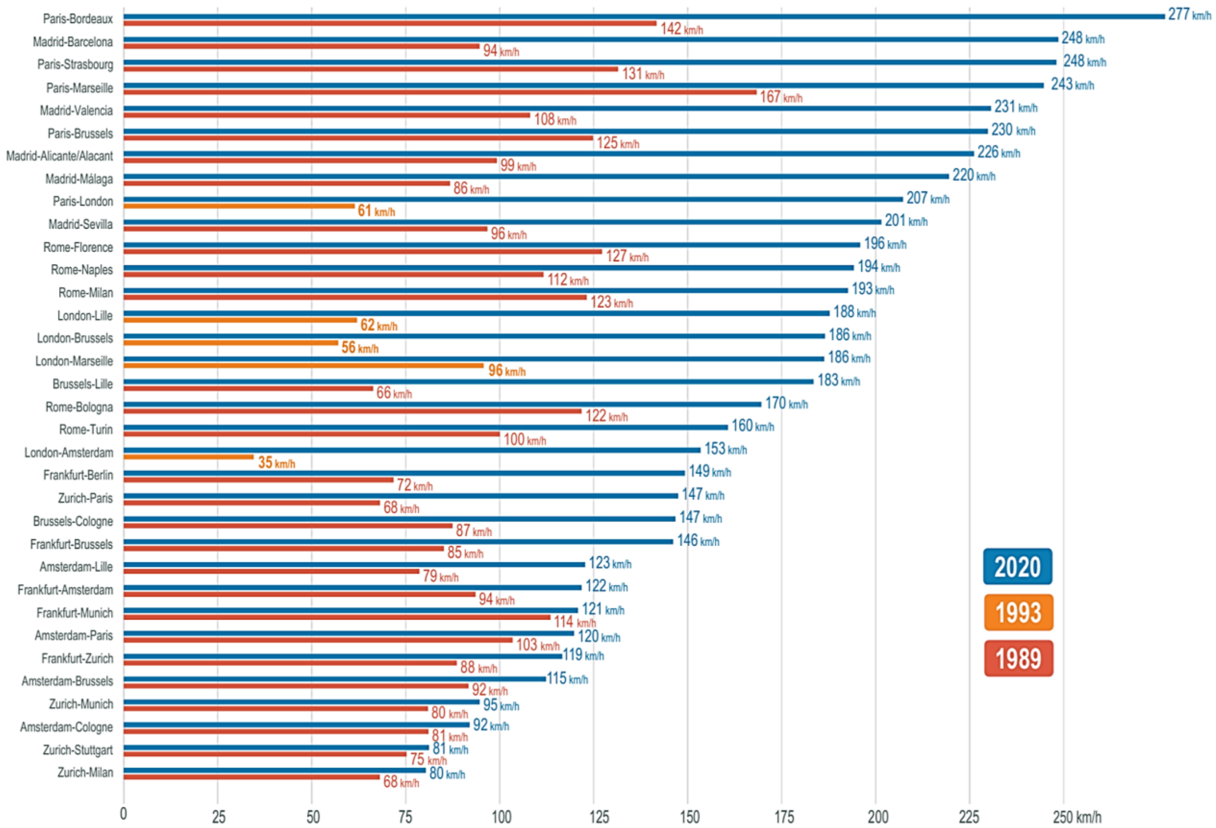


Figure 44: Evolution of the average speed on European high-speed lines (International Union of Railways, 2021)

6. Policies

The transition towards more sustainable transport options can be assisted by implementing certain policies and regulations. Some countries have implemented regulations to make flying more expensive or have completely banished flying on specific routes. In this section are a variety of policies discussed.

Transportation causes external costs; economists propagate taxes to cover these costs: the underlying thought is that, by charging these external costs, one confronts the user of the transportation services with the entire social cost that is caused by using it. (Blauwens et al., 2016)

6.1 Belgium

In April 2022, the Belgian government implemented a new 'flight tax' for all aeroplane passengers taking the plane in Belgium. The tax is only applicable for departing passengers from two years old, as infants travel on the lap of their parents. No difference is made between Belgian, Europan or other airlines; all passengers need to pay the tax. (Willems, 2022)

The amount that is owed depends on the distance of the flight:

- €10: short-haul flights within a 500 km radius around Brussels
- €2: medium-haul flights within the European Economic Area (more than 500 km, but within the European Economic Area (EEA), the United Kingdom and Switzerland)
- €4: long-haul flights

