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Smart and Affordable Rail Services in the EU: a socio-economic and environmental study for High-Speed in 2030 and 2050

Technical report 1. 23/01-2023

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Executive summary

High speed rail has proved to be a low-emission, productivity-enhancing, and energy-efficient mode of transport. These attributes make it a suitable tool to overcome the long-term challenges to the European Union (EU) such as climate change. In relation to this, the European Commission (EC) has set an ambitious target of doubling HSR traffic by 2030 and tripling it by 2050. To achieve this target, there is a need for extending the current HSR network to both central and eastern Europe while stimulating demand through new technologies and sound policies.

This report presents a market assessment of two future HSR networks and the effects of introducing new technologies and adopting new policies. To simulate this, three scenarios were specified: (1) a baseline or business-as-usual, where the current HSR network is not expanded, (2), a conservative and certain 2030 scenario of all HSR lines under construction scheduled to be completed by 2030 and (3) a comprehensive 2050 scenario connecting all major European cities. The effects of new technologies and policies are introduced through ten demand "shocks" based on previous estimations of their effects on traffic. Based on these scenarios, the study estimates the future demand for HSR and long-distance passenger transport.

The results point towards restricted growth demand in case of low investment in the High-Speed Rail (HSR) network, a substantial increase in passengers following the completion of the currently planned HSR lines, and an exponentially larger demand under a scenario where all major urban areas in the EU are connected. The shocks indicate that the opening up to competition in the HSR market, an extended HSR network and investments in innovative railway technologies have a considerable positive effect on demand. Overall, a comprehensive HSR network and a full adoption of policies and deployment of technologies will result in HSR becoming the dominant mode with a 54% modal share in 2070.

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List of Abbreviations

CBA	Cost-Benefit analysis
GDP	Gross Domestic Product
EU	European Union
EC	European Commission
ERTMS	European Rail Traffic Management System
FUA	Functional Urban Area
HSR	High-speed rail
km	Kilometre
M	Million
MS	Member States
pkm	Passenger Kilometre
TEN-T	Trans-European Transport Network
UIC	International Union of Railways

1. Introduction

Recent decades have seen trains taking an ever more prominent role in the European Union's (EU) transport policy, with the end goal being shifting demand for transport from aviation and road transport to rail where possible. For medium-to-long distance passenger transport, high-speed rail has the least negative externalities in terms of environmental footprint as it partially replaces other modes of transport such as airplanes and cars. According to the literature, High-Speed Rail (HSR) offers lower cost and environmental footprint as compared to air and road transport, while supplying fast transport, connecting citizens and cities, and stimulating regional development[1]. The benefits of HSR compared to competing modes of transport have already been showcased in certain member states, where HSR is outcompeting aviation, almost doubling the share of HSR while halving the share of aviation[2]. Moreover, the construction of HSR lines has been estimated to generate € 250 million per year in regional production increases due to better accessibility[3]. Lastly, HSR has the potential of spurring additional demand for regional and freight rail[4].

The European Commission (EC) has set out detailed targets for the future HSR traffic in Europe in its Sustainable and Smart Mobility Strategy. The EC aims to double HSR traffic by 2030 and triple it by 2050[5]. The increased HSR traffic can be fostered through both constructing new tracks and upgrading the current network by, for example, deploying European Rail Traffic Management System (ERTMS) on the network.

This study presents the possible net benefits of connecting the main European regions and majority of European citizens through an expansion of the European HSR network. The report is made up of two main sections: a market assessment of the current and future HSR network in Europe (Technical Report 1), and an impact assessment that estimates the impact of such a HSR network to the European society (Technical Report 2).

This report describes the methodological approach and the results of the market assessment. It maps out a possible HSR network connecting the major population centres in Europe and estimates analytically the effects of such a network on the demand for passenger transport in Europe. The report and its results provide the base for the content of the Technical Report 2, which in turn estimates the impact of the proposed HSR networks. The main concepts of this report are included in the Executive Report and presentation.

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[1] United Nations Economic Commission for Europe (2021). Trans-European Railway High-Speed Master Plan Study: Phase 2. Retrieved from 2017852_E_web_light+c1.pdf (unece.org).
[2] Desmarism C. (2016). High Speed Rail competition in Italy: A major railway reform for a "win-win game"?. *ITF Discussion Paper*, 2016-11.
[3] United Nations Economic Commission for Europe (2017). Trans-European Railway High-Speed Master Plan Study: Phase 1. Retrieved from TER_High-Speed_Master_Plan_Study.pdf (unece.org)
[4] Idem p.15.
[5] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (2020). *Sustainable and Smart Mobility Strategy – putting European transport on track for the future* {SWD(2020) 331 final}. Retrieved from EUR-Lex - 52020DC0789 - EN - EUR-Lex (europa.eu)

The report addresses the developments of HSR in Europe and in the world in section 2 with an account of the evolution of the HSR network and traffic in the EU and the rest of the world. Section 3 presents the methodological approach of the market assessment including the future HSR network growth scenarios as proposed by the study. In Section 4 the findings of the market assessment and the future demand for HSR are presented as per each scenario. Lastly, in section 5 the results are discussed and, from them, conclusions drawn on how the demand forecast will feed into the impact assessment.

2. The evolution of HSR in Europe

This section presents the development of HSR in Europe and the evolution of the European HSR network as well as the global HSR developments.

2.1 The European HSR network and market

Spurred on by the introduction of the Shinkansen in Japan in 1964, the first European HSR lines were constructed in the late 70s in the aftermath of the Oil Crisis[6][7]. The HSR network began growing considerably in the 90s, when the total European HSR network length saw a ten-fold increase compared to a decade earlier. This increase was mainly spurred on by the efforts made by Italy, Spain, and France[8]. The result of the investments in HSR infrastructure gave rise to a dense HSR network across Western Europe with the lion's share of the network located in Italy, Spain, France and Germany (as shown in Fig. 1).

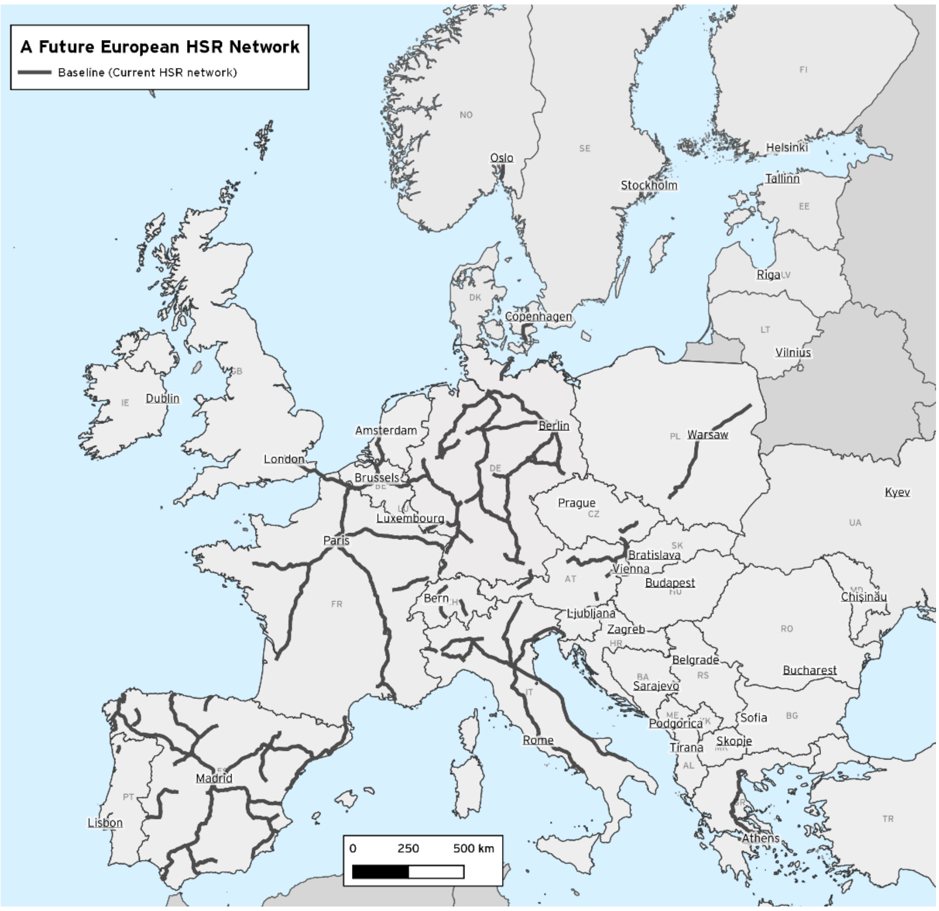

Figure 1: HSR network in Europe (2022)[9]

Despite the monumental level of engineering achieved across the continent, HSR in Europe remains incomplete in two main areas: Central-Eastern European

[6] European Court of Auditors (2018). *A European high-speed rail network: not a reality but an ineffective patchwork*. Retrieved from https://data.europa.eu/doi/10.2865/105814

[7] Dubois, S. (2010). TGV : un quart de siècle de bouleversements géoéconomiques et géopolitiques. *Géoéconomie*, 52, 89-104. https://doi.org/10.3917/geoec.052.0089

[8] European Commission, Directorate-General for Mobility and Transport (2020). *EU transport in figures: statistical pocketbook 2020*, Publications Office of the European Union. Retrieved from https://data.europa.eu/doi/10.2832/491038

[9] As per the maps of the TEN-T Revision Council general approach: Trans-European transport network: Council agreement paves way for greener, smarter and more resilient transport in Europe (europa.eu)

networks and transnational connections. There is currently almost no HSR infrastructure in the Member States (MS) that joined the EU in the 2004 enlargement. In that regard, there are large HSR projects currently in development in most of the current EU MSs. The Baltic states are constructing the Rail Baltica project. It aims to connect the capitals of the three countries with an 870 km (HSR ready) rail line, which will extend further to Warsaw in Poland[10]. The project is estimated to generate €16.2 billion in net socio-economic benefits[11]. A HSR network is in the planning phase in Czechia, which aims at connecting the major Czech cities with each other and the neighbouring countries[12].

At the same time, however, the HSR network counts only a handful of direct international routes. This aspect of the European rail network renders, in the current state, competition with other modes of transport, especially aviation, difficult. Nevertheless, where present, international routes have proven to be efficient in competing with aviation[13] suggesting that investing in more international connections is profitable.

The European HSR market has witnessed substantial regulatory developments in terms of harmonisation during the last decade. The regulatory requirements to both split up the infrastructure manager and operator and de jure allowing for competition on the network have spurred changes in the market structure. It has allowed for new entrants to compete with incumbents in Italy and Spain, which in some cases has led to higher and cheaper supply, resulting in larger demand for public transport[14]. Nevertheless, the European HSR market is still mainly operated by national companies, with some starting new ventures in neighbouring countries (such as SNCF with OuiGo in Spain) or cooperating across borders (Thalys).

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[10] Rail Baltica (2022). *Rail Baltica – Project of the Century*. Retrieved from Rail Baltica Official Website | Rail Baltica

[11] EY (2017). Rail Baltica Global Project Cost-Benefit Analysis. Rail Baltica Global Cost-Benefit Analysis: The Project is Financially and Economically Viable | Rail Baltica

[12] Vláda ČR (2017). *Vláda schválila více peněz pro vědu i školství a plán rozvoje vysokorychlostní železnice v ČR*. Retrieved from Vláda schválila více peněz pro vědu i školství a plán rozvoje vysokorychlostní železnice v ČR | Vláda ČR (vlada.cz)

[13] Doomernik, J. (2016). Competitive position of high-speed rail in Western Europe. *World Conference on Transport Research - WCTR 2016 Shanghai. 10-15 July 2016*. Retrieved from (PDF) Competitive position of high-speed rail in Western Europe (researchgate.net)

[14] Desmaris, C. & Croccolo, F. (2018). La compétition « sur le marché » de la grande vitesse ferroviaire en Italie : une innovation de marché majeure pour un jeu « gagnant-gagnant » ?. *Les Cahiers scientifiques du transport*, AFITL, 74, pp. 29-59. Retrieved from https://halshs.archives-ouvertes.fr/halshs-03116203

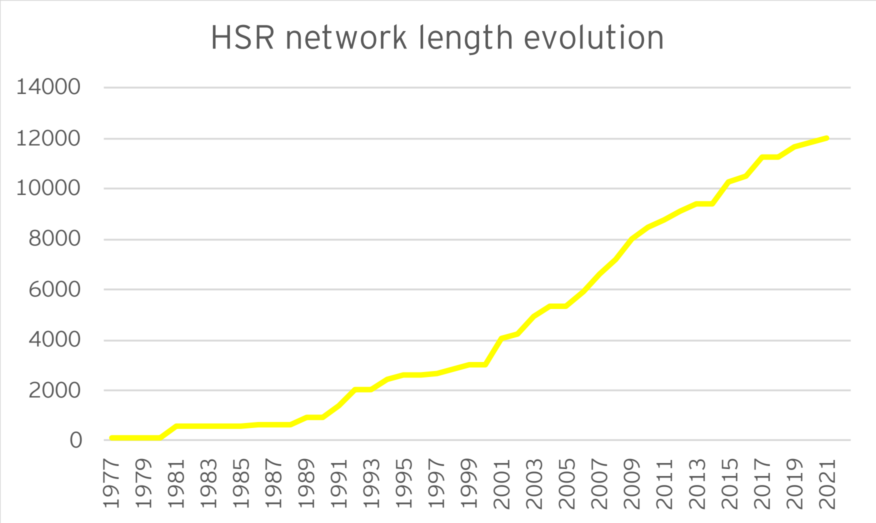


Figure 2: Historical evolution in HSR network length (UIC data)[15]

2.3 HSR in the rest of the world

While the European HSR network remains one of the most developed and dense in the world, other countries have developed extensive HSR networks, notably Japan and China. Japan has historically been at the forefront of HSR developments with their Shinkansen trains covering a HSR network of 3081 km in 2020[16] since the introduction of the service in 1964. Consequently, HSR effectively services the most of Japan allowing passengers to choose between modes. This is most evident on the Tokyo-Osaka line, which is one of the most utilised in the world with 400.000 passengers per day[17]. Following the Japanese example other Asian countries such as South Korea have invested in expanding the HSR network to service the major cities, effectively becoming the densest network in the world. Most notably is the case of China, which has made substantial investments in HSR and within a few decades expanded its network to be, by far, the largest in the world. Currently, the network length is 40.474 km and carried an estimated 1.5 billion passengers in 2020[18]. Notably, 37.900 km has been constructed since 2008 and an additional 30.000 km is expected to be constructed until 2035[19].

[15] It should be noted that the TEN-T Network on completed HSR lines is longer than the UIC's. This is due to different definitions. This figure has been modelled with UIC data as they have historical data on the HSR network's evolution.
[16] International Union of Railways (2022). *Atlas High-Speed Rail 2022*. Retrieved from [High-Speed Databases and Atlas | UIC - International union of railways]
[17] United Nations Economic Commission for Europe (2021). Trans-European Railway High-Speed Master Plan Study: Phase 2. Retrieved from [2017852_E_web_light+c1.pdf (unece.org)]
[18] International Union of Railways (2022). *Atlas High-Speed Rail 2022*. Retrieved from [High-Speed Databases and Atlas | UIC - International union of railways]
[19] [How China's high-speed rail network got built so fast | CNN Travel]

3. Methodology

This section describes the approach of the market assessment and the related scenarios and assumptions. Unless specified otherwise, all traffic demand figures are in passenger kilometre (pkm)[20]. It will firstly present the scenarios developed under this study and the respective network. Hereafter, it will describe the methodological approach of the demand "shock" model which serves as the main component of the market assessment.

The study covers the EU Member States (MS) where there currently are railways in operation and, in addition, Switzerland, Norway and the United Kingdom. The inclusion of Switzerland and Norway is due to their geographical location and connections to the Trans-European Transport Network (TEN-T). The United Kingdom was included with their current and planned high-speed lines, HS1 and HS2, directly connected to the EU via the Eurotunnel. Countries with candidate or potential candidate status for accessing the EU have been added as an additional scenario[21]. This was done to take into account their possible future accession to the EU given the long timeframe of the study.

3.1 Scenarios

Four main scenarios have been specified for the study: a Baseline scenario, a 2030 scenario, a 2050 scenario and a 2050 EU accession candidate countries scenario. The scenarios are presented briefly in Table 1 below and in greater detail in their respective sections (3.1.1-4), while the shocks applied per scenario are detailed further below.

Scenario	Description
Baseline (15.200 km)[22]	**Network comprised of lines in operation as per the revised TEN-T Maps** ▶ Includes dedicated HSR lines (250 km/h and above) and upgraded lines (200-250 km/h). ▶ There will be no infrastructure expansion for HSR or conventional rail. ▶ Infrastructure of other modes expected to increase in accordance with their forecasted demand increase.
2030 scenario (20.500 km)	**Network comprised of lines in operation and lines to be completed as part of the Core TEN-T Network (by 2030)** ▶ Includes the baseline network and all lines with a scheduled finish date by 2030. Thus, the network in this scenario will be in operation by 2030. ▶ Includes dedicated HSR lines (250 km/h and above) and upgraded lines (200-250 km/h). ▶ Infrastructure expansion for other modes in accordance to demand increase.
2050 scenario (49.400 km)	**Network comprised of lines connecting all Functional Urban Areas (FUAs) (above 250 k inhabitants) in Europe, in addition to the HSR lines forming part of the Extended**

[20] A passenger kilometre is the movement of one passenger over one kilometre.
[21] European Commission (2022). *Candidate Countries and Potential Candidates*. Retrieved from Candidate Countries - Enlargement - Environment - European Commission (europa.eu)
[22] The length of the networks per scenario were measured using the Geographic Information System software, QGIS. Some differences with other sources may appear.

Scenario	Description
	Core TEN-T Network (2040) and the Comprehensive Ten-T Network (2050) ▶ FUAs are defined as a city core and its commuting zone[23]. ▶ FUAs can either be departure and destination cities or stops along the line. FUAs are considered connected if a HSR line passes within a 20km radius of the FUA. ▶ Lines will only be constructed as dedicated HSR lines with speeds of 250 km/h or above. ▶ Infrastructure expansion for other modes in accordance to demand increase. ▶ Includes planned lines not in the TEN-T Network such as HS2 in the UK. ▶ The use rate of infrastructure for other modes is conserved, thus infrastructure expansion for these modes will be at the same rate as demand increase. Which means that a slower increase of demand for these modes (compared to other scenarios) results into less infrastructure construction, thus lower economic and socio-economic costs.
2050 EU accession candidate scenario (4300 km)	**Network comprised of a network connecting the main cities of the EU accession candidate countries** ▶ Lines will only be constructed as dedicated HSR lines with speeds of 250 km/h or above. ▶ Lines follow the current railway lines as per the TEN-T Interactive Map. ▶ Comprised only of the EU accession candidate countries. ▶ Assumed completed by 2050.

Table 1: The four scenarios and their descriptions

The three scenarios differ in the extent of new HSR infrastructure built (no new HSR infrastructure, a completion of the lines under construction, one where all major population centres are connected by HSR and an EU accession candidate scenario). The infrastructure of other modes is assumed to follow the increase in their forecasted demand. Hence, for example, highways are assumed to be widened and airports to expand with new runways to meet the increased demand. The study runs until 2070 to allow for the full effects of the HSR infrastructure to set in, given that the 2050 network is assumed to be complete by 2040. An important disclaimer is to be made in relation to the 2050 scenario. The 2050 scenario includes (i) HS lines planned to be finalized after 2030 and (ii) additional HS lines envisaged by the study with the view to completing a comprehensive pan European HS network connecting all major EU cities. All lines in the 2050 scenario have been considered new construction, although some lines may be planned as upgrade of current lines.