The rate is highest for short-haul flights to encourage passengers to use other modes of transport and to make passengers more aware of the relatively higher external costs in the immediate environment (air pollution, greenhouse gases, noise, congestion) associated with short-haul flights to and from Belgium. When travelling further than 500 km but within the EEA, two euros are owed to the government. This is because the government sees 500 kilometres as the critical distance where the aeroplane becomes the more preferred transport option but still emits more CO_2 than its alternatives, so taxation is also in place. Further flights have a tax of four euros because those flights emit more emissions than short/medium-haul flights. (Willems, 2022)

6.2 The Netherlands

The government of The Netherlands wants to make taxes more sustainable oriented. The government also wants air travellers to take more account of the environment; since 1 January 2021, an air passenger tax applies to all passengers departing from a Dutch airport. The airports charge the airline for each passenger departing from a Dutch airport. The air passenger tax is € 7,845 per person per flight. The tax does not apply to transfer passengers and children under two years of age. (Ministerie van Financiën, n.d.)

The main thought behind the tax is to make aviation contribute to less price difference between flying and the train. International flights were not taxed with excise duty or VAT in the past. Neither the tickets nor the fuel (kerosene). This is in contrast to the car, bus or train. But flying also contributes to global CO_2 emissions. That is why the government has introduced the air passenger tax; to make alternatives such as car, bus or train more attractive. (Ministerie van Financiën, n.d.)

6.3 France

The French parliament implanted a bill banning domestic flights to destinations that can be reached by train within 2,5 hours. This proposal on domestic flights is part of the climate law that aims to reduce CO_2 emissions by 40 per cent by 2030 compared to 1990. (Huisman, 2021)

Originally, the plan to restrict domestic flights came from the French citizens' council for the climate. This group of 150 randomly selected citizens advises the government on measures to combat climate change. But the bill differs from the original plan; the original plan intended to cancel air travel to destinations that can be reached in a maximum of four hours by train. The four-hour travel directive threatened to isolate specific regions, but environmentalists claim that the plan only affects five of the more than one hundred air connections, and it is precisely the most polluting routes that are now excluded from banishment. (Huisman, 2021)

For example, flying from Paris to Nantes, Lyon or Bordeaux will no longer be possible. But busy routes such as Paris-Nice, Paris-Toulouse and Paris-Marseille are spared. So, there are still a lot of emissions from domestic air travel; only 4 per cent of all domestic flights are now being restricted. (Huisman, 2021)

6.4 Europe

Currently, several European countries have implemented their own respective airport taxes, ticket taxes and VAT. Every country has its own rules and regulations regarding the difference in pricing strategy. (Ricardo Energy & Environment, 2021)

- Austria
  - €30 for flights <350 km
  - €12 for all other flights
  - 13% VAT on domestic flights
- Belgium
  - €10 for flights <500 km
  - €2 for all other flights within the European Economic Area (EEA)
  - €4 for all other flights

- France
    - Civil aviation tax:
        - €4,63 for flights within the EEA, incl. domestic flights
        - €8,32 for all other flights
    - Air passenger solidarity tax:
        - Economy passengers:
            - €2,63 to EEA, incl. domestic
            - €7,51 for all other flights
        - Premium passengers:
            - €20,27 to EEA, incl. domestic
            - €63,07 for all other flights
    - 10% VAT on domestic aviation
    - Airport tax:
        - €10,80 for class 1 airports (e.g. Paris CdG)
        - €3,5 - €9,5 for class 2 airports (e.g. Marseille)
        - Up to €14 for other airports
- Germany
    - €12,90 for short-haul flights
    - €32,67 for flights <6000 km
    - €58,82 for flights >6000 km
    - 19% VAT on domestic aviation
- Italy
    - City council tax:
        - €7,07 on all flights
    - Luxury tax:
        - €10 for flights <100 km
        - €100 for flights <1500 km on executive air charter flights
- Netherlands
    - €7,85 on all flights
    - 21% VAT on domestic flights
- Portugal
    - €2 for all flights (except to/from the islands of Portugal)
    - 6% VAT on domestic flights on the mainland
- Spain
    - 10% VAT on domestic flights, except to/from the Canary Islands, Ceuta and Melilla
- Sweden
    - 62 SEK (± €5,9) to EU, incl. domestic
    - 260 SEK (± €24,75) for all other flights
    - 6% VAT
- Switzerland
    - 30 – 120 CHF (± €29 – €117) on all flights, incl. domestic
    - 500 CHF (± €487) for private flights, incl. domestic
    - 8% VAT on domestic flights
- United Kingdom