[23] Dijkstra, L., Poelman, H. & Veneri, P. (2019). The EU-OECD definition of a functional urban area. *OECD Regional Development Working Papers*, No. 2019/11. Retrieved from https://doi.org/10.1787/d58cb34d-en

3.1.1 Baseline Scenario

The baseline consists of the current HSR network in operation in Europe as per the revision of the TEN-T Network guidelines[24]. The revised TEN-T maps lists all the HSR lines in the EU currently in operation, and the targets for years to come. This includes the Core Network (completion in 2030), the Extended Core Network (completed in 2040) and the Comprehensive Network (completed in 2050). For countries not part of the TEN-T Network, the UIC HSR Atlas has been used[25]. The "lines in operation" consists of all lines where passenger railway undertakings currently are operating HSR services. The baseline scenario includes upgraded lines (speeds in the order of 200 km/h) in addition to lines equipped for speeds of 250 km/h or above[26]. The total network length in the baseline scenario is 15.200 km and is depicted in Figure 3.

HSR definition

This study applies the definition of Directive 2016/797 on the interoperability of the rail system within the European Union of what constitutes high-speed rail[1]. Thus, HSR is defined as rail lines specifically equipped for speeds equal to or greater than 250 km/h and upgraded lines equipped for speeds in the order of 200 km/h (200-250 km/h).

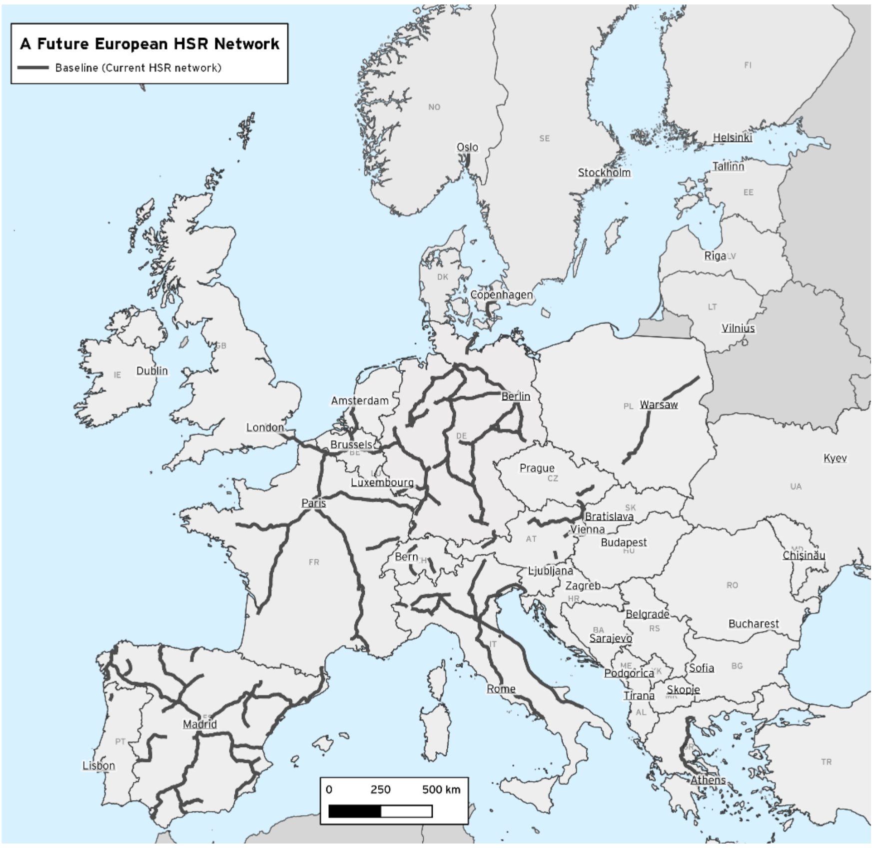


Figure 3: Baseline scenario

[24] As per the maps of the TEN-T Revision Council general approach: [Trans-European transport network: Council agreement paves way for greener, smarter and more resilient transport in Europe (europa.eu)]

[25] International Union of Railways (2022). *Atlas High-Speed Rail 2022*. Retrieved from [High-Speed Databases and Atlas | UIC - International union of railways]

[26] The definition of HSR has the effect of including lines which are not deemed as HSR elsewhere, hereby making the length of the Baseline scenario longer than in other sources.

3.3.2 2030 Scenario

The 2030 scenario is a conservative estimate for the future growth of the European HSR network. The scenario includes the lines currently in operation (as in the baseline scenario) and incorporates all the lines in the TEN-T Core Network scheduled to be in operation by 2030. The UIC HSR Atlas[27] has been used to obtain information on the planned start of operation of new lines, which are therefore added to the assessment as of the respective year indicated. The scenario, moreover, includes lines from the TEN-T Core network under construction or projected finished by 2030[28]. Where no information was available on the planned start of operation, the lines have been assumed to be in operation by 2030 the latest. The total network length in this scenario is roughly 20.500 km, meaning a total of est. 5300 km of track is to be built and an additional 86 million people will be connected to a HSR network.

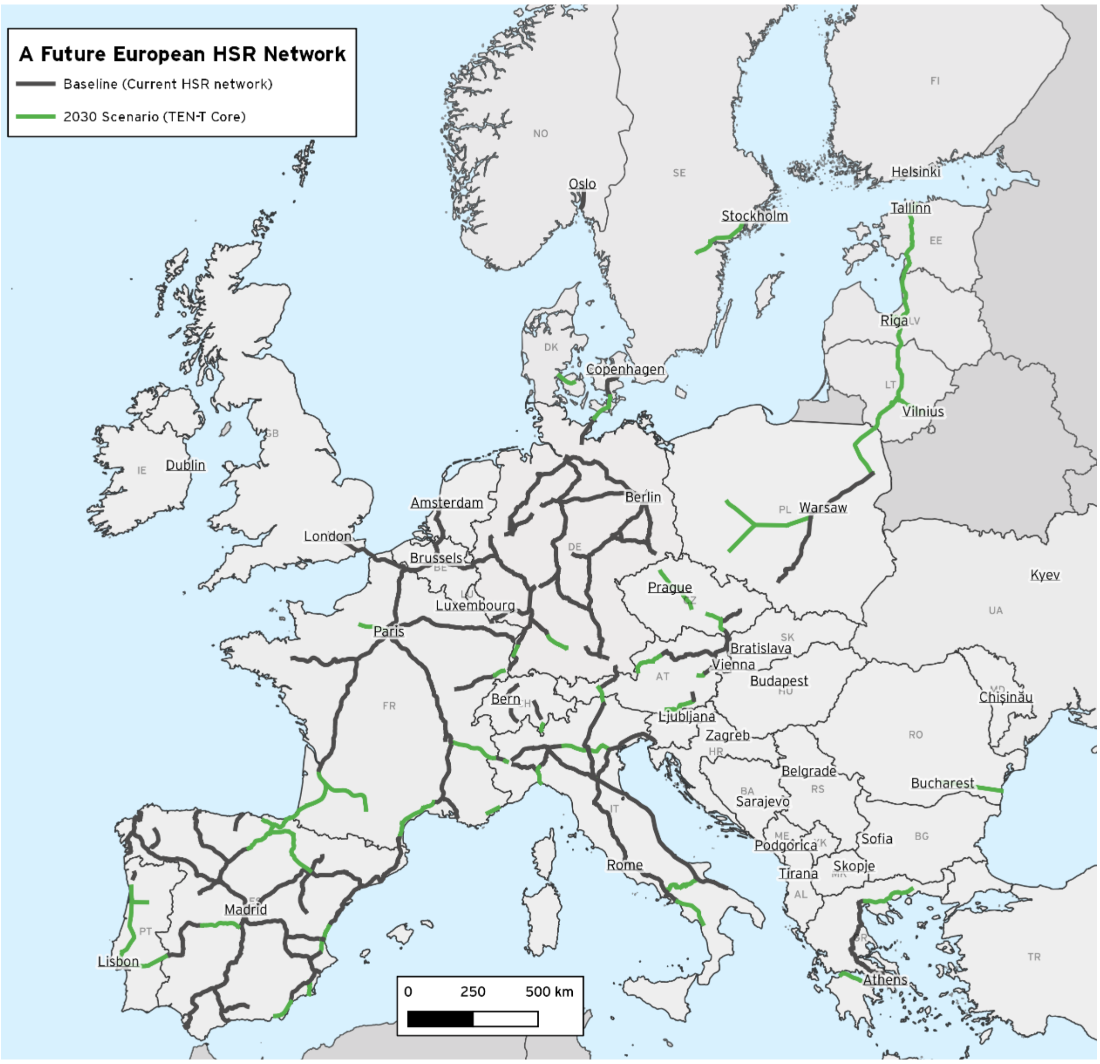


Figure 4: Baseline and 2030 Scenario

[27] International Union of Railways (2022). *Atlas High-Speed Rail 2022*. Retrieved from [High-Speed Databases and Atlas | UIC - International union of railways]

[28] As per the maps of the TEN-T Revision Council general approach: [Trans-European transport network: Council agreement paves way for greener, smarter and more resilient transport in Europe (europa.eu)]

3.3.3 2050 Scenario

The 2050 Scenario builds on the 2030 Scenario by taking into account a possible expansion of the HSR network where all European Functional Urban Areas (FUA) above 250k inhabitants are connected by HSR. The expansion to cover all FUAs above 250k inhabitants is in addition to the TEN-T Extended Core and Comprehensive Networks, which are to be completed in 2040 and 2050 respectively. They are marked in brown in figure 5 below.

A functional urban area is defined as a city and its surrounding commuting zone. Functional urban areas therefore consist of a densely inhabited city and a less densely populated commuting zone where the labour supply is highly integrated with local businesses[29]. Metropolitan (Population: 250k-1.5m) and Large Metropolitan areas (Population: +1.5m) are included in this study. FUAs were chosen to include both the city (centre) and a commuting zone with available data for key parameters. Where a conventional rail line connects the FUAs, the scenario assumes the new HSR line to follow the path of the shortest conventional line connecting it to the current/planned HS network, while in the case of an FUA not being connected by a rail line, the new HS line will follow the most direct path, while taking into account major natural obstacles. For FUAs that are located within a 20 km radius of a current HSR line, they are considered to be part of the current HSR network[30].

The network is assumed completed and in operation by 2040. The underlying assumption behind this timeline is based on the estimated construction time of a HSR line of 16 years[31]. While a considerable amount of track-km has to be constructed at the same time, the latest developments in railway infrastructure construction indicates that significant improvements in terms of costs, environmental impact and construction speed could be expected[32].

The proposed 2050 scenario will considerably increase the inter-regional European connectivity. There are virtually no HSR routes serving Eastern MSs, leaving the citizens in these regions and countries with no alternative to travelling by passenger car or aviation. The 2050 scenario will offer them the benefits of HSR, highlighted in section 2, such as low emissions and a faster and more comfortable trip. Moreover, the network will remove bottlenecks around the Alps, and allow for a more direct route from the north to the south of Europe. The total length of the 2050 scenario is an estimated 49.400 km, meaning a total of roughly 34.200 km of HSR is to be built in the 2050 scenario. Approximately 216 million persons will be connected to a HSR network in this scenario. The scenario is depicted in Figure 5 below. Comparing figure 3 to figure 4, it becomes clear that, although the HSR network is expanding until 2030, it is not enough to connect the entire Europe.

[29] Dijkstra, L., Poelman, H. & Veneri, P. (2019). The EU-OECD definition of a functional urban area. *OECD Regional Development Working Papers*, No. 2019/11. Retrieved from https://doi.org/10.1787/d58cb34d-en

[30] Certain regions in Europe have a high density of FUAs. An example would be the area in the vicinity of Frankfurt.

[31] Special report: A European high-speed rail network (europa.eu)

[32] Trafikverket (2020) *Functional design for a cost effective production and Maintenance.*

Other specifications could have been considered for the 2050 scenario as well. Notably, connecting only larger metropolitan areas (above 1.5 M inhabitants). This could possibly have limited the kilometres of track to be constructed by offering the possibility of more direct routes. Nevertheless, the current scenario specifications were chosen as, most of the metropolitan areas would be on a potential line connecting larger metropolitan areas, and secondly, as only connecting large metropolitan areas would offer a too limited network considering competition with other modes.

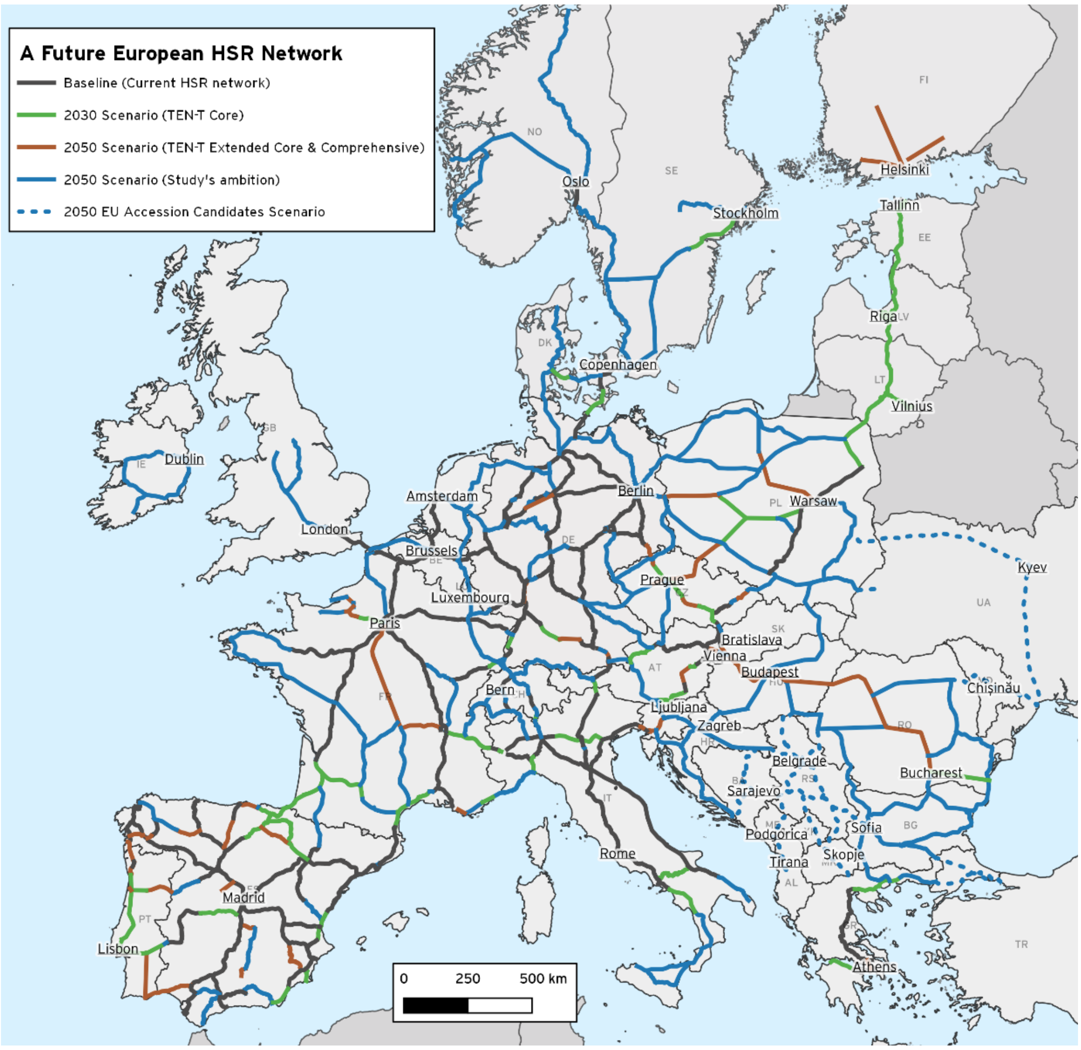


Figure 5: HSR network, all scenarios[33]

3.3.4 2050 – EU accession candidate countries scenario

In addition to the network scenarios described above, an additional scenario has been constructed to include the countries currently are candidate or potential candidate countries to access the EU[34]. These countries have been included following the latest proposal to further include neighbouring countries to the TEN-T network. Moreover, given the study's long timeframe, one can assume these

[33] The 2050 scenario is divided into two: brown representing lines that are based on the TEN-T Extended Core and Comprehensive Network and a blue representing the lines that are invented by the study connecting the major European cities. They are considered as part of the same scenario nonetheless.

[34] European Commission (2022). *Candidate Countries and Potential Candidates*. Retrieved from Candidate Countries - Enlargement - Environment - European Commission (europa.eu)

countries to access the EU within the time period under study. Nevertheless, these countries have been added within a separate scenario due to shortcomings in available data for passenger transport demand. Where data was missing, the data has been estimated by regressing the present data against population and Gross Domestic Product (GDP). This, unfortunately, renders the findings of this scenario uncertain and hence it is presented as a separate scenario. This extension is marked by the blue dotted lines in the map above. The following countries are included in the extended 2050 scenario: Albania, Bosnia and Hercegovina, Kosovo, Moldova, the Republic of North Macedonia, Montenegro, Serbia, Turkey and Ukraine. For this scenario to be realized, a total of 4300 km of track has to be constructed. The results of this scenario have been added to the annex. Approximately 40 million persons would be connected to a HSR network in this scenario.

3.2 Demand/shock model

The primary methodological component of the market assessment is the demand/shock model. It estimates the demand for HSR and the competing modes of transport year by year until 2070.

The main principle is to define the forecasted evolution of passenger demand by an endogenous trajectory (solely influenced by GDP, population and previous demand trends) to which different shocks (including new infrastructure, regulation…) are applied on different forecasted dates.

Baseline demand for future years for each of the travel demand category were estimated by regressing the transport demand (in pkm) against GDP and population growth forecasts and the growth trend of demand for passenger transport since 2010. Data for the transport demand, GDP and population at a country level was collated for historical years (2010 - 2019) from the Eurostat database for all modes included in the study[35].

To allow for a fair comparison between modes, an inter-modal market was defined. This market includes HSR, long-distance conventional rail, long-distance bus and coach, long-distance passenger cars and short-distance aviation (in bold in Table 2). As limited data is available with a distinction between distance travelled, the modes were split as indicated in Table 2 below[36][37]. No distinction is made for HSR as it is

Simplifying assumptions of the study

- No capacity constraints on the network.
- The study does not take into consideration the procurement of vehicles, airplanes or rolling stock to match the growth in demand.
- Railway undertakings operate at equilibrium between revenue and costs.
- Track access charges completely cover infrastructure maintenance at micro-level.
- The study makes no assumption on the evolution of the fares.

[35] Eurostat (2022). *Data Browser Transport*. Retrieved from https://ec.europa.eu/eurostat/databrowser/explore/all/transp?lang=en&display=list&sort=category

[36] Own elaboration on Eurostat data and Wilkerson, J. T., Jacobson, M. Z., Malwitz, A., Balasubramanian, S., Wayson, R., Fleming, G., Naiman, A. D., & Lele, S. K. (2010). Analysis of emission data from global commercial aviation: 2004 and 2006, *Atmos. Chem. Phys.*, 10, pp. 6391-6408. Retrieved from https://doi.org/10.5194/acp-10-6391-2010.

[37] European Environment Agency (2015). *Focusing on environmental pressures from long-distance transport. TERM 2014 : transport indicators tracking progress towards environmental targets in Europe*. Publications Office. Retrieved from https://data.europa.eu/doi/10.2800/857401

assumed to be long-distance in all cases. For land transport (road and conventional rail), long-distance signifies trips above 100km and for aviation all flights below 3hrs are deemed short-distance. Short-distance flights up to three hours have been included based on an assumption of the advent of HSR night trains, where passengers would be able to travel longer distances at night, which would ultimately be able to compete with up to three-hour flights[38].