    - Economy passengers:
        - £13 (± €15) on flights <3219 km
        - £80 (± €94) on flights >3219 km
    - Premium passengers:
        - £26 (± €31) on flights <3219 km
        - £176 (± €208) on flights >3219 km
    - No VAT on domestic aviation
- Norway
    - 76,50 NOK (± €7,4) for all EU flights
    - 204 NOK (± €20) for all other flights

For the competition between air transport, rail transport and road transport to be affected by uneven taxation levels, three conditions need to be met (Ricardo Energy & Environment, 2021):

1. There needs to be a viable alternative to air travel, typically by road or rail.
2. On the routes that are subject to competition, the difference in tax regimes affects the relative cost of different modes of transport, namely, giving a cost advantage to the sector that is not subject to taxes on their environmental externalities – especially when those would represent a high proportion of total variable costs.
3. Higher taxes in the sectors for which environmental fiscal regimes are in place translate into higher prices for consumers, potentially favouring the options with favourable tax regimes.

For passenger transport, the first condition on the availability of transport alternatives will typically be met for a limited range of distances and travel times, for which road and rail can compete with air transport. High-speed rail is widely acknowledged as a (partial) substitute to air transport on short-haul routes, this is, distances up to 800 km and total journey time under around 200 minutes (Faber & O'Leary, 2018).

6.5 Need for action at the EU level

There are different levels of aviation tax between EU member states with different levels of ticket tax and VAT (only on domestic flights). In EU member states, VAT or other domestic aviation taxes are the most common and exist in 17 member states. Without an EU harmonization of aviation taxes, Member States have followed the traditional ICAO position to exempt kerosene from any tax, except for some non-scheduled/non-fee flights. This choice is also set out in their bilateral air services agreements, which have traditionally exempted kerosene from taxes. The cross-border nature of the externalities related to the aviation sector and its impact on climate change justifies the need and relevance of action at the EU level. (Ricardo Energy & Environment, 2021)

One of the measures could be the proposal to introduce a harmonized minimum tax on aviation fuels. A minimum degree of coordination is warranted in view of the practical obstacles preventing Member States from just introducing energy taxes on the supply of aviation fuel, including the practice of refuelling by airlines and the risks associated with the distorted competition between EU airports and carriers operating there. A proposal for a harmonized ticket tax would most likely also comply with the principles of proportionality and subsidiarity, but possibly on slightly different grounds. EU action would have a clear added value compared to action at the Member State level, as domestic action can lead to very different levels of air ticket taxes (e.g. per ticket class, with regard to transit and transfer journeys, etc.). Harmonization at EU level would help achieve a minimum degree of coordination in line with the overall EU decarbonisation objectives and minimize the risks of hub and destination switching, due to very different levels of taxation in the EU. (Ricardo Energy & Environment, 2021)

6.6 Discussion

Currently, there is no legislation in place on a European or worldwide level to levy taxes on aviation. Each country has its own respective rules or no rules at all. One country, France, took the lead in banning flights on specific routes where the train is an alternative, while other countries like Belgium just introduced flying taxes in 2022 in an effort to boost green transport modes for trips to destinations that are less than 500 kilometres from Brussels. Towards the future, policies at a European level are suggested, as this is the best way to charge air and invest the money in more green cross-border transportation modes.

7. Recommendations

Shifting from air to rail and coach is desirable on several investigated routes. To realise these modal shifts, the following recommendations are made to put forward to relevant stakeholders such as governments and transportation companies and operators:

1. **Exploring the costs and benefits of missing links in the high-speed rail network to better connect Europe by rail and reduce travel time**
   This measure suggests having a look at the entire European high-speed rail network. Currently, there are a lot of gaps, resulting in high travel times and low commercial speeds. When these missing links were eliminated, the high-speed train would become a much more attractive way of transport over the European continent. Research should be done to drastically improve the connectivity of the most prominent origin-destinations in Europe.

2. **Enhancing the Air + Rail services**
   a. **By Implementation of more early/late train services connecting Brussels to the main Hub airports in the neighbouring countries**
   There is a mismatch between the timetables of the current train services and the international long-haul flights arriving and departing at Amsterdam, Charles de Gaulle, Frankfurt and London Heathrow. If an air-to-rail shift were to be achieved, certainly for the short feeder flights, more rail services would be needed to connect early and late departing and arriving long-haul flights. If the current rail timetable is maintained, a complete modal shift will not be possible, and feeder flights will continue to be needed in the early morning and late evening. This will have a negative effect on the environmental benefits of the air-to-rail shift. Thus, additional services are required to facilitate this connectivity between the two modes at all times of the day.

   b. **Stimulate relations between airlines and HSR companies**
   To encourage air + rail co-operations, governments could provide subsidies to cover start-up costs by means of increasing taxes on short-haul (feeder) flights, especially when an alternative is available. These incentives lower the barrier to entering into a partnership between airlines and railway companies and thus achieve a modal shift from air to rail, certainly on these feeder routes that are relatively short.