Mode	Share of total trips made	
	Short-distance	Long-distance
Conventional rail	30%	**70%**
Passenger car	70%	**30%**
Bus and coach[39]	91,3%	**8,7%**
Aviation	**54%**	46%

Table 2: Modal split for short distances and long distances

Ten shocks[40] were identified and applied to the scenarios (safe for the baseline where no shocks were applied) to simulate the effects of future regulatory or technological developments on the demand for passenger transport in Europe. The demand was forecasted for land borne (bus/coach, passenger car and rail) and airborne modes (short-haul and long-haul flights). Data on current pkm travelled were sourced from the EU statistical pocketbook, while data on GDP and population at both country level and Functional Urban Area (FUA) level were sourced from the OECD statistical database. This approach was considered the most suitable for the incorporation of future developments related to the demand for passenger transport and due to robust back testing results: future identified shocks can be added to the model without jeopardizing its internal structure.

The proposed estimation method has been as rigorous as possible. The shocks included in the study were all based on either peer-reviewed scientific articles, or studies conducted by the EC or ministries of national governments. The methodological approach for forecasting future demand has been made in accordance with current academic standards, as witnessed by the participation of the University of Bocconi. It was discussed and approved following several meetings with experts as well as railway sector stakeholders, representing infrastructure managers, railway undertakings (incumbent and non-incumbent) and railway equipment and rolling stock manufacturers. However, it must be acknowledged that estimating the timing, magnitude and impact of future events carries a high level of uncertainty and relies on structural assumptions. Moreover, some shocks are based on observed effects in one or more countries to model the EU total effect.

3.2.1 Shocks

[38] UIC & DB International (2013) *UIC Study night trains 2.0. New opportunities by HSR?*. UIC Study night trains brochure. New opportunities by HSR ? Executive summary (shop-etf.com)

[39] Internal elaboration based on MIT, Conto Nazionale delle Infrastrutture e dei Trasporti (2022). Conto Nazionale delle Infrastrutture e della Mobilità Sostenibili. Anni 2020-2021. Retrieved from Conto Nazionale delle Infrastrutture e della Mobilità Sostenibili - Anni 2020-2021 | mit

[40] The "shocks" are described in more detail in section 3.2.1

The shocks simulate possible and measurable future developments which may affect demand for transportation. An initial comprehensive list of possible shocks was assessed and refined based on predictability, scalability and reliability of their related impacts.

The selected shocks applied to stimulate the demand for passenger transport are listed below and are explained in greater detail in annex 1. The shocks included in the final list were selected based on the presence of academic articles or official government-level studies having been conducted on the effect of the shocks. Some shocks are based on studies for one country only and therefore present a higher degree of uncertainty in relation to their estimations than shocks based on studies for the entire EU. These issues have been mitigated through the sensitivity analyses on the robustness of the results presented in detail in annex 2. Table 3: Effect of shocks per transport mode

below highlights the effects the shocks have on the modes included in the study. It has to be noted that the effect of the shocks can vary depending on the context in which they are applied. For example, the construction of HSR infrastructure may have a positive effect on long-distance rail in France, whereas it may have a negative effect on the Rail Baltica link. This is mainly due to the HSR lines either replacing or complementing the conventional rail lines. Similar, there would be a difference in effect between the 2030 and 2050 scenario, as the 2050 scenario covers more of the existing network and would be less complementary than in the 2030 scenario. In any case, would the construction of HSR infrastructure have a positive effect on short-distance rail, which is not covered in the study. The effect summarised below have been assessed at a European wide scale.

Shock	High speed rail	Rail- Long Distance (Non-HSR)	Car: Long Distance	Bus: Long Distance	Air: Short Distance
Infrastructure	+	-	-	-	-
Competition	+	+	-	-	-
Aviation fuel tax hike	+	+	+	+	-
Aviation ticket Tax hike	+	+	+	+	-
Short Haul flight ban	+	+	+	+	-
Fuel price increase	+	+	-	-	-
Shared Mobility	-	-	+	-	-
Bus Liberlization	-	-	-	+	-
S2R technologies	+	+	-	-	-
Highway toll	+	+	-	-	+

"+" indicated increase in travel demand and "- " indicates reduction in travel demand

Table 3: Effect of shocks per transport mode

The shocks have been added cumulatively and in accordance with their effect on mode shift where the authors made assumptions on it. They, moreover, only take effect gradually over a period of years. The shocks have been chosen, as much as was possible, to assure a balance of the effects on the modes. Nevertheless, it can be seen, in table 3, there is a slight dominance in shocks with positive effects for rail. This is as a result of the saliency, both politically and public, surrounding regulation of the aviation sector due to its relative high impact on the environment[41] [42]. No shocks on technological improvements of other modes are included in the study. The major changes foreseen to affect demand would be autonomous driving for passenger cars and clean fuel for aviation. Both technologies are, at this point, too immature for any estimations of their effect. Electric vehicles were considered, however, they are assumed not to increase demand but rather maintain demand by replacing vehicles with internal combustion engines.

Shock	Main effect	Source	Traffic shifted to HSR	Timing
New HSR infrastructure	3,27% increase in HSR demand (pkm) per 1% of pop. Affected	Beria, Grimaldi, An ex-post cost benefit analysis of Italian High-Speed train, five years after (2016) Cascetta, "Le conseguenze dell'alta velocità in Italia" Betancor, Contabilidad Financiera y Social de la Alta Velocidad en España (2015) Giuricin, Tosatti, The history of Italo and the benefits of competition in the Italian HSR sector (2018) Cascetta et al, Analysis of mobility impacts of the high speed Rome-Naples rail link using within-day dynamic mode service choice models (2011) Beria et al, Delusions of success: Costs and demand of high-speed rail in Italy and Spain (2018) Bergantino et al, The impact of open access on intra- and inter-modal rail competition. A national level analysis in Italy, (2015)	▶ Induced demand: 45% ▶ From rail: 14% ▶ From road: 19%. ▶ From air: 23%.	According to the forecasted opening of the lines.

[41] Becken, S. & Stantic, B. & Chen, J. & Connolly, R. (2022). Twitter conversations reveal issue salience of aviation in the broader context of climate change. *Journal of Air Transport Management*, 98. Retrieved from https://doi.org/10.1016/j.jairtraman.2021.102157

[42] European Commission (2022). Reducing emissions from aviation. Retrieved from Reducing emissions from aviation (europa.eu)

Shock	Main effect	Source	Traffic shifted to HSR	Timing
Open-access competition on LD services	2,58% increase in long distance demand (pkm) per 1% increase in degree of mkt opening (share of services operated by non-incumbent Rus)	Beria, Grimaldi, An ex-post cost benefit analysis of Italian High Speed train, five years after (2016)- Desmaris, Croccolo, High speed rail open access competition in Italy: a major railway market innovation for a win-win game? [La compétition sur le marché de la grande vitesse ferroviaire en Italie : une innova" (2018)	▶ Induced demand: 45% ▶ From other rail: 14% ▶ From road: 19%. ▶ From air: 23%.	Average market opening: 30% in 2030, 40% in 2050, 50% in 2070
Shared mobility	+ 2,8 percentage demand for car	« Projections de la demande de transport sur le long terme » Ministère de l'Environnement, de l'Energie et de la Mer.	▶ Induced demand : 4% ▶ From rail : 89% ▶ From air : 4% ▶ From bus : 4%	From 2022
LD bus comp.	-2.7 percentage demand for rail.	« Projections de la demande de transport sur le long terme » Ministère de l'Environnement, de l'Energie et de la Mer.	▶ From road : 19% ▶ From rail : 81%	From 2022
Fuel price	Increase of 10% in gasoline price leads to increase in HSR demand of 2,4% and a 2.8% decrease in passenger car demand.	Marianne Delsaut / Transportation Research Procedia 1 (2014) 177 - 187	Indicates a mode shift but no direct shift is mentioned in the article. The modes have been assigned their respective changes in demand.	From 2022
Short-haul flight ban	15% of all flights with up to 6-hour rail alternative will be replaced by rail Kwasiborska et al. (2015). and 7% of all intra-EU short/medium distance flights can be replaced without	Kwasiborska et al. (Eds.): ATE 2020, LNITI, pp. 146-163, 2021. Avogadro, Nicolò & Cattaneo, Mattia & Paleari, Stefano & Redondi, Renato, 2021. "**Replacing short-medium haul intra-European flights with high-speed rail: Impact on CO2 emissions and regional accessibility**," Transport Policy, Elsevier, vol. 114(C), pages 25-39.	▶ Lost demand[43]: 10% ▶ From rail: 80% ▶ From road: 10%	From 2025

[43] When lost demand is mentioned, it means that the study does not mention the traffic shifting elsewhere. Hence it has been assumed "lost" meaning less people will travel.

Shock	Main effect	Source	Traffic shifted to HSR	Timing
	increase in travel time Avogardo et al., (2021)			
Ticket tax	-8,3% demand for aviation.	Study on the taxation of the air transport sector. Ricardo for the European Commission DG TAXUD	▶ Lost demand for aviation: 98.1%[44] ▶ From rail: 1.9%.	From 2025
Aviation fuel tax	-9,2% demand for aviation.	Study on the taxation of the air transport sector. Ricardo for the European Commission DG TAXUD	▶ Lost demand for aviation: 98.3% ▶ From rail: 1.7%.	From 2025
Impact of S2R technologies	11,4 percentage point increase in HSR modal share	Strategic support to the Shift2Rail Joint Undertaking | S2R.19.OP.02. LOT 1 Strategy Advice *I.3 Work to support with a cost-benefit analysis the definition of migration paths for the implementation of S2R selected innovations on the European network.*	▶ From car: 48% ▶ From bus: 31% ▶ From air: 21%.	Full deployment of all S2R technologies 2034. The S2R technologies are described in-depth in the annex.
Highway tolls	-3% decrease in demand for passenger car	Litman, T. (2022) Understanding Transport Demand and Elasticities: How Prices and Other Factors Affect Travel Behavior, *Victoria Transport Policy Institute*	No mention of traffic shift due to highway tolls.	From 2030

Table 4: Shocks, their main effects and sources

The shocks included per scenario are presented in the table below. A 0 denotes when the shock is not included, while a 1 denotes the inclusion of the shock. The inclusion of the shocks per scenario has been made based on assumptions on the likelihood of them occurring prior to the year where the network is completed. Hence, the 2030 scenario, having a closer horizon, includes only those shocks which are considered could be introduced before 2030. These include an aviation ticket tax[45], an increase in the price of gasoline[46] and the introduction of highway

[44] The study does not mention directly the shift in traffic due to the fuel or ticket tax. It mentions the decrease in demand for aviation (main effect column) and the increase in passenger rail demand (0.23% increase for fuel tax and 0.25% increase for ticket tax by 2030 compared to the baseline forecast). Based on this, the traffic shift above has been calculated. The effects of the two shocks on rail can be assumed to increase once the HSR network has been expanded as there would be more alternatives to aviation.

[45] The Danish government has already proposed a tax - 13 kroner pr. flytur skal bidrage til grønne flyrejser i 2030 | Politik | DR.

[46] Gasoline prices have been increasing this year Europe's gas prices have broken a new record. How high can they go? | Euronews.

tolls across Europe[47]. The 2050 scenario includes all shocks and a scenario representing a full case for rail and the environment. It has to be mentioned that the effect of the shocks on demand may vary over time, however, in this study the shocks has been applied with the intensity indicated above.

Shock	Baseline scenario	2030 Scenario	2050 Scenario
Infrastructure (HSR)	0	1	1
Competition (HSR and rail)	0	0	1
Aviation fuel tax	0	0	1
Aviation ticket tax	0	1	1
Short Haul flight ban	0	0	1
Gasoline price increase	0	1	1
Shared Mobility	0	0	1
Bus Liberlization	0	0	1
Impact of S2R technologies	0	0	1
Highway tolls	0	1	1

Table 5: Shocks included in the model scenarios

[47] Road charging (europa.eu)

4. Findings

The subsequent section will present the results of the market assessment and hereby the forecasted demand per network scenario as presented above. Firstly, the demand for HSR in the scenarios will be presented. Afterwards, the modal share evolution in the scenarios will be presented.

As presented above, the results will be displayed, in pkm and percentage share, for the market in which HSR competes. To recap, the following modes are included in the market for HSR:

- HSR
- Long distance conventional rail
- Long distance bus and coach
- Long distance passenger vehicles
- Short-haul aviation

4.1. General presentation of the HSR network

The four network scenarios are displayed in full in figure 6 below. As can be seen the baseline and 2030 scenarios only covers a little part of Europe and remains a predominantly Western European mode of transport. The 2050 scenario will considerably expand the HSR network and offer the benefits of HSR to the entire Europe[48].

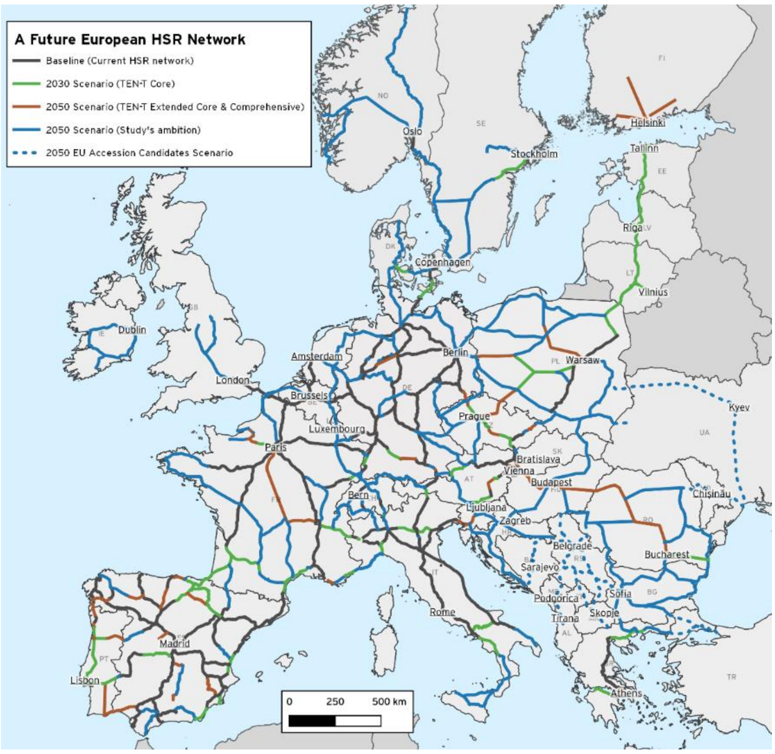


Figure 6: The Future HSR Network under different scenarios

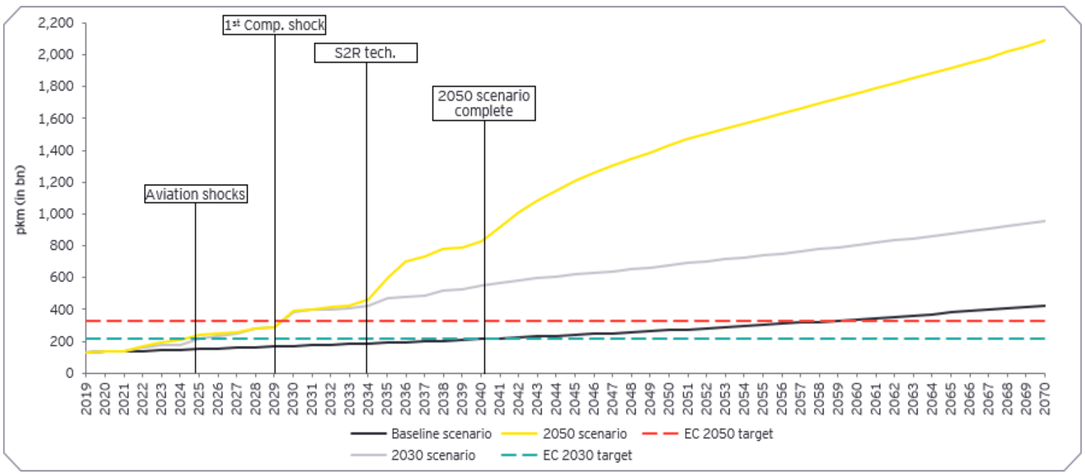
As indicated further above, the current HSR network (in full black) is a patchwork of HSR lines connecting a limited number of major cities. This has the effect of creating bottlenecks and gaps in the network along the major corridors connecting

[48] Regional maps can be found in the annex.

Europe. Rendering cross-European travel with HSR difficult and depended on several stops and changes of trains. Moreover, HSR remains limited in Eastern and Northern Europe resulting in few alternative offers to aviation or personal vehicles. The HSR network proposed in the 2050 scenario would eradicate the bottlenecks and gaps by connecting the major European cities. In comparison to the scope and scale of the European highway network (75.000 km) and the European airport network, the HSR network proposed will offer proper alternative to competing modes, in particular considering the possibility of travelling further by capillary lines.

4.2. Evolution of the passenger demand for high-speed rail

The forecasted traffic for HSR is depicted in the figure below, including the three traffic scenarios. As can be seen the 2030 and 2050 scenarios spur considerable growth in HSR traffic. The 2050 scenario will increase from 138 billion pkm in 2021 to 2089 billion pkm in 2070. The increase in traffic as of 2041 is due to the completion of the 2050 scenario network and the resulting increased traffic, while the increase in demand around 2034[49] is due to the complete deployment of all S2R technologies like a single ticketing platform and those related to ERTMS. Along with the gradual completion of the 2050 scenario. As can be seen below in figure 5, the S2R technologies will increase the HSR modal share with around 10 percentage points. This highlights the need for research and development (R&D) in the railway sector and the importance for further funding of the European programs related to R&D, such as S2R/Europe's Rail. Moreover, the illustrated effect calls for additional funding for the deployment of railway technologies for example through the Connecting Europe Facility and the European Regional Development Fund. Although slightly hidden by the increase in HSR network length from 2040 onwards, the findings support an opening of the HSR market to more competition. The increased competition can be seen firstly in 2030, where the non-incumbents have gained a third of the market. The lines in Figure 7 indicate the application of the main shocks applied.



[49] 2034 is the year of completion of a rapid deployment of the technologies as per the S2R Technological Program CBA.

Figure 7: HSR Passenger demand evolution in different scenarios[50]

Both developments, network effects and S2R technologies are highly beneficial to HSR traffic. The baseline scenario represents a theoretical worst case where all infrastructure projects (including under construction) are not finished and no technological or regulatory evolution occur; the increase in passenger demand will then be only attributed to GDP and population growth. The blue and red lines depict the EC's targets for the future growth of HSR traffic within the EU as set out in the EC's Sustainable and Smart Mobility Strategy[51]. As is evident, the measures proposed by this study will meet these targets well in advance, while the baseline scenario will result in reaching the 2030 target by 2050 and the 2050 target by 2070 only.

4.3. Evolution of the modal share

The subsequent section will describe the evolution of the modal share for passengers across the analysed transport modes.

4.3.1 Baseline Scenario

The below figures present the modal share of passenger transport in the market where HSR is competing, therefore present. This market includes short-haul aviation, long distance bus and coach, long distance personal vehicle transport and non-HSR long distance rail in addition to HSR. In 2021 railway constitutes 18% of the traffic, out of which 8% are HSR.

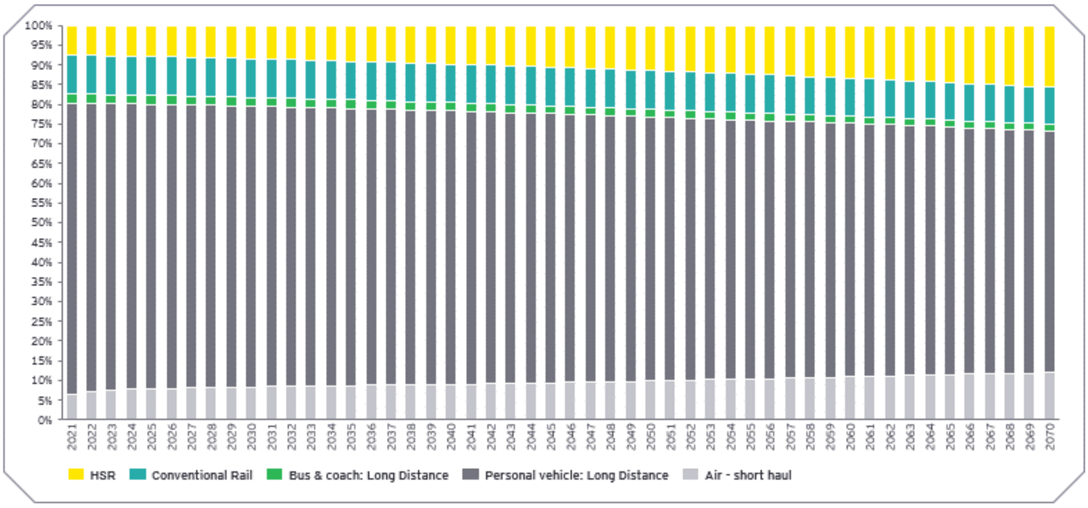


Figure 8: Passenger modal share evolution – Baseline scenario

In the baseline scenario, some small evolutions in modal share are still observable. These are attributed to the different correlation coefficients between transport modes use, GDP and population. This difference explains why, in this scenario, air

[50] The HSR infrastructure shock here denotes the effect of the 2050 network. The effect of the 2030 network can be seen on the grey line at around 2030. The difference between the two graphs in this period is due to the 2050 scenario including the two shocks: bus liberalisation and shared mobility increase. They have the effect of reducing HSR demand.

[51] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions (2020). *Sustainable and Smart Mobility Strategy – putting European transport on track for the future* {SWD(2020) 331 final}. Retrieved from [EUR-Lex - 52020DC0789 - EN - EUR-Lex (europa.eu)]

and HSR modal share will keep increasing (from 7% to 12% and from 8% to 16% respectively), being the use of these two modes positively correlated with GDP growth in Europe.

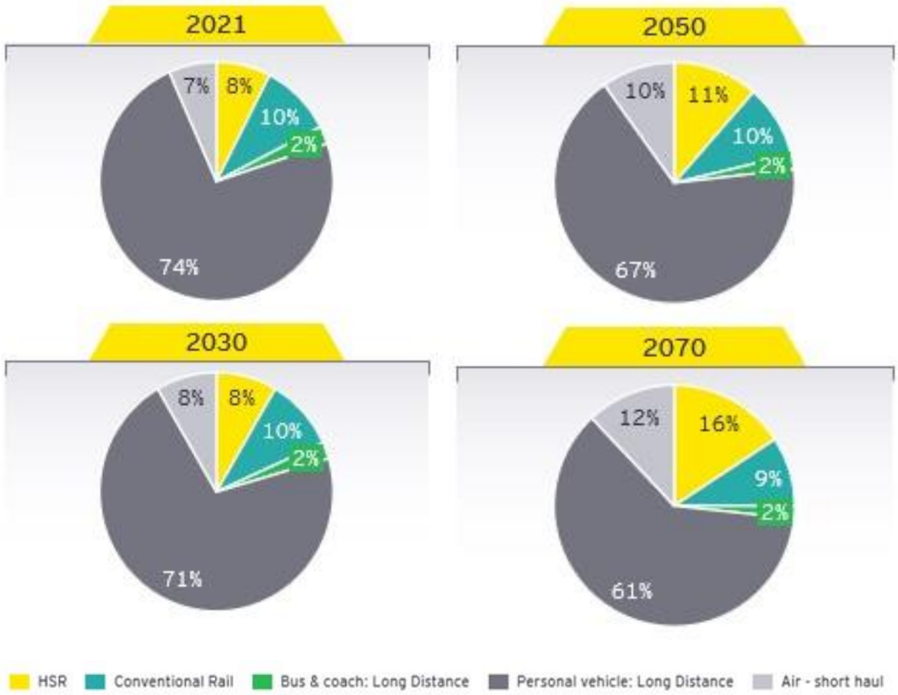


Figure 9: Modal share distribution – Baseline scenario

4.3.2 2030 Scenario

The 2030 scenario includes the HSR network currently in operation and the HSR lines, which are under construction as per the UIC HSR Atlas. Moreover, it includes the shocks deemed certain to happen prior to 2030, which are listed in Table 5 above. In this scenario, the overall modal share for rail increases from 8% in 2021 to 18% in 2030, to 26% in 2050 and then up to 32% in 2070. Only applying the effects of constructing the network would result in HSR obtaining 30% modal share by 2070.

Conversely, this scenario reduces the modal share of rail's less sustainable competitors; road traffic (combined personal vehicle and collective) goes from 74% in 2021 to 57% in 2050 and to 50% modal share in 2070, and air traffic will increase slightly due to the non-introduction of a short-haul ban or taxes on tickets and aviation fuel.

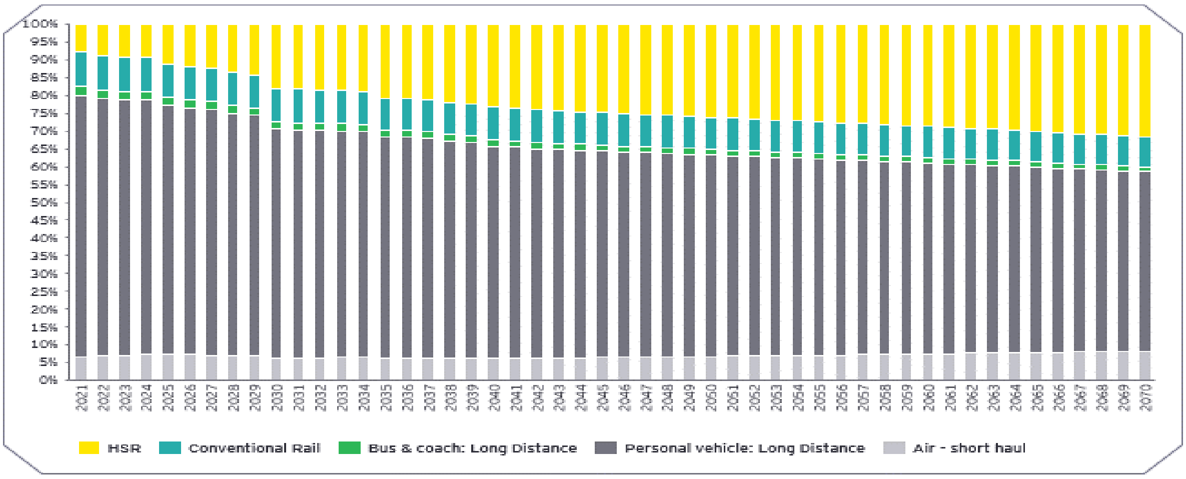


Figure 10: Passenger modal share evolution – 2030 scenario

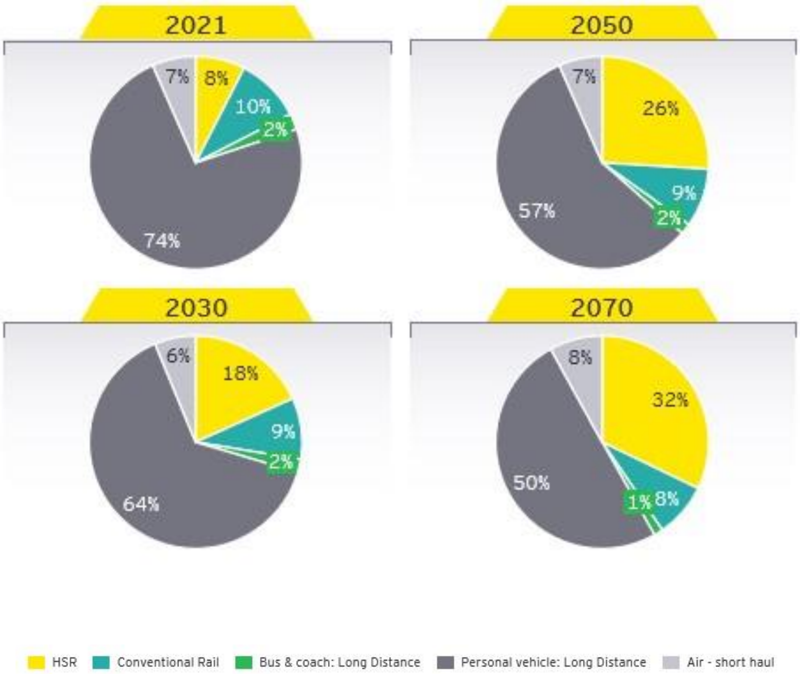


Figure 11: Modal share distribution – 2030 scenario

4.3.2 2050 Scenario

The 2050 scenario includes the proposed network connecting all European FUAs by HSR as well as all shocks included in the study.

In the first decade and a half, 2030 and 2050 scenarios remain similar in terms of modal share distribution: which is an expected outcome as the main added assumption in 2050 scenario is the construction of a full connected European network, the effect of which will set-in starting from 2040. In the long run, on the other hand, this scenario provides a significantly more positive outcome for rail.

As is witnessed by the figures below, a sort of duopoly will arise between rail and passenger cars in the market for long distance passenger transport. HSR will reach a modal share of 54% in 2070 covering more than half of the traffic, in the market segment under study, in Europe[52]. This is the effect of full comprehensive HSR network, which increases the demand considerably by allowing for more passengers to travel with HSR as new regions and countries are covered by the HSR network. Short-haul aviation virtually disappears due to the ban on short-haul aviation, where travel with HSR is possible. Passenger cars maintain a non-negligible share of the market (32% in 2070) as some potential HSR passengers, especially families, tend to favour travel by personal vehicle due to not having to travel to the HSR stations. Similar to the 2030 scenario, conventional long-distance rail will benefit from the spill-overs of increased HSR traffic and account for 13% of the passenger transport traffic in 2070. Referring back to Figure 7 in comparison to Figure 12 below, it can be seen that the aviation shocks mainly impact the demand for aviation, while rail-specific shocks have the largest impact on demand for rail. Concludingly, the increase in traffic and modal share of HSR as compared to the baseline and the 2030 scenario highlights the results of accelerated investments in HSR and related railway technologies. Hereby, indicating the need for accelerated investments in HSR at both European and national level.

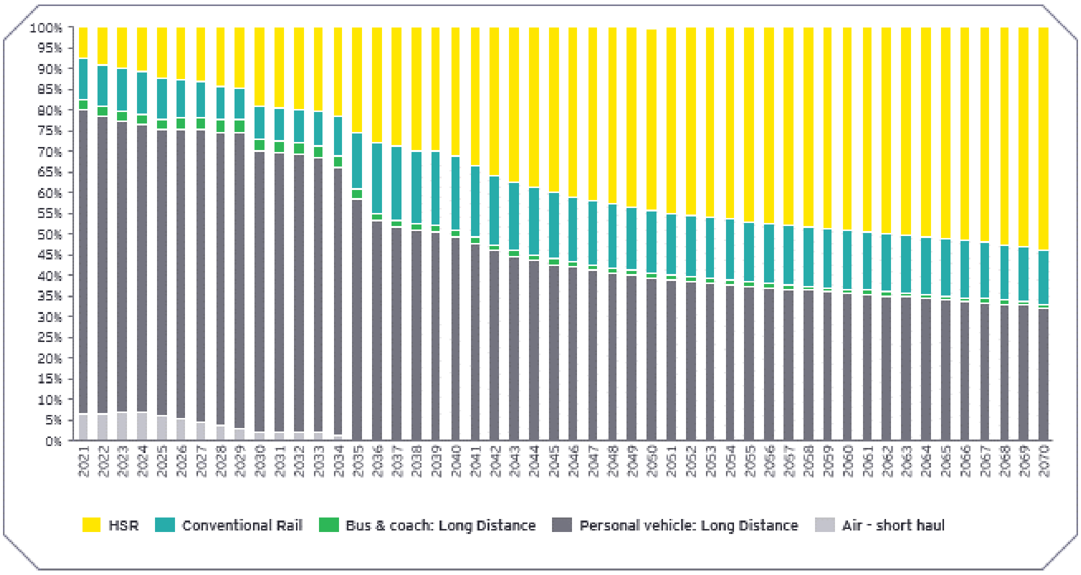


Figure 12: Passenger modal share evolution – 2050 scenario

[52] Accounting only for the infrastructure, HSR would account for 45% of the market by 2070.

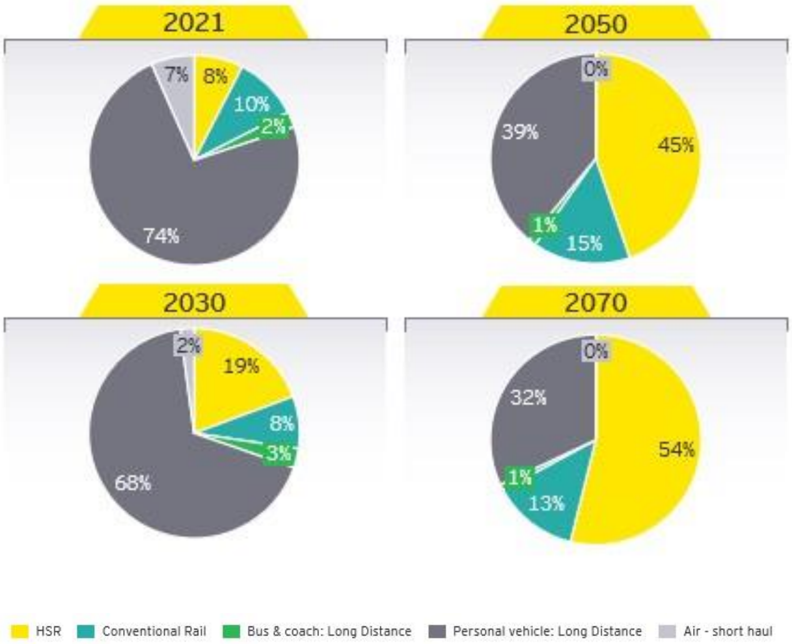


Figure 13: Modal share distribution – 2050 scenario

5. Conclusions

A comprehensive academic literature, estimating the costs and benefits of HSR, points towards an overall positive impact on demand following the construction of high-speed infrastructure. This report seeks to estimate the future demand for HSR and competing modes in case the current HSR network is expanded to cover the major European cities.

The quantitative analysis provides three main conclusions, drawn from the three different scenarios. The first is that without new investment in HSR, demand for it (and therefore its utilisation) will increase slightly, while in addition leaving other, more polluting, forms of transport as the only alternatives for travellers across Europe. Moreover, competing modes will slightly increase their market share.

The 2030 scenario describes a future where a limited investment in this type of infrastructure will prompt an increase in demand (958 billion pkm in 2070). The HSR modal share of total transport will, in addition, double by 2050 and triple by 2070 *vis-à-vis* other alternatives.

The third scenario indicates an international comprehensive infrastructure investment in a complete European HSR network, which will elicit a more than proportional response from travellers (2089 billion pkm in 2070). This will result in HSR achieving the majority of its market with a market share of 54% by 2070. More importantly, the expansion will result in additional cities being connected to the network. This result indicates economies of scale both for demand and, indicatively, for its potential economic and environmental benefits. The findings of the 2050 scenario in particular highlights the need for adopting sound policies fostering a modal shift. These policies include opening up to competition for HSR and regulating the aviation market. Moreover, there should be an intensified focus on developing and deploying railway technologies.

Future research ought to focus on expanding the structural models created by EY and academic researchers and test new shocks and scenarios. The possible inclusion of other variables and timeframes and the use of suitable econometric estimation methods can further increase both the plausibility and the accuracy of the models.

6. Annex

Annex 1: Limitations of the study

The following section will discuss the limitations of the market assessment and its applied methodology.

The main methodological component of the market assessment is the demand-shock model, which forecasts demand for passenger transport until 2070. The method of applying previously estimated shocks to take into account future events is a limitation. Firstly, as the future is difficult to predict, any previous estimation of a shock may not have the same effect when applied 20 years from now. Secondly, some shocks applied in this study are based on studies the estimations of only one country, while this study applies it across Europe. This limits the applicability of the shocks based on the estimations for only one country. In addition, the risk of optimism bias has to be noted. It could be related to either overestimation of demand or a potential underestimation of costs (more related to tech. report 2).

Secondly, while the study has been as comprehensive as possible in including all possible demand shocks, some future shocks may have not been included sue to the non-existence of any previous estimations. Moreover, the applications of the shocks together may yield different outcomes in comparison to their single applied effect. Nevertheless, this has been controlled for through the sensitivity analyses performed, which showed that the results were robust.

Lastly, the study applies a long-time frame which renders the forecast beyond 2040 more unpredictable. Nevertheless, this was done to allow for the effects of the infrastructure to kick in.

Annex 2: Detailed description of the shocks

The following section describes in further detail the shocks applied to the model.

The effect of new HSR infrastructure:

The effect of new HSR infrastructure is the most important shock and forms an integral part of the study. This shock represents the impact of the construction of new HSR infrastructure on the demand for HSR. The shock is based on various academic papers estimating both the effects of new HSR infrastructure and open-access competition. The estimated effect of the infrastructure is estimated at 3,27% increase in LD demand (pkm) per 1% of population affected, computed at FUA level. The demand growth is estimated to be 45% generated, 14% shifted from other rail, 19% shifted from road, 23% shifted from air.

Sources:

- Beria, Grimaldi, An ex-post cost benefit analysis of Italian High Speed train, five years after (2016)
- Cascetta, Le conseguenze dell'alta velocità in Italia
- Betancor, Contabilidad Financiera y Social de la Alta Velocidad en España (2015)
- Giuricin, Tosatti, The history of Italo and the benefits of competition in the Italian HSR sector (2018)

- Cascetta et al, Analysis of mobility impacts of the high speed Rome–Naples rail link using within day dynamic mode service choice models (2011)
- Beria et al, Delusions of success: Costs and demand of high-speed rail in Italy and Spain (2018)

This analysis has been partially performed jointly with the one for the following shock (HSR open-access competition). The impact of the opening of a new HS infrastructure where open access services are operated has been estimated, then the two different effects have been computed separately: the one only deriving by the opening of a new HS infrastructure and the one deriving only by the open access competition. The results come from the listed sourced and by internal calculations. The impacts documented in cases where just new infrastructure has been opened (Spain and Italy in the first two years, before the entrance to the market of Italo) have been compared with the one documented in cases where a newcomer started operating long distance services in open market regime (Italy after the entrance of Italo and Austria with WestBahn).

HSR open-access competition:

The competition shock will account for the future liberalisation and competition in the HSR market. The type of competition considered is open-access competition where operators compete directly in the market with the incumbent. The potential effects of increased competition are many. Firstly, it leads to lower fares due to the non-incumbent being deprived of its possibility to set fares at more than its marginal costs. For this study, the estimation is 1,36% decrease in LD services prices per 1% increase in degree of market opening (share of services operated by non-incumbent RUs). Secondly, capacity will increase since more operators will provide their services. Lastly, service quality will improve. All in all, these factors will increase demand for HSR. For this study a 2,58% increase in HSR demand (pkm) per 1% increase in degree of mkt opening (share of services operated by non-incumbent RUs). The demand growth is estimated to be 45% generated, 14% shifted from other rail, 19% shifted from road, 23% shifted from air. The study has taken into consideration the prevalence of Public Service Obligation (PSO) competition for passenger rail services, however as competition on HSR lines are generally in the form of open-access, it has been chosen as the form of competition for the shock[53]. The shock assumes the share of the non-incumbent(s) to be 50% by 2070, however not if the non-incumbent is an incumbent in another country included in the study.