3. **Introducing policies to punish or banish very short flights where alternatives are possible**
   Currently, there are a lot of very short (feeder) flights to and from Brussels Airport. The Belgian government introduced a 'flying tax', but the tax excludes transit passengers. A new form of taxation needs to be implemented on a European level, taking transit passengers and feeder flights into account. Or altogether banishing flights, where alternatives are possible, as the French regulation.

4. **Introducing policies to improve coach travelling**
   Currently, travelling by coach is not incentivised in many European countries; VAT needs to be paid to every country the bus travels through. In some countries, this is free, like Luxembourg, but in others, this is 10%, as in France, or even as high as 25%, as in Croatia. A unified taxation system is needed in the EU to incentivise the use of this transportation mode and make travelling accessible, preferably by having a low tax on this relatively green transport mode. (Schroten et al., 2019)

	Standard VAT rate applied in the country (%)	VAT rate on bus tickets (%)	VAT rate on coach tickets (%) Domestic trips	VAT rate on coach tickets (%) Domestic[18] part of international trips
Austria	20%	10%	10%	10%
Belgium	21%	6%	6%	6%
Bulgaria	20%	20%	20%	20%
Croatia	25%	25%	25%	25%
Cyprus	19%	9%	9%	19%
Czech Republic	21%	15%	15%	0%
Denmark	25%	0%	0%	0%
Estonia	20%	20%	20%	0%
Finland	24%	10%	10%	0%
France	20%	10%	10%	10%
Germany	19%	7%[a]	19%[a]	19% [a]
Greece	24%	24%	24%	24%
Hungary	27%	27%	27%	0%
Ireland	23%	0%	0%	0%
Italy	22%	10%	10%	0%
Latvia	21%	12%	12%	0%
Lithuania	21%	9%	9%	0%
Luxembourg	17%	3%	3%	0%
Malta	18%	0%	0%	0%
Netherlands	21%	6%	6%	6%
Poland	23%	8%	8%	8%
Portugal	23%	0%	0%	0%
Romania	20%	20%	20%	0%
Slovakia	20%	20%	20%	0%
Slovenia	22%	10%	10%	10%
Spain	21%	10%	10%	10%
Sweden	25%	6%	6%	0%
United Kingdom	20%	0%	0%	0%
Norway	25%	8%	8%	0%
Switzerland	8%	8%	8%	8%

Figure 45: VAT rates on coach tickets (Schroten et al., 2019)

8. Conclusion

The main objective of the thesis is an evaluation of the offer of different transportation modes to destinations that are served to and from Brussels by airline services and identifying possible missing links in the alternative transportation networks that could make the alternatives more attractive.

The main findings of this thesis are that several destinations have transportation options, train and coach services, that are faster and have cheaper ticket prices than the aeroplane. Also, the train and coach have significantly less CO_2 emissions, resulting in an overall journey with less monetary and indirect costs. By coach, Amsterdam can be reached faster than by aeroplane, for Paris is the travel time difference 14 minutes. But for both destinations, the train is the faster travel option between the city centres. As seen in Figure 46, the train is also faster to London, Frankfurt and Lyon. To Stuttgart, Birmingham, and Marseille is the difference in travel time less than one hour more by train than by aeroplane.

The aeroplane, train and bus all have their own characteristics; the top speed, commercial speed, costs, pollution, etc. Each route has its own best way of travelling with the best suiting transportation mode. Destinations served by direct, non-stop, high-speed train service has the train as the best option; all destinations, except Bordeaux and Marseille, have faster city centre travel times by train than by aeroplane. Also, the emissions are much lower; France has an electricity mix with almost no CO_2 output, resulting in train journeys that emit nearly no greenhouse gases.

All three modes have known a rich development history; Sabena used to be the Belgian flag carrier until it went bankrupt in 2001. In the late nineties, the first low-cost carriers were entering the scene and taking parts that belonged to Sabena. Out of Sabena followed a new, more modest carrier, SN Brussels Airlines. Later, the new carrier merged with a low-cost airline to form Brussels Airlines as we know it today. Brussels Airlines is now part of the Lufthansa Group. The world of coaches had a different history; the first big coach network was formed by the national train companies. Later, that network evolved into a private company, Eurolines, with long-distance bus routes all over Europe. In the last decade, a new player, Flixbus, entered the scene. Flixbus merged several times and finally took over Eurolines and became the biggest operator of regular coach services in Europe. The history of high-speed rail is in Japan, where the first operational HST entered service in 1964. Europe followed, with the first service between Paris and Lyon in 1981. Belgium launched the STAR 21 project with the construction of four high-speed lines that connect the country to France, Germany and The Netherlands.