Sources:

- Beria, Grimaldi, An ex-post cost benefit analysis of Italian High Speed train, five years after (2016)
- Cascetta, Le conseguenze dell'alta velocità in Italia
- Betancor, Contabilidad Financiera y Social de la Alta Velocidad en España (2015)
- Giuricin, Tosatti, The history of Italo and the benefits of competition in the Italian HSR sector (2018)
- Cascetta et al, Analysis of mobility impacts of the high speed Rome–Naples rail link using withinday dynamic mode service choice models (2011)

[53] See p, 25 in CER (2017). *Public Service Rail Transport in the European Union: an Overview.* Retrieved from CER_PSO_Brochure.pdf

- Beria et al, Delusions of success: Costs and demand of high-speed rail in Italy and Spain (2018)
- Desmaris, Croccolo, High speed rail open access competition in Italy: a major railway market innovation for a win-win game? [La compétition sur le marché de la grande vitesse ferroviaire en Italie: une innova" (2018)
- Bergantino et al, The impact of open access on intra- and inter-modal rail competition. A national level analysis in Italy, (2015)

This analysis has been partially performed jointly with the one for the preceding shock (new HSR infrastructure). The impact of the opening of a new HS infrastructure where open access services are operated has been estimated, then the two different effects have been computed separately: the one only deriving by the opening of a new HS infrastructure and the one deriving only by the open access competition. The results come from the listed sourced and by internal calculations. The impacts documented in cases where just new infrastructure has been opened (Spain and Italy in the first two years, before the entrance to the market of Italo) have been compared with the one documented in cases where a newcomer started operating long distance services in open market regime (Italy after the entrance of Italo and Austria with WestBahn).
The impact in term of price reduction has been taken by the listed sources and confirmed by internal elaborations.

Shared mobility:

The shared mobility shock will account for the estimated effects of car sharing on the demand for passenger land transport. The reasoning behind its effect on demand for HSR is that certain passengers, more specifically passengers with a low willingness to pay and to some extent environmentally conscious, would choose car sharing services where the price would be lower than for HSR. The shock is based on a study conducted by the French ministry for the Environment, Energy and the Sea. Consequently, the study is based on the French market, which is quite mature due to the presence of consolidated car sharing platforms available. The demand for car sharing would increase with 9,9 billion PKM while the demand for rail will decline with 8,9 billion PKM by 2050 as compared to 2015. Also in France, a 2014 national survey found that one-way carsharing reduces public transit use. In the US, where carsharing finds its roots, a study of the Transportation Sustainability Research Center also confirms this decline. Out of their survey respondents 9,4% reduced their rail use, while 7,9% increased it. This results in a net decrease of rail use.

Source:

- Le Service de l'économie, de l'évaluation et de l'intégration du développement durable, & Ministère de l'Environnemnt, de l'Energie et de la Mer. (2016). *THÉMA Analyse : Projections de la demande de transport sur le long terme*.
- 6t. (2014). One-Way Carsharing: Which Alternative to Private Cars?
- Martin, E., & Shaheen, S. (2011). The Impact of Carsharing on Public Transit and Non-Motorized Travel: An Exploration of North American Carsharing Survey Data. Energies, 4(11), 2094–2114. https://doi.org/10.3390/en4112094

Long-distance bus competition:

The liberalisation of long-distance bus competition shock is based on the same report as for the car sharing shock above. The liberalisation is expected to introduce more routes throughout Europe, which can offer a lower cost alternative to other modes. While the study only accounts for France, many of the operators are present in the markets of other European countries. The study estimates bus and coach traffic to increase with 11.8 billion PKM by 2050 compared to no liberalisation. Resulting in a decrease with 8.7 billion PKM for rail. This hypothesis is supported by past data. A 2019 study describing the intercity bus market in France found that the liberalisation of this market resulted in 2,7 billion pkm travelled by long-distance bus in 2018 (an increase of 19,2% compared to the previous year). Meanwhile, interurban train use amounted to 5,5 billion pkm in 2018. This is a decline by 7,5% compared to 2013 though. The study suggests that this decline is likely in favour of long-distance bus travel.

Source:

- Le Service de l'économie, de l'évaluation et de l'intégration du développement durable, & Ministère de l'Environnemnt, de l'Energie et de la Mer. (2016). *THÉMA Analyse : Projections de la demande de transport sur le long terme*.
- Laurent Guihéry. (2019). Long Distance Coach Services in France and Germany: the new European competition between Flixbus and BlaBlaBus. Research Papers in Economics. https://ideas.repec.org/p/hal/journl/halshs-02374703.html

Fuel (passenger car) price:

The fuel price shock covers the effects of an increase in the fuel (pump) price for passenger cars on the demand for passenger car and rail traffic. The study covers France and is based on French data from 1990 to 2010 calculating the demand elasticities for the two modes. The study finds that a 10% increase in fuel prices will lead to a 2,9% decrease in highway traffic and a 2,4% increase in rail traffic in the long-term. The results are concluded to mainly be due to mode shift as a result of the increase in the costs of travelling by car. Several studies with previous data on the French national railway network further confirm this conclusion of increasing rail traffic when fuel prices are rising. Blain & Nguyen (1994) find an elasticity of 0,20; meaning a 2% increase in rail travel when Fuel prices rise by 10%. Bergel et al. (1995) found an elasticity of 0,21. These values all are very close to the most recent elasticity value of 0,24 that is used for this shock.

Source:

- Delsaut, M. (2014). The Effect of Fuel Price on Demands for Road and Rail Travel: An Application to the French Case. *Transportation Research Procedia*, *1*(1), 177–187. https://doi.org/10.1016/j.trpro.2014.07.018
- Blain, J.C., Nguyen, L. (1994) Modélisation de trafics de voyageurs: prise en compte de la qualité de l'offre, Notes de synthèse du OEST. Bonnel, P.

(2001) Prévision de la demande de transport, Rapport présenté en vue de l'obtention du diplôme d'habilitation à diriger les recherches, Université Lumière Lyon 2

- Bergel, R., Blain, JC., and Fiang, F. (1995) Elasticités du trafic ferroviaire de voyageurs à la consommation et aux prix, Synthèse OEST.

Short-haul flight ban:

This shock incorporates the effects of ban on short-haul flights where there is a rail line serving the same connections and the rail travel time is lower than 6 hours. The study covers Europe based on route data from 2019 for both passenger aviation and rail (mainly HSR). The shock is included to account for the introduction of the ban considered in some European countries. The study estimates that 15% of flights all flights covered by the study with a 6-hour rail alternative will be replaced by rail. The findings are supported by Renato et al. (2021) who find that 17% of all intra-European flights can be replaced by rail if travel time is allowed to increase 20% and 7% can be substituted by rail with no increase in travel time. Data on local markets points in the same direction. A 2022 study by Reiter et al. examined four substitution scenarios for the German market. This study assumes a minimum amount of short haul flights to be maintained as to not harm Germany's feeding flights for its long-haul network. When the number of German short-haul flights decreases, the study shows rail demand across both the German and European rail networks would increase between 4% and 13% compared to 2019. A similar policy is being introduced in France[54].

Source:

- Szymczak, R. (2021). *Assessing the Impact of a Potential Short-Haul Flights Ban on European Airports* (pp. 146–163). https://doi.org/10.1007/978-3-030-70924-2_12
- *Avogadro, Nicolò & Cattaneo, Mattia & Paleari, Stefano & Redondi, Renato, 2021. "**Replacing short-medium haul intra-European flights with high-speed rail: Impact on CO2 emissions and regional accessibility**," Transport Policy, Elsevier, vol. 114(C), pages 25-39.*
- Reiter, V., Voltes-Dorta, A., & Suau-Sanchez, P. (2022). The substitution of short-haul flights with rail services in German air travel markets: A quantitative analysis. Case Studies on Transport Policy, 10(4), 2025–2043. https://doi.org/10.1016/j.cstp.2022.09.001

Aviation ticket tax:

This shock concerns the implementation of an EU-wide application of a €10.12 flat rate ticket tax on intra-EEA flights. This intra-EEA distinction includes flights inside the European Economic Area up to 6.000 km. It based on the distance zones used in existing German ticket tax legislation. A focus on intra-EEA flights is useful because possibilities for transport mode substitution are more evident. Important to note is that transit passengers (with destination and origin outside the EEA) are excluded from this ticket tax. These passengers are estimated to represent up to 15% of all passengers departing from EU airports. The shock is based on a study by

[54] EU approves France's short-haul flight ban — but only for 3 routes – POLITICO

Ricardo for the European Commission on possible ways to tax the aviation sector. This ticket tax should replace the current ticket taxes that are implemented by some member states (Austria, France, Germany, Italy, Netherlands, Portugal and Sweden). The implementation by member states has proven less than effective. Expected or factual avoidance reactions of passengers, who are migrating to non-taxed airports induce tax competition between member states. Therefore, an EU-wide implementation is suggested as a more effective way to tax aviation (Krenek & Schratzenstaller, 2017). The study decides on a €10,12 tax rate based on the equivalent fuel tax rate: average flight distances within each distance band and average fuel consumption per pkm on these flights are taken into account. The fuel tax rate used is 0,33 cents/L (see Aviation fuel tax shock). The study estimates that by applying a €10.12 ticket tax demand for passenger aviation on intra-EEA flights will decrease by 9%.

Source:

- European Commission DG TAXUD. (2021). *Study on the taxation of the air transport sector*.
- Krenek, A., & Schratzenstaller, M. (2017). Sustainability-oriented tax-based own resources for the European Union: a European carbon-based flight ticket tax. Empirica, 44(4), 665–686. https://doi.org/10.1007/s10663-017-9381-7

Aviation fuel tax:

This shock introduces the effects of an EU-wide aviation fuel tax of €0.33 per litre of fuel. The estimation of the effect is sourced from the same study as the aviation ticket tax. It is estimated that passenger aviation demand will decrease with 9.2% following the application of the fuel tax on all intra-EEA flights. The tax is based on article 14(2) of the Energy Taxation Directive (2003/96/EC), where a minimum excise duty rate of 33 cents/L can be applied to kerosene. A 2019 report for the European Commission describing existing and proposed aviation taxes and their impact confirms this decrease. They model for a EU-wide taxation regime, based on the same €0,33 per litre fuel tax. The study predicts a 11% decrease in passenger demand. No differentiation is made between intra- and extra-EEA flights. The shock used for our model is based on the 9,2% decrease from the Ricardo study because of the more detailed methodology.

Source:

- European Commission DG TAXUD. (2021). *Study on the taxation of the air transport sector*.
- European Commission, Directorate-General for Mobility and Transport, (2019). *Taxes in the field of aviation and their impact: final report*, Publications Office. https://data.europa.eu/doi/10.2832/913591

Highway toll fare:

The highway toll fare shock is comprised of the effect of the application of a highway toll fare on the European countries, where no toll/vignette is levied on passenger cars currently. It is based on various studies on the demand elasticity of the application of a highway toll. The estimated effect is a -0,3% demand elasticity of the application of a highway toll: highway use decreases by 3% per 10% increase in toll fare. The toll is only applied to the countries without a toll, since this study assumes the infrastructure costs covered fully by track access charges. Hence, the current highway tolls are assumed priced efficiently. Past research supports these numbers. A US study of Beaty et al. (2012) modelled an elasticity of traffic volume to toll prices of -0,35 for Texas highways, meaning that a 10% increase in toll fare would result in a 3,5% decrease in traffic volume. Also in the US, a 2010 study by Spears et al. found that traffic volumes to decrease by 1% to 4,5% for a toll increase of 10%; the elasticities of traffic volume to toll prices of -0,1 to -4,5. This study includes data from all around the US.

Source:

- Litman, T. A., & Victoria Transport Policy Institute. (2022). *Understanding Transport Demands and Elasticities How Prices and Other Factors Affect Travel Behavior*. www.vtpi.org
- Curtis Beaty, Mark Burris, and Tina Geiselbrecht (2013), Toll Roads, Toll Rates, and Driver Behavior, Texas A&M Transportation Institute
  Steven Spears, Marlon G. Boarnet and Susan Handy (2010), Draft Policy Brief on the Impacts of Road User Pricing Based on a Review of the Empirical Literature, California Air Resources Board (http://arb.ca.gov/cc/sb375/policies/policies.htm).

Shift2Rail technologies:

The effects of new railway technologies are included through a previous Shift2Rail Cost-Benefit analysis (CBA) study on the impact of the JUs program. It covers 36 technologies, grouped into 4 innovation programmes, promoted by the JU including digitalisation of the signalling (ETCS) and ticketing. The effects of the technologies are based on a case study from the Impact 1 study of the JU[55], where the generic track reference is the HSR line Paris-Tours-Poitiers. The CBA study estimates the total technological package to increase demand for HSR with 29,5% in 2050 as compared to a baseline where the S2R technologies are not deployed. The tables below provide an overview of the technologies included in this shock and their contribution to the modal shift of this shock.

Innnovation programmes (IP) contribution to modal shift

Mode	IP relative contribution to modal shift (sum=100%)	Rationale
High Speed	**IP**: 15%, **IP2**: 35%,	The changes in customer experiences (**IP4**) are expected to contribute most to the modal shift to high-speed lines. Advanced traffic management and

[55] Shift2Rail (2021). *Indicator Monitoring for a new railway Paradigm in seamlessly integrated Cross modal Transport chains – Phase 1, Deliverable D 3.3 use cases for SPDs*. Retrieved from Indicator Monitoring for a new railway PAradigm in seamlessly integrated Cross modal Transport chains - Phase 1 | IMPACT-1 Project | Results | H2020 | CORDIS | European Commission (europa.eu)

	IP3: 10%, **IP4**: 40%,	control systems to be developed through **IP2** will allow for some efficiency gains and improve the service offering. Performance and capacity improvements derived from **IP1 and IP3** will allow for an increase in traffic to a type of segment which already run at maximum capacity in large knots and some highly utilized lines (mainly in France).

Shift2Rail Technologies and their impact

Innovation Programme (IP) 1: Future generation of passenger trains	
IP 1 is focused on delivering a new generation of passenger trains, lighter and more energy- and cost-efficient, while at the same time providing a comfortable, safe and affordable travel experience for all passengers. It is organised around eight TDs[56]	
Technical Demonstrator (TD)	Expected Impact
TD 1.1 - Traction system. It will develop new traction components and subsystems, for Metro, Regional train and High-Speed Trains.	Through higher reliability, it will reduce maintenance costs but also slightly increase the capital costs of passenger fleets.
TD 1.2 - Train control and monitoring system (TCMS). A new-generation TCMS will allow bottlenecks caused by physically coupled trains to be overcome. The new drive-by-data concept for train control, along with wireless information transmission, aims to make new control functions possible.	It will slightly reduce the capital and maintenance costs of high-speed trains. The main impacts are unlocking functionalities developed in other TDs.
TD 1.3 - The new generation of car body. Lightweight materials will lead to significantly lighter vehicles.	More passengers within the same axle load constraints (higher revenue), use less energy (lower operating costs) and have a reduced impact on rail infrastructure (lower maintenance costs).
TD 1.4 - Running gear. It will develop innovative combinations of new architectural concepts, new actuators in new lighter materials.	New functionalities, and significantly improved performance levels with the possibility of vibration energy recovery.
TD 1.5 - New braking systems. They will allow higher brake rates and lower noise emissions will.	Higher mass and volume in bogies, leading to higher line capacity (increased revenue).
TD 1.6 - Innovative doors. New lightweight composite structures could be made to react faster at existing safety and reliability levels.	Reducing platform dwell times and increasing overall line capacity, and Better consumer experience (increased revenue), lower energy consumption (lower operating costs).
TD 1.7 - Train modularity in use. New modular concepts for train interiors that allow operators to adapt the vehicle layout to the actual usage conditions, and will improve passenger flows, thus optimising both the capacity of the vehicle and dwell times.	Increased capacity (increased revenue).
TD 1.8 - Heating, Ventilation, Air conditioning and Cooling (HVAC) systems. It will help limiting the climatic	No clear financial impact.

[56] Source for the description of TDs: Europe's Rail (2022). *Innovation Programme 1*. Retrieved from https://shift2rail.org/research-development/ip1/

impact from these systems within rail vehicles.	
IP 2: Communication, traffic management and control systems	
IP 2 is focused on deploying advanced communications systems and enhancing traffic management (including predictive and adaptive operational control of train movements). Shift2Rail activities will support the rapid and widespread deployment of advanced traffic management and control systems by providing improved functionalities and standardised interfaces based on common operational concepts, easing migration from legacy systems, lowering overall costs, and adapting them to the needs of different rail segments as well as a multimodal smart mobility system. It is organised around 11 TDs[57]	
Technical Demonstrator (TD)	Expected Impact
TD 2.1 - Communication System. It aims to overcome the shortcomings in the current European Train Control System (ETCS) and Communications-Based Train Control (CBTC) and deliver an adaptable train-to-ground communications system usable for train control applications in all market segments, using packet switching/IP technologies (GPRS, EDGE, LTE, Satellite, Wi-Fi, etc.). The system will enable easy migration from existing systems (e.g., GSM-R), provide enhanced throughput, safety and security functionalities to support the current and future needs of signalling systems, and be resilient to interference and open to developments in radio technology. Backwards compatibility with ERTMS will be ensured.	Increased capacity, speed (quality of service), safety and security.
TD 2.2 - Automatic Train Operation (ATO). The aim is to develop and validate a standard ATO up to GoA3/4 over ETCS, where applicable, for all railway market segments (mainline/high speed, urban/suburban, regional and freight lines).	Increased capacity and safety.
TD 2.3 - Moving Block. It aims to improve line capacity by decoupling the signalling from the physical infrastructure, and removing the constraints imposed by trackside train detection, thereby allowing more trains on a given main line, especially for high-density passenger services.	Increased capacity, speed (quality of service) and safety.
TD 2.4 - Safe Train Positioning. It aims to develop a fail-safe, multi-sensor train positioning system (applying Global Navigation Satellite Systems (GNSS) technology to the current ERTMS/ETCS core and possible introducing an add-on for fulfilling the scope). It will enable the use of other new technologies (e.g., inertial sensors) or sensors (e.g., accelerometers, odometer sensors), to boost the quality of train localisation and integrity information,	Increased capacity, speed (quality of service) and safety, reduction of costs.

[57] Europe's Rail (2022). *Innovation Programme 2*. Retrieved from https://shift2rail.org/research-development/ip2/

while also reducing overall costs, in particular by enabling a significant reduction in all trackside conventional train detection systems (balises, track circuits and axle counters).	
TD 2.5 - Train Integrity. It aims to specify and prototype an innovative on-board train integrity solution, capable of autonomous train-tail localisation, wireless communication between the tail and the front cab, safe detection (SIL4) of train interruption and autonomous power supply functionality without the deployment of any fixed trackside equipment. This functionality will be developed for those market segments (e.g., freight and low traffic lines) lacking such a function.	Increased safety and reduction of costs.
TD 2.6 - New laboratory test framework. The development of a new framework comprises simulation tools and testing procedures for carrying out open test architecture with clear operational rules and simple certification of test results. It aims to minimise on-site testing by performing full laboratory test processes. The test framework will also allow remote connection of different components/subsystems located in various testing labs.	Reduction of costs, increased capacity in marshalling yards (due to testing grounds no longer being required).
TD 2.7 - Standardised engineering and operational rules. It aims to contribute to the creation of an open standard interface and a functional ETCS description model, all based on formal methods. It will ease verification and authorisation processes, eventually leading to improved interoperability, while reducing the need for extensive field tests in future.	Reduction of costs and reduction of administrative burden for market entries and innovative solutions.
TD 2.8 - Virtual Coupling. It aims to enable 'virtually coupled trains' to operate much closer to one another (within their absolute braking distance) and dynamically modify their own composition on the move (virtual coupling/uncoupling of train convoys).	Significantly increased capacity and speed (quality of service).
TD 2.9 - Traffic Management System. It aims to improve traffic management operations with automated processes for data integration and exchange with other rail business services. The backbone of the new architecture will be a scalable, interoperable and standardised communication structure applicable within an integrated rail services management system. These features will be combined with new business service applications to allow for predictive and dynamic traffic management. It will use and integrate real-time status and performance data from the	Increased attractiveness of service through higher punctuality, increased capacity, reduced operational expenditures.

network and from the train, using on-board train integrity solutions and network object control functions, supported by wireless network communication.	
TD 2.10 - Smart radio-connected all-in-all wayside objects. This TD aims to develop autonomous, complete, intelligent, self-sufficient smart equipment ('boxes') able to connect not only with control centres (e.g., interlocking) or other wayside objects and communicating devices in the area (by radio or satellite), but also, for instance, with on-board units. Such intelligent objects – knowing and communicating their status conditions – would not only provide opportunities in terms of cost reduction and asset management improvement, but also set out new means of railway network information management and control.	Increased attractiveness of service through higher speeds and punctuality, reduced operational expenditures.
TD 2.11 - Cyber Security. It aims to achieve the optimal level of protection against any significant threat to the signalling and telecom systems in the most economical way (e.g., protection from cyber-attacks and advanced persistent threats coming from outside).	Reduced cyber risks - no direct impact on cash flow.
IP 3: Infrastructure	
IP3 is focused on enhancing and upgrading the rail network infrastructure and optimizing its management and maintenance. It is organised around 11 TDs[58]	
Technical Demonstrator (TD)	**Expected Impact**
TD3.1 - Enhanced Switch & Crossing System is to improve the operational performance of existing Switch & Crossing (S&C) designs by delivering new S&C subsystems with improved RAMS, LCCs, sensing and monitoring capabilities, self-adjustment, noise and vibration performance, interoperability, and modularity.	Increased capacity and quality of service (safety & speed), reduction of operational expenditures.
TD3.2 – Next Generation Switch & Crossing System intends to produce radical, creative system solutions that deliver new techniques for guiding trains to cross tracks with the goal of improving capacity while lowering maintenance costs, traffic disruptions, and LCCs.	Increased capacity and quality of service (safety & speed), reduction of operational expenditures.
TD 3.3 - Optimised Track System will examine how new solutions in the form of goods, processes, and procedures might achieve improved levels of dependability, sustainability, capacity, and LCC savings by challenging track construction assumptions now inherent in track design. The goal is to provide medium-term solutions, which necessitates that the	Increased capacity and quality of service (safety & speed), reduction of operational and capital expenditures for new infrastructure.

[58] Europe's Rail (2022). *Innovation Programme 3*. Retrieved from https://shift2rail.org/research-development/ip3/

solutions be compatible with existing solutions and regulations.	
TD 3.4 – Next-Generation Track System intends to significantly improve the track system, with a time frame of 40 years beyond the current state of the art. This suggests that significant improvements in performance should be prioritized. The TD process will follow a tightly connected chain, beginning with analyzing the railway's long-term needs and feasible ways to achieve them.	Increased capacity, and quality of service (safety & speed).
TD 3.5 – Proactive Bridge and Tunnel Assessment, Repair, and Upgrade project's major goal is to enhance inspection procedures and repair processes in order to minimize costs, improve quality, and, if possible, extend the service life of bridges and tunnels. Furthermore, noise and vibration reduction are prioritized goals.	Reduced maintenance costs and operational costs.
TD 3.6 – Dynamic Railway Information Management System (DRIMS) aims to create an innovative system for managing, processing, and analyzing railway data. This TD's operations will be closely linked to the other two TDs in the area of data collection and administration. The purpose of DRIMS is to collect data from the Railway Integrated Measuring and Monitoring System (RIMMS – TD 3.7) and offer high-quality input to Intelligent Asset Management Strategies (IAMS – TD 3.8).	More targeted investments and lower risk investments.
The goal of **TD 3.7 - Railway Integrated Measuring and Monitoring System (RIMMS)** is to provide non-intrusive and completely integrated tools and methodologies for obtaining information on the present status of assets. To that purpose, the TD will concentrate on collecting asset status data in collaboration with TD3.1 through TD3.5.	More targeted investments and lower risk investments, higher quality of service (information to the customer).
The vision of **TD 3.8 - Intelligent Asset Management Strategies (IAMS)** is a holistic, whole-system approach to asset management that uses data collected and processed by TD3.6 and TD3.7. This includes incorporating long-term strategies into the day-to-day maintenance and other maintenance tasks.	More targeted investments and lower risk investments.
The **TD 3.9 – Smart Power Supply** project's overall goal is to establish a railway power grid as part of a larger integrated and communicating system.	Lower exposure to global energy price volatility, higher quality of service (less pollution, higher speeds and lower noise levels).
TD 3.10 – Smart Metering for Railway Distributed Energy Resource	More targeted investments and lower risk investments, lower energy cost (OPEX).

Management System aims to create a precise map of energy flows throughout the railway system, which will serve as the foundation for any energy management strategy.	
TD 3.11 - Future Stations project's main ambition is to improve the station's consumer experience. The TD is organized around four core functional demands: two demands address capacity and security in large stations, one demand addresses small station design with the goal of lowering whole-life costs and standardizing design, where practicable, and the final demand addresses accessibility[59].	Improved quality of service (customer experience)
IP 4: Technical framework, Customer experience applications and Multimodal travel services.	
IP4 is focused on significantly improving service quality for rail users and making multimodal travel easier. It develops interoperability standards for TSPS, solutions to ease ticket search and purchase, and journey tracking. It is organised around 6 TDs[60]	
Technical Demonstrator (TD)	Expected Impact
TD4.1 - Interoperability Framework aims to make multimodal travel easier in a diversified setting with several modes of transportation. The world of transportation service providers requires flexibility; it advances at its own speed and employs a variety of data types and interfaces. At the semantic level, interoperability creates formal and explicit representations of the transportation domain in an open, standard, machine-readable language that computers can exchange automatically.	Increased quality and thus attractiveness of service.
TD4.2 – Travel Shopping intends to provide a comprehensive shopping application enabler that includes all modes of transportation, all operators, and all geographies, and produces a list of customer-relevant trip offers that are guaranteed available for booking, purchase, and ticketing. The IP4 model encourages the integration of data from distributed travel providers as well as the orchestration of services like expert journey planning. The Interoperability Framework will make things easier by allowing applications based on multiple standards or code lists to communicate meaningfully without requiring costly application adjustments.	Increased demand for rail transport.

[59] Europe's Rail (2022). *Innovation Programme 3*. Retrieved from https://shift2rail.org/research-development/ip3/

[60] Europe's Rail (2022). *Innovation Programme 4*. Retrieved from https://shift2rail.org/research-development/ip4/

TD4.3 - Booking & Ticketing will manage multiple but concurrent interactions with several booking, payment, and ticketing engines, including the all-important roll-back activities. The traveller will have easy access to the whole and integral components of his or her journey, including easy generation of the entitlement tokens required for all ticket validation controls encountered en-route, thanks to the concept of a unique passenger identify and wallet. It will drastically simplify the traveller's life by eliminating the uncertainties associated with several booking, payment, and ticketing processes that take place "behind the scenes".	Improved customer experience (information).
TD4.4 - Trip-tracker will provide travellers with in-trip assistance when navigating transportation nodes, as well as personalized information (based on predefined preferences) and up-to-date status reports on subsequent legs of the journey; it will also assist them in the event of a disruption by suggesting updated booking options as well as updated travel rights.	Improved customer experience (information).
TD4.5 Travel Companion keeps and communicates traveller's personal preferences in a wallet, the traveller will have complete control over their journey. It will provide access to all travel services, including purchasing and booking, as well as the ability to store travel rights. Retailers and operators will be able to identify and authorize the Travel Companion to access their systems at the same time.	Improved customer experience (information).
TD 4.6 - Business Analytics Platform will be in charge of managing those data. Novel 'big data' technologies, such as 'intentional' semantic information (denoting objects by properties rather than values), will enhance the ability to analyse distributed and heterogeneous linked data, opening up a slew of new opportunities for all ecosystem actors to gain unprecedented insights and new intelligence for the benefit of operators and travellers.	

Annex 3: Sensitivity analysis

As referred to in section 3.2.1, the parameters used to quantify the impacts of the different shocks are based on an analysis of different academic sources. These parameters can be subject to debate because of different possible limitations, noticeably the fact that they are based on the experience of a specific European country.

The objective of the sensitivity analysis is to quantify the impact of the variation in the different parameters. Hereby, assessing the degree of robustness of the results and to suggest future improvement points.

The table below summarises the parameters that will be subject to sensitivity analysis in this section:

Shock	Parameter	Base value
New HSR infrastructure	x% increase in HSR demand (pkm) per 1% of pop. affected	3,27%
Open-access competition on LD services	x% increase in long distance demand (pkm) per 1% increase in degree of mkt opening (share of services operated by non-incumbent RUs)	2,58%
	x% market opening in 2030	30%
	x% market opening in 2050	40%
	x% market opening in 2050	50%
Shared mobility	x% market demand for car	2,8%
LD bus comp.	-x% for market demand for rail	-2,7%
Fuel price	Increase of x% in market demand for rail	2,4%
Short-haul flight ban	x% of all flights with up to 6-hour rail alternative will be replaced by rail	15%
Ticket tax	-x% demand for aviation.	-8,3%
Aviation fuel tax	-x% demand for aviation.	-9,2%
Impact of S2R technologies	x% increase in HSR modal share	11,4%
Highway tolls	-x% decrease in demand for passenger car	-3%

Table 6: Parameters included in the sensitivity analysis

In the sensitivity analyses, besides the varying parameter, all other shocks are applied at their base value, which means that the active scenario will be scenario 2050 (the only scenario with all the shocks being applied).

Sensitivity to new infrastructure effect

One of the main defining features of the market assessment model is the assumption that a new HSR infrastructure induces an increase of market demand that is proportional to the percentage of the population affected by this new line compared to the overall national population. The underlying assumption is: "if a new infrastructure affects *y%* of the country population, then it results in an increase of *x*y%* of the traffic demand for HSR". In the model, the value of x is equal to 3,27, and it is based on the analysis of various studies on different European examples (see paragraph 3.2.1 and the annexes for more details).

The figures below show the impact of varying the parameter x around the value used in the model, specifically between 2,45 (75% of the base value) and 4,09 (125% of the base value):

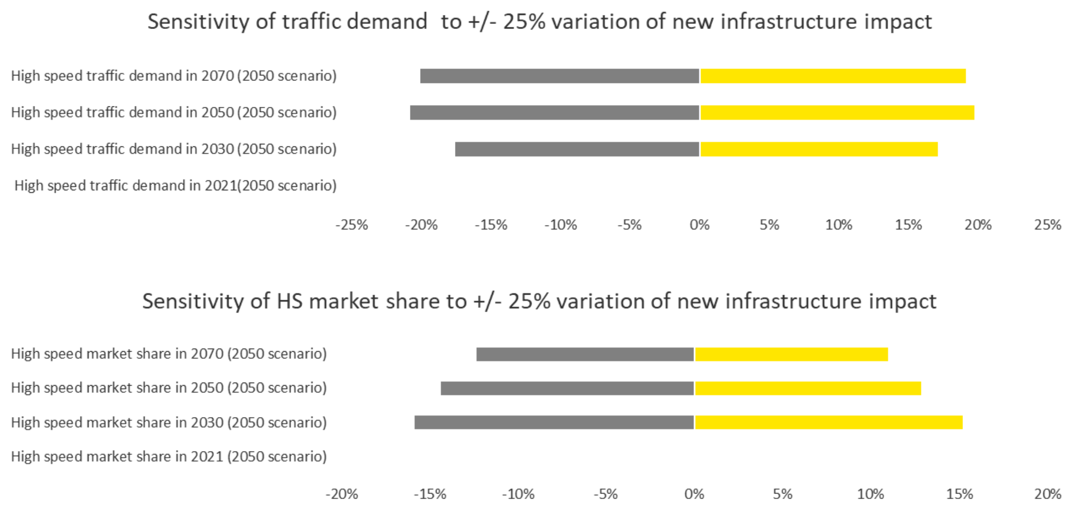


Figure 14: Sensitivity of market assessment model to the infrastructure shock impact

Two comments can be made on these results:

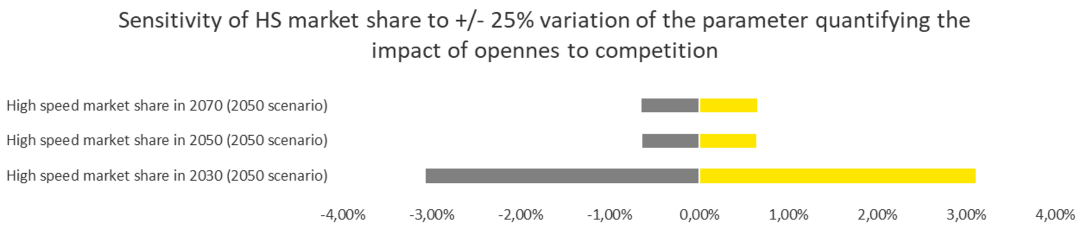
- In general, the model sensitivity to the variation of the parameter quantifying new infrastructure impact has on average elasticity between 0,5 and 1. This elasticity is lower on the market share side. This stems from the uncertainty in the model's forecast of the overall traffic demand (the baseline scenario) which is based on a forecast of population and GDP growth (two uncertain variables). This factor of uncertainty is removed when considering the market share evolution.
- In a somewhat counter-intuitive manner, the sensitivity of market share shows that the farther the model goes down the projection, the lower the impact of the parameter variation. This means that the various impacts of the different shocks converge in the longer run and hereby balancing each other. This result is also perceivable, to a lesser extent, on the traffic demand. The difference being that the traffic demand is, as mentioned in the first point, influenced by the overall traffic demand forecast, where uncertainty increases the farther the project goes.

Sensitivity to market opening to competition

As for new infrastructure, this shock impact is quantified by the multiplication of two variable. The assumption being: "if *Δy%* of the HSR market is gained by non-incumbent Rus between year n-1 and year n, then the traffic demand for HSR increases by of *x*Δy%* in the same period". But, contrarily to the previous shock where the assumption of construction of new lines is based on a whole separate methodology, here the degree of openness to competition is a variable parameter that can be include in a sensitivity analysis. So, there will be two sensitivity analyses for this shock w=one for the parameter x and one for the degree of openness to competition y.

Sensitivity to the parameter x (impact of market openness)

In the model the parameter quantifying the impact of market openness is equal to 2,58%, based on academic sources (section 3.2.1 and annex for more details). The sensitivity is done for a variation between 1,94% and 3.23% (i.e., +/- 25% of this value).



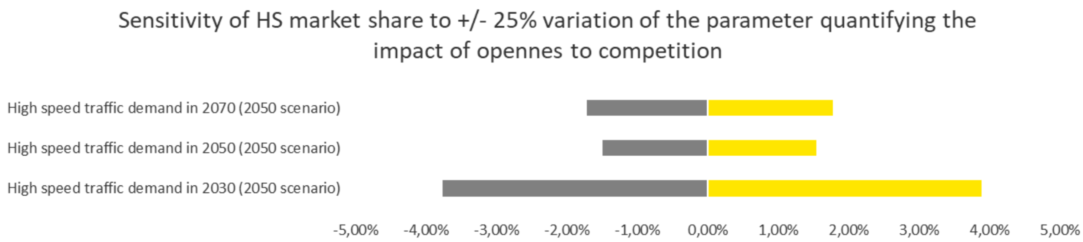


Figure 15: Sensitivity of the model to the parameter quantifying the impact of openness to competition

The sensitivity analysis shows that the model is virtually not sensitive to the parameter. But before dressing any conclusions, let's examine the sensitivity to the other variable defining the shock:

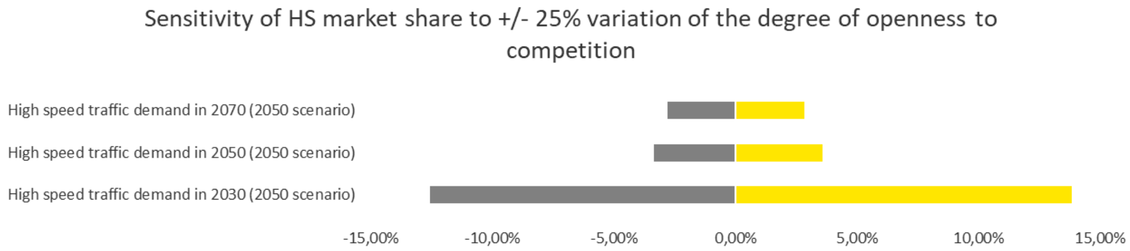
Sensitivity to the degree of market openness

In the model, the current (and different) degrees of openness to competition of the different EU countries have been taken into account as a starting point, but a convergence is assumed within the European union towards these averages: 30% in 2030; 40% in 2050 and 50% in 2070.

The sensitivity analysis varies simultaneously these three numbers as such:

Openness to competition	"-25,0%"	"-12,5%"	Base value	"+12,5%"	"+25,0%"
In 2030	20%	25%	30%	35%	40%
In 2050	30%	35%	40%	45%	50%
In 2070	40%	45%	50%	55%	60%

The results of the sensitivity analysis are shown in the figures below:



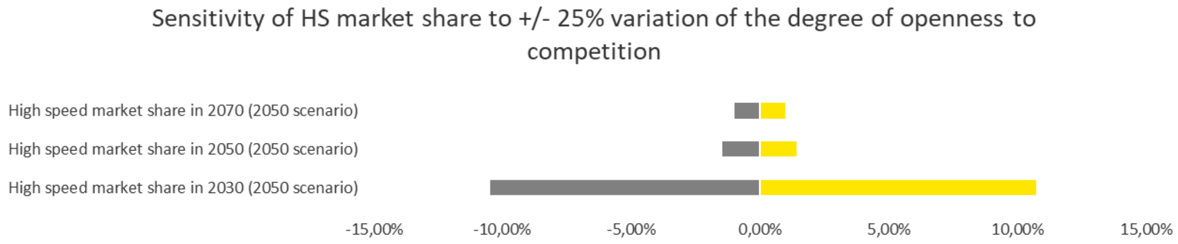


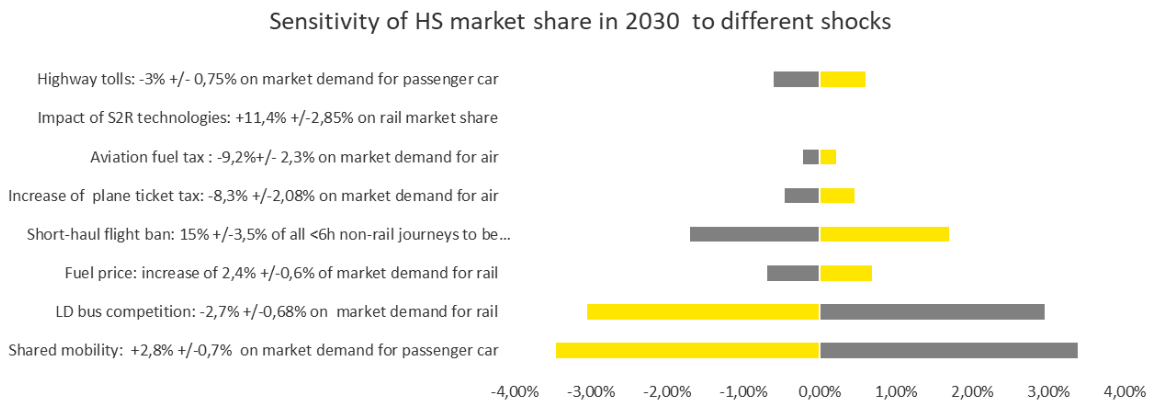
Figure 16: Sensitivity analysis to the degree of openness to competition

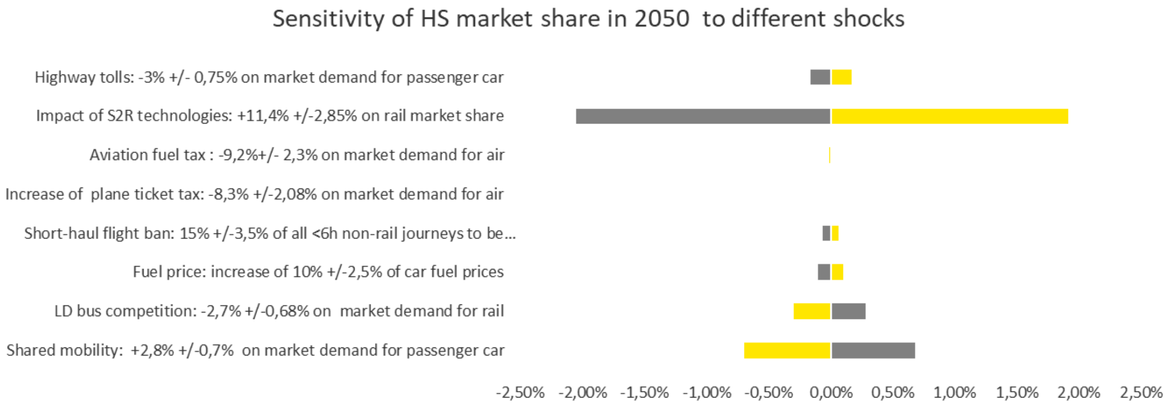
It appears that while in the long run the results of the model have a low sensitivity to the evolution of the openness to competition (as the new infrastructure shock includes implicitly the assumption that HS market is fully open to competition), the results of the model for the middle run are strongly sensitive to the degree of openness to competition.

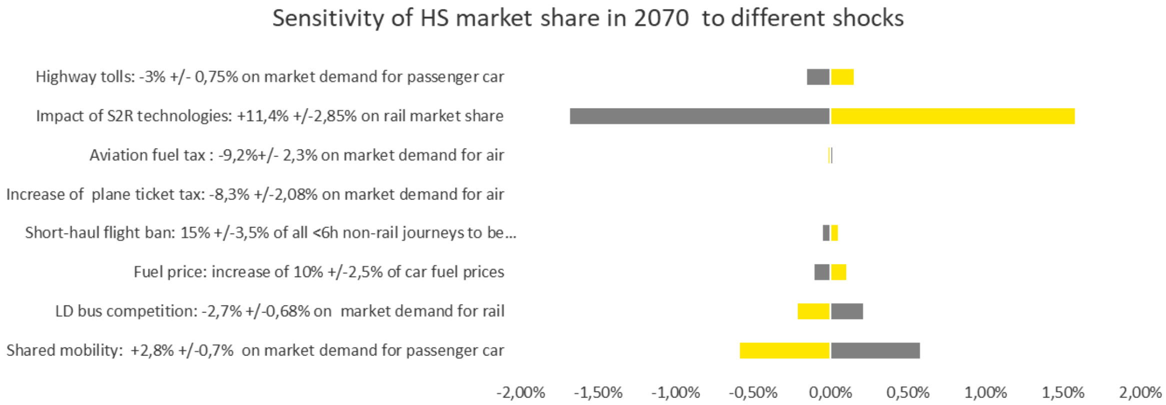
Sensitivity to other shocks:

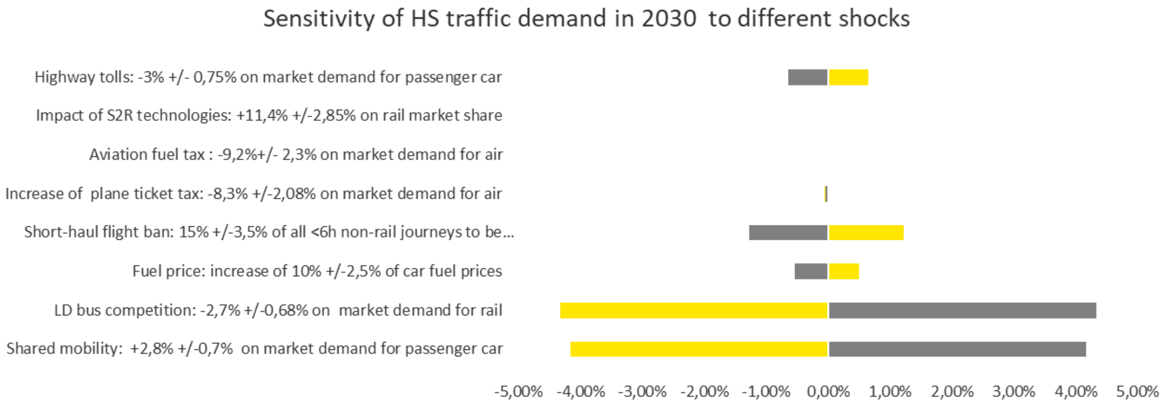
For other shocks listed in the beginning of this section, the sensitivity analysis is more straightforward as only one parameter can be varied.

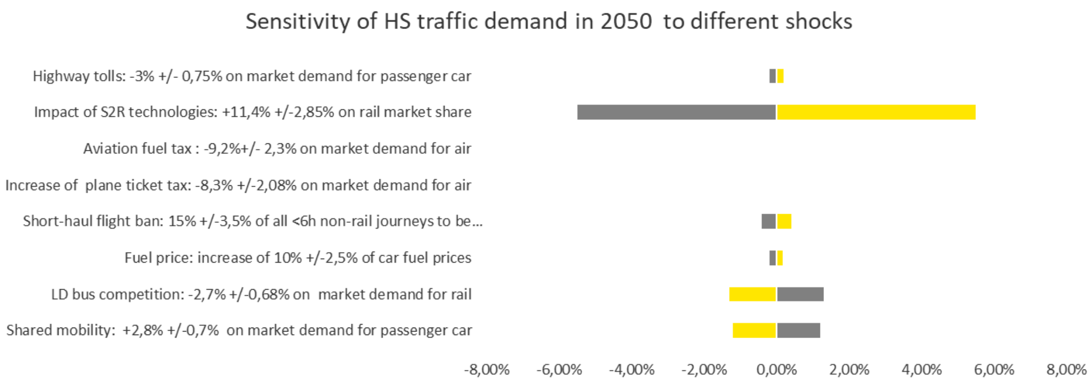
The figures below show the results of the sensitivity analysis to the different shocks:




Sensitivity of HS market share in 2050 to different shocks
Highway tolls: -3% +/- 0,75% on market demand for passenger car
Impact of S2R technologies: +11,4% +/-2,85% on rail market share
Aviation fuel tax : -9,2%+/- 2,3% on market demand for air
Increase of plane ticket tax: -8,3% +/-2,08% on market demand for air
Short-haul flight ban: 15% +/-3,5% of all <6h non-rail journeys to be...
Fuel price: increase of 10% +/-2,5% of car fuel prices
LD bus competition: -2,7% +/-0,68% on market demand for rail
Shared mobility: +2,8% +/-0,7% on market demand for passenger car
-2,50% -2,00% -1,50% -1,00% -0,50% 0,00% 0,50% 1,00% 1,50% 2,00% 2,50%


Sensitivity of HS market share in 2070 to different shocks
Highway tolls: -3% +/- 0,75% on market demand for passenger car
Impact of S2R technologies: +11,4% +/-2,85% on rail market share
Aviation fuel tax : -9,2%+/- 2,3% on market demand for air
Increase of plane ticket tax: -8,3% +/-2,08% on market demand for air
Short-haul flight ban: 15% +/-3,5% of all <6h non-rail journeys to be...
Fuel price: increase of 10% +/-2,5% of car fuel prices
LD bus competition: -2,7% +/-0,68% on market demand for rail
Shared mobility: +2,8% +/-0,7% on market demand for passenger car
-2,00% -1,50% -1,00% -0,50% 0,00% 0,50% 1,00% 1,50% 2,00%


Sensitivity of HS traffic demand in 2030 to different shocks
Highway tolls: -3% +/- 0,75% on market demand for passenger car
Impact of S2R technologies: +11,4% +/-2,85% on rail market share
Aviation fuel tax : -9,2%+/- 2,3% on market demand for air
Increase of plane ticket tax: -8,3% +/-2,08% on market demand for air
Short-haul flight ban: 15% +/-3,5% of all <6h non-rail journeys to be...
Fuel price: increase of 10% +/-2,5% of car fuel prices
LD bus competition: -2,7% +/-0,68% on market demand for rail
Shared mobility: +2,8% +/-0,7% on market demand for passenger car
-5,00% -4,00% -3,00% -2,00% -1,00% 0,00% 1,00% 2,00% 3,00% 4,00% 5,00%


Sensitivity of HS traffic demand in 2050 to different shocks
Highway tolls: -3% +/- 0,75% on market demand for passenger car
Impact of S2R technologies: +11,4% +/-2,85% on rail market share
Aviation fuel tax : -9,2%+/- 2,3% on market demand for air
Increase of plane ticket tax: -8,3% +/-2,08% on market demand for air
Short-haul flight ban: 15% +/-3,5% of all <6h non-rail journeys to be...
Fuel price: increase of 10% +/-2,5% of car fuel prices
LD bus competition: -2,7% +/-0,68% on market demand for rail
Shared mobility: +2,8% +/-0,7% on market demand for passenger car
-8,00% -6,00% -4,00% -2,00% 0,00% 2,00% 4,00% 6,00% 8,00%

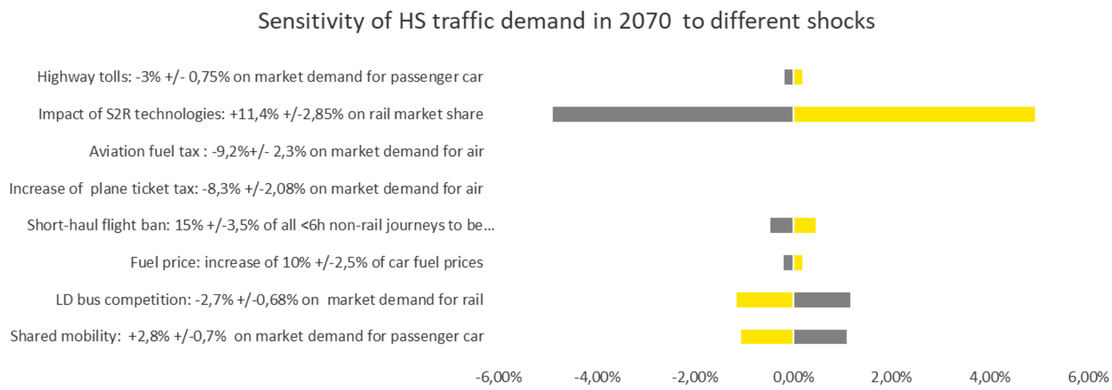


Figure 17: Model sensitivity to the different shocks

These different graphs show that:

- In general, the overall sensitivity of the model to the parameters defining the shocks is quite low: for a variation of the parameter of +/- 25%, the result varies, at most, by 6%.
- The impact strength of the different shocks is highly correlated with the nature of the shock: conjunctural shocks that are assumed to appear punctually and early have a strong impact on 2030 figures but see their impact decrease on the long run. On the other hand, structural shocks, noticeably S2R technological pack, sees its impact at a maximum in 2050.
- When compared with the shocks examined in the beginning of the section, it appears that, by far, the most impactful shock is resulting from new infrastructure development. This is why this shock benefited from a special attention all along the development of the model: scenario 2050 represents an ambitious target for high-speed rail in Europe: its realization will bring significant increase of market share and market demand for rail, and subsequently tangible economic and socio-economic benefits.

Annex 4: Maps of the HSR network per region/country

The following section presents the network per country. The ochre areas denote an Urban Area.

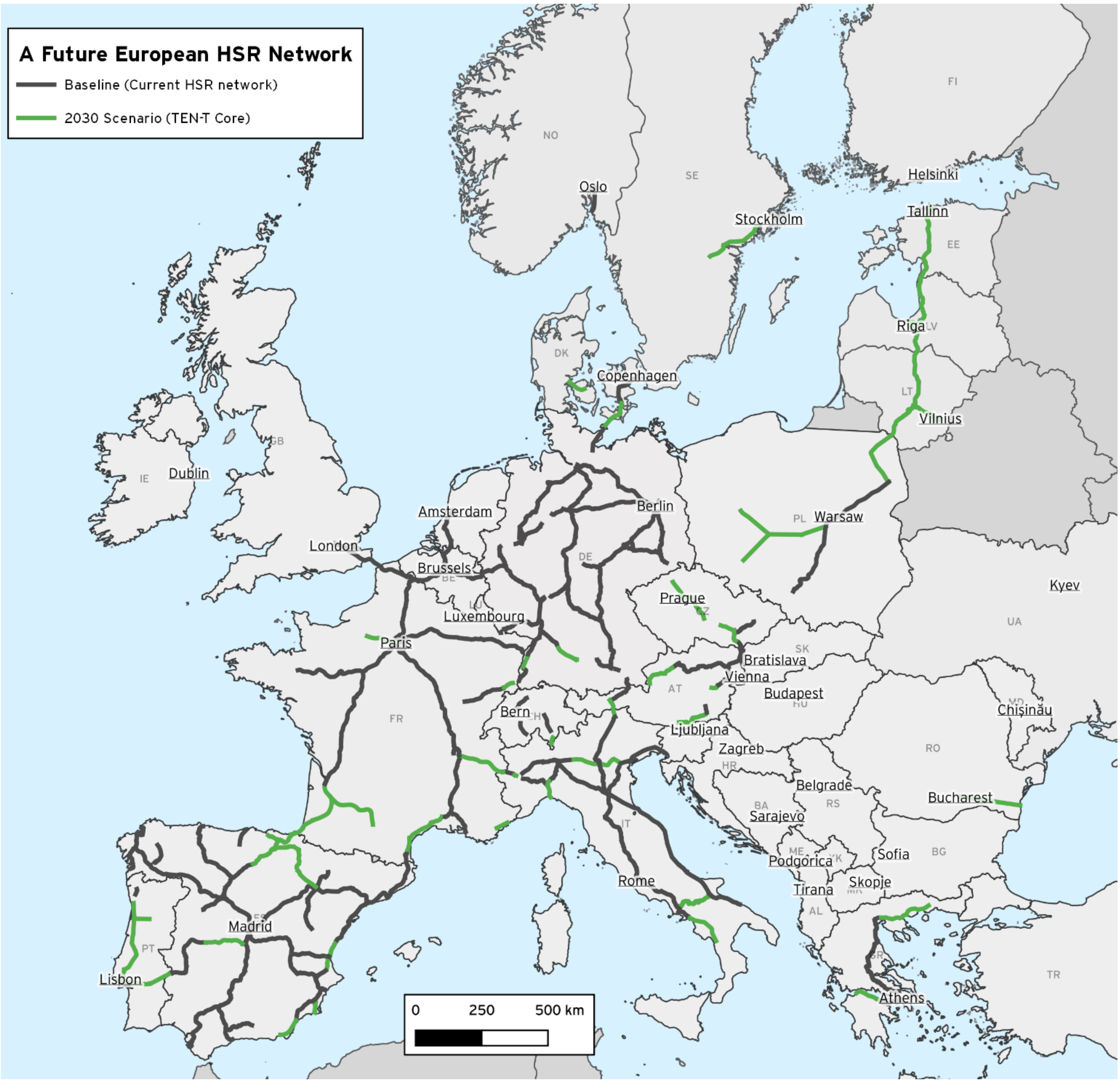


Figure 18: Baseline and 2030 scenario

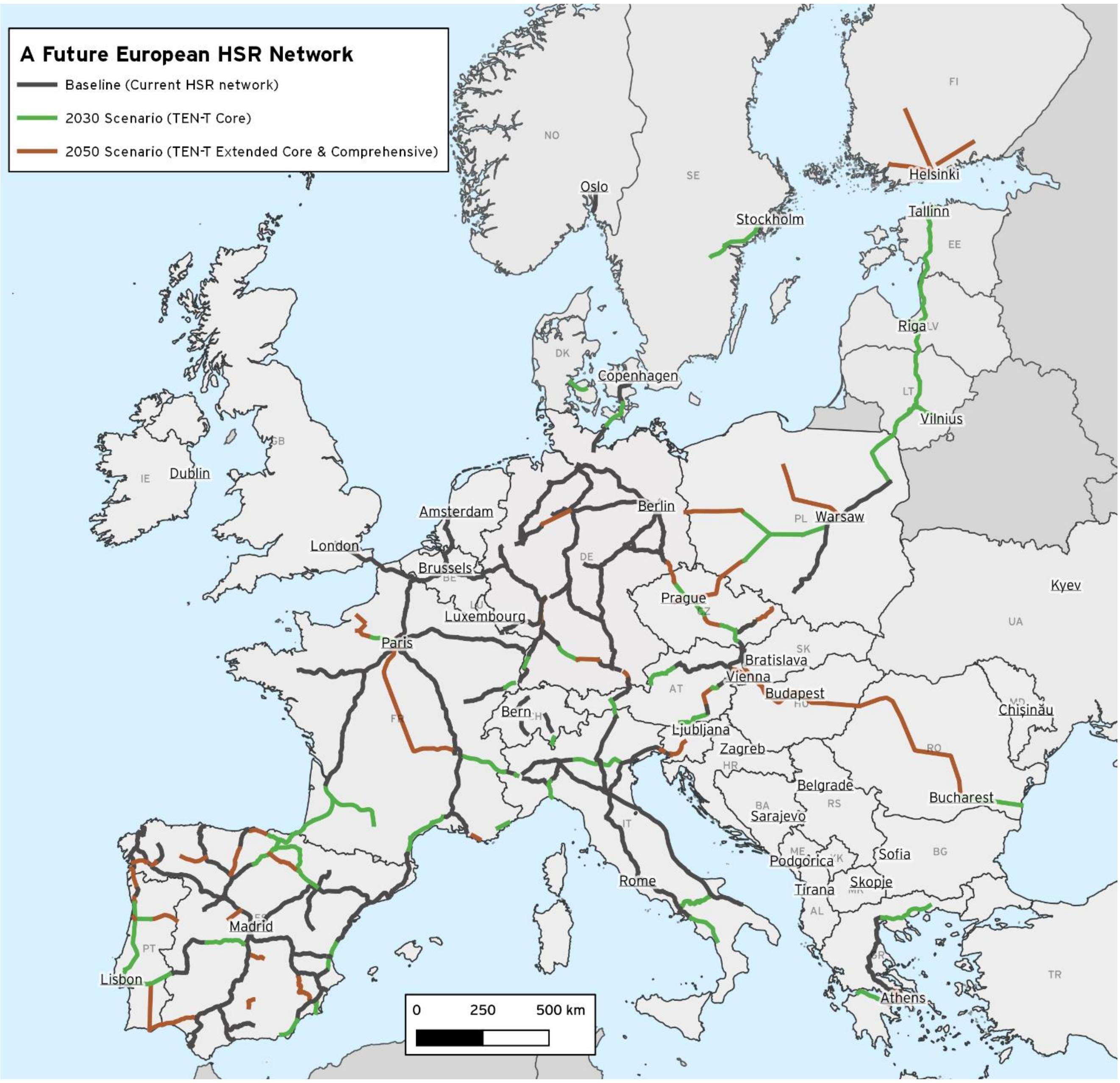


Figure 19: Lines that are in operation, under construction or planned.

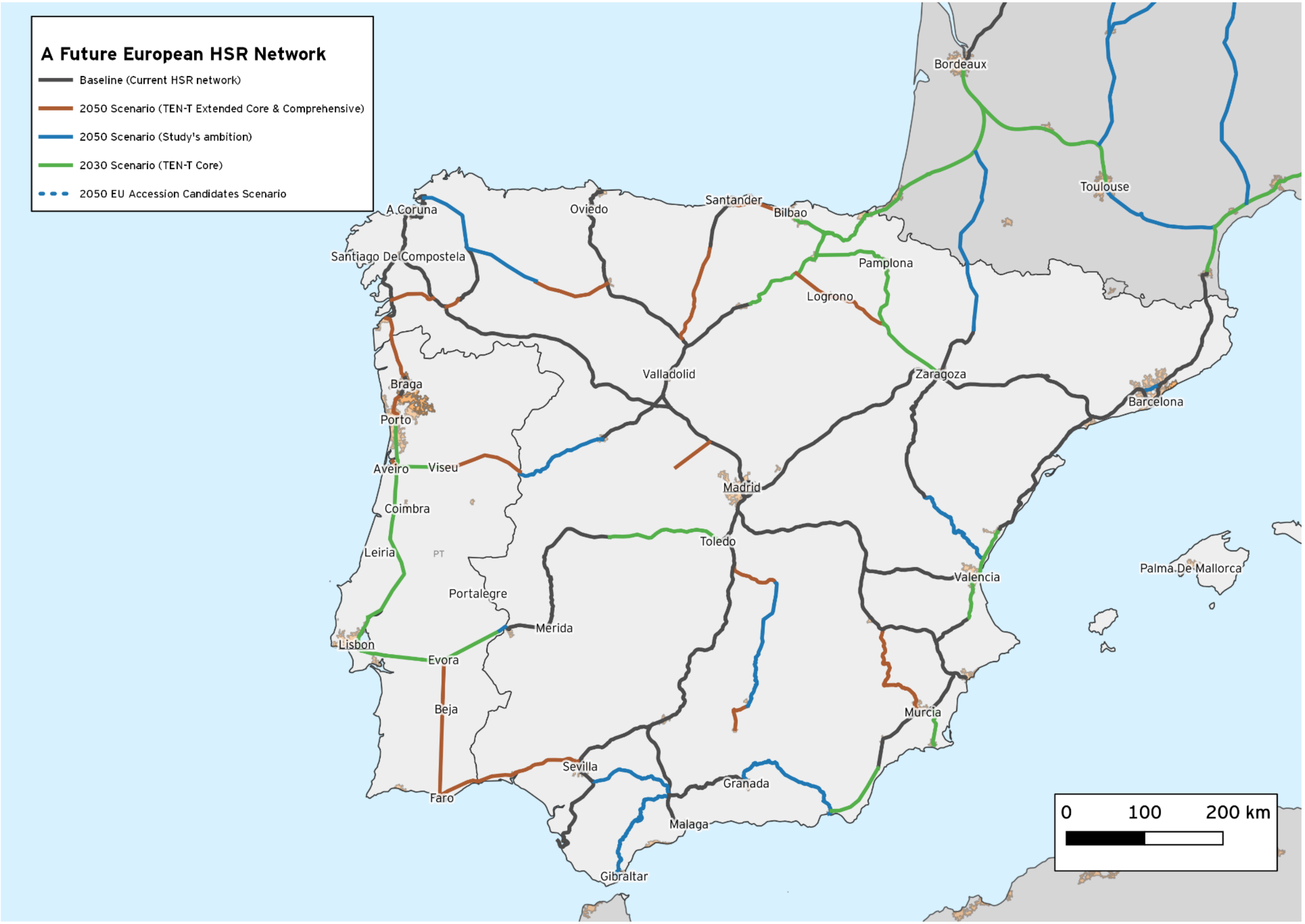


Figure 20: HSR networks - Spain and Portugal

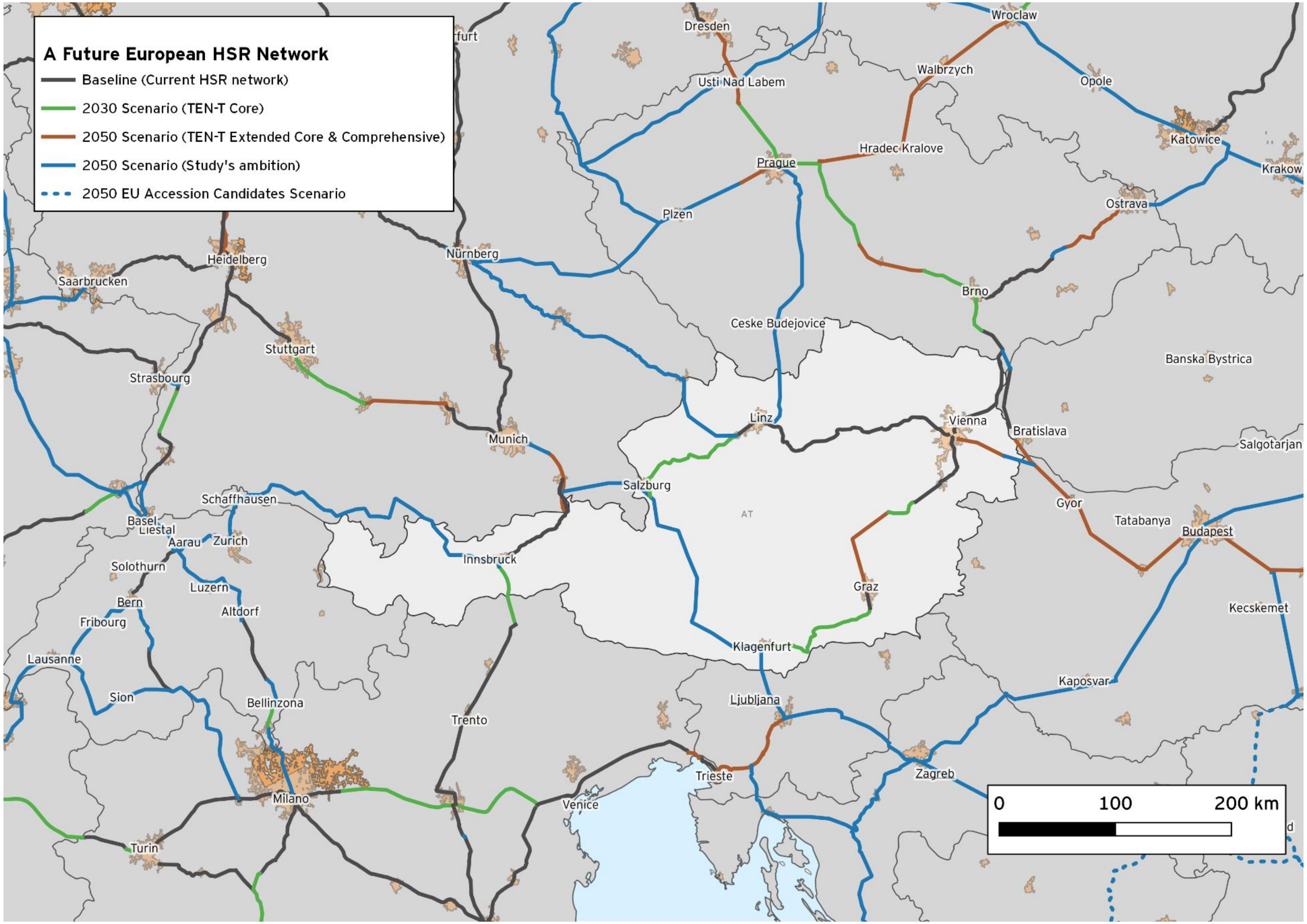


Figure 21: HSR network - Austria

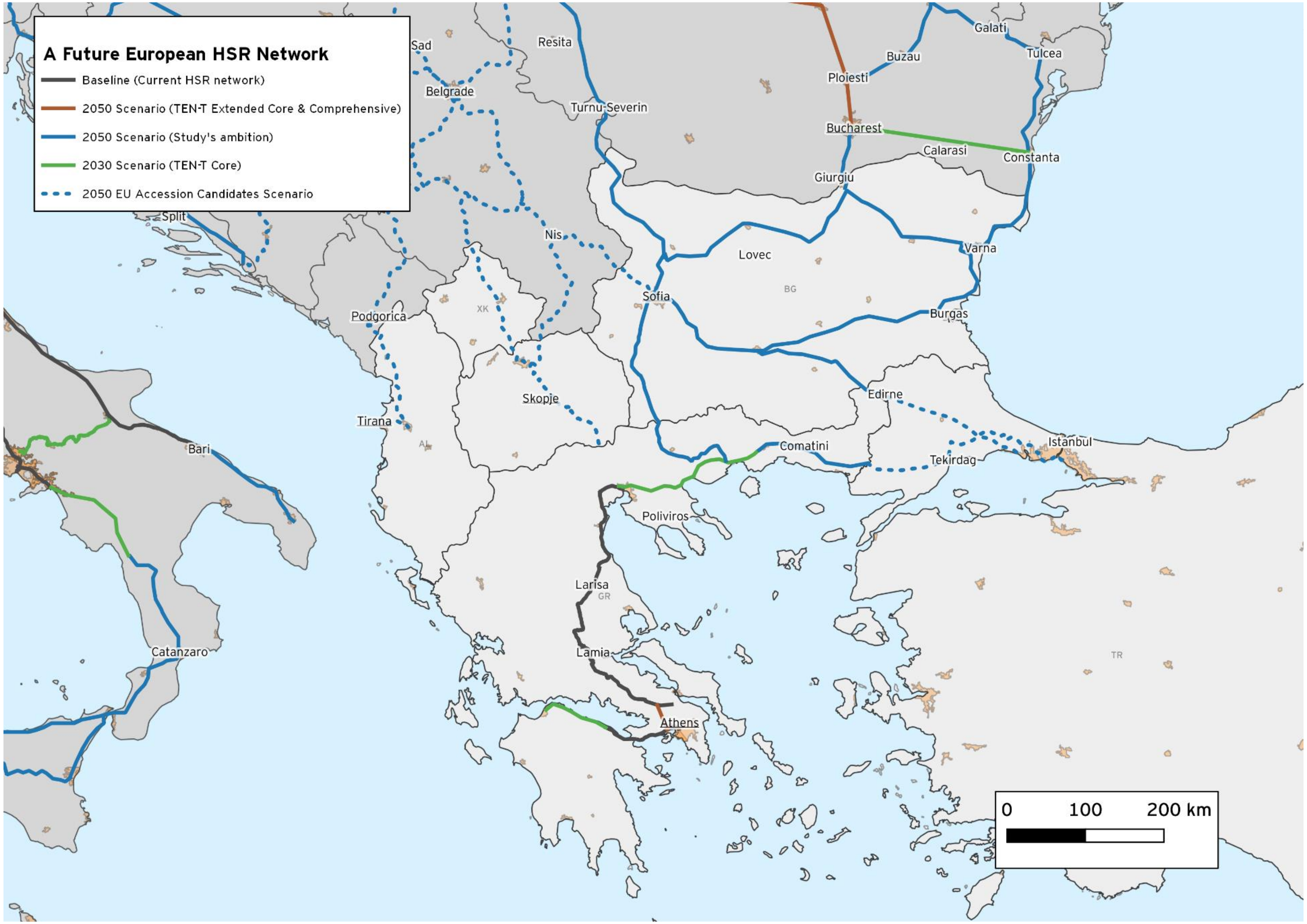


Figure 22: HSR network - Macedonia, Bulgaria, Albania, Greece and Turkey

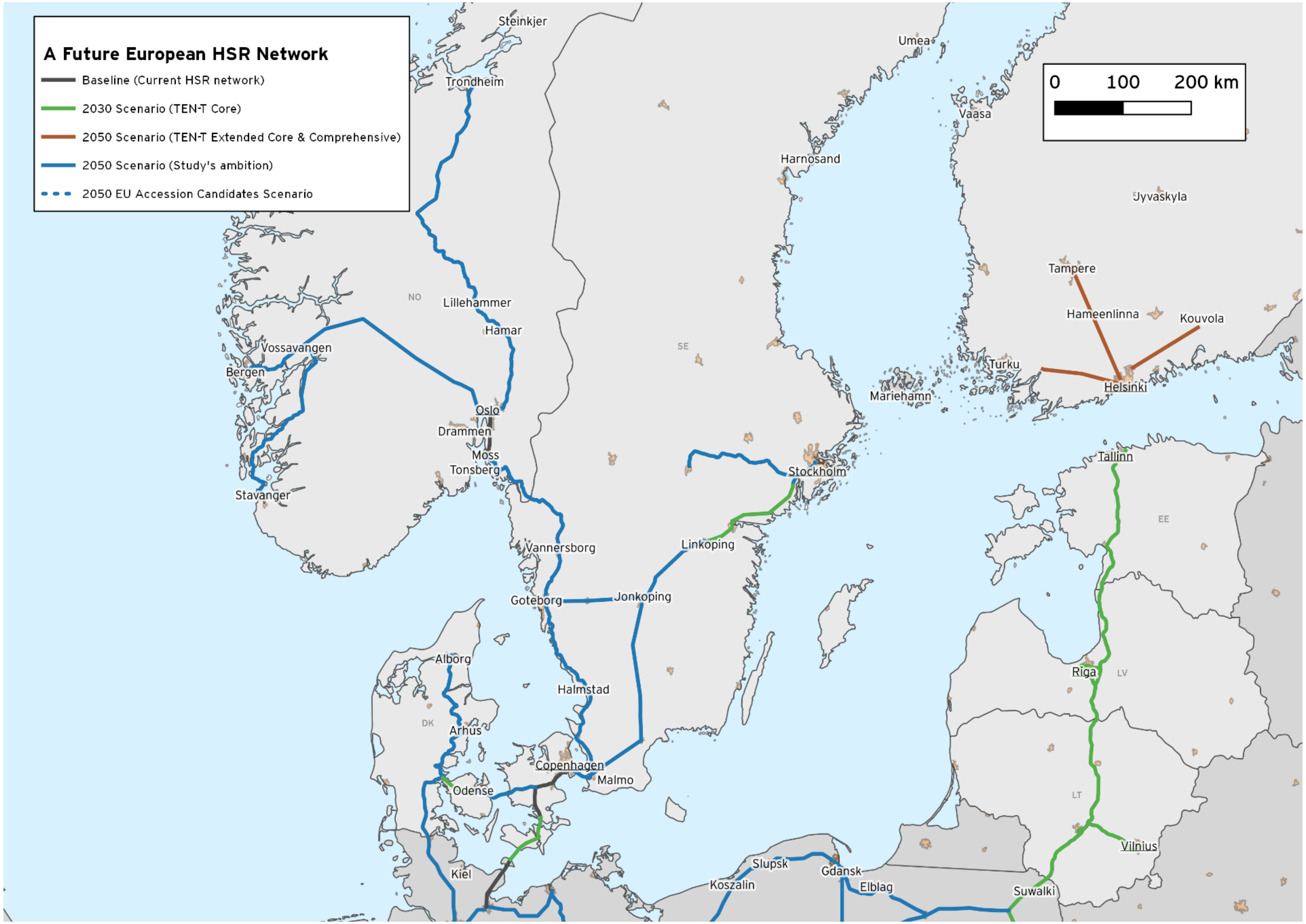


Figure 23: HSR network - Nordic and Baltic countries

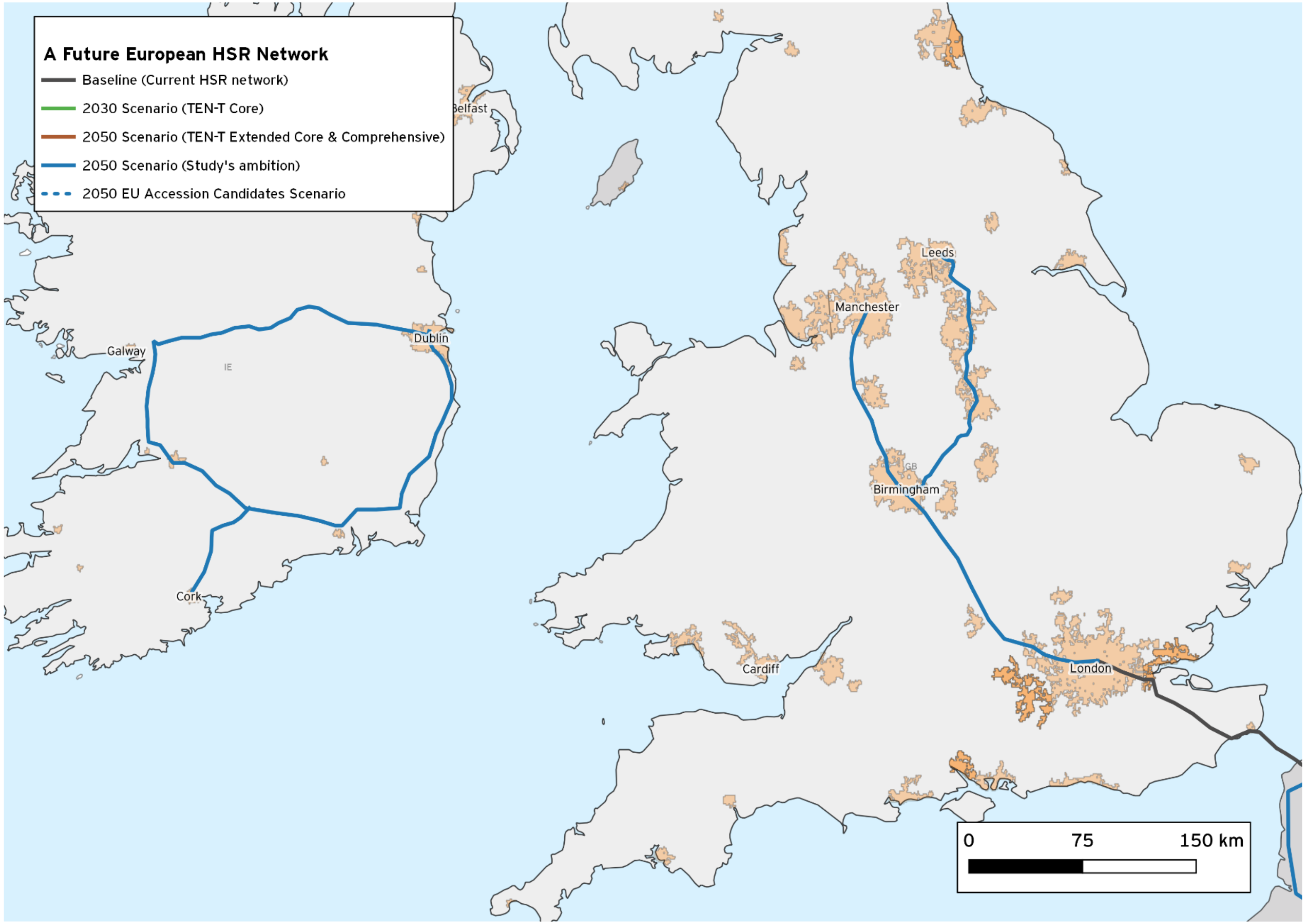