Towards the future, most developments are seen in the construction of new railway lines; new high-speed lines and passages through the Alps, ensuring faster travel speeds. For coaches, new driving technologies are being implemented; electric and hydrogen buses are being implemented to make zero-emission travel possible.

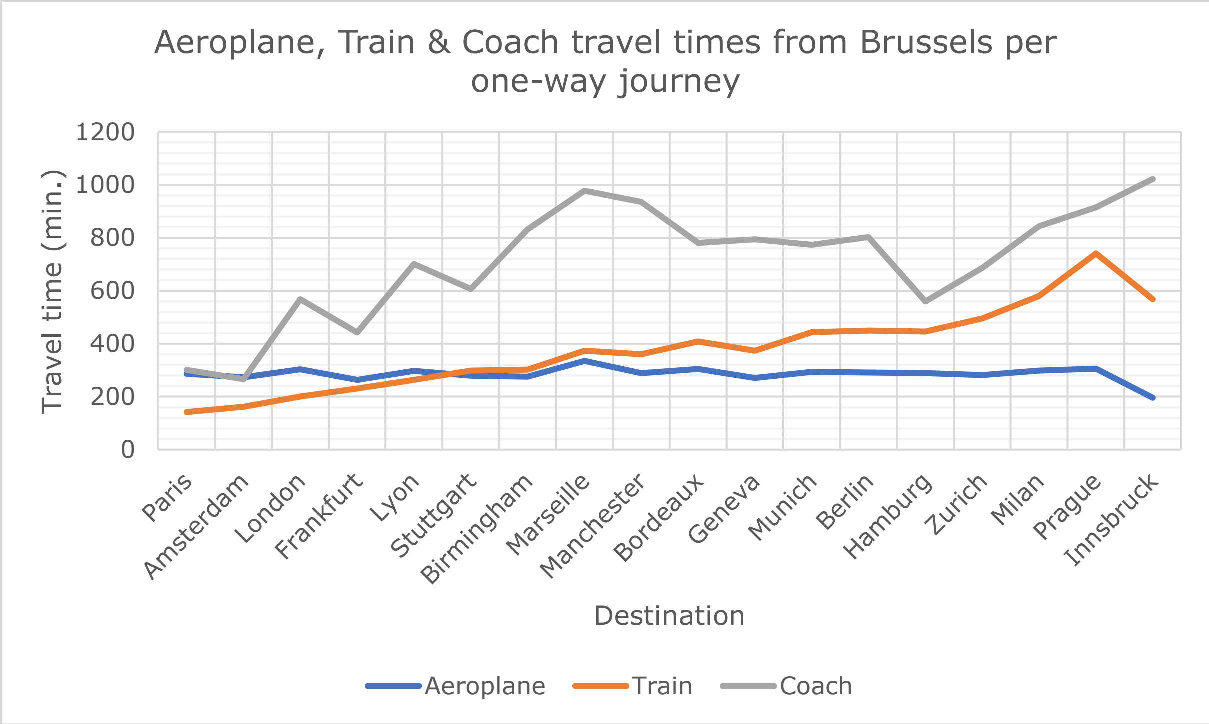


Figure 46: Aeroplane, Train & Coach travel times from Brussels per one-way journey

The high-speed rail network that is relevant for popular destinations from Brussels has the most missing links located in Germany and France. Until Frankfurt and Paris, there is a full high-speed infrastructure. But afterwards, do the trains need to switch to conventional rail, which dramatically increases travel times and decreases commercial speeds.

Currently, many European countries have implemented their own policies regarding the usage of the aeroplane for short and long distances. Most countries apply VAT on domestic tickets, and the countries that have taken extra measures have additional taxes on those short flights. Towards the future, policies at a European level are suggested, as this is the best way to charge air and invest the money in more green cross-border transportation modes.

The main conclusion of this thesis is that the train or bus can be a good alternative for the aeroplane, depending on the route and distance covered. Amsterdam, Frankfurt, London and Paris are destinations where the train is an excellent alternative to the city centre and where there is great potential to substitute feeder flights with air + rail service. The conditions for each destination are different, so future research is needed to ensure and facilitate this modal shift. Research is recommended in the following fields:

- Research in the most attractive destinations to/from Brussels
- Research in the development and construction of missing links
- Research in the implementation of policies to boost more sustainable transport options

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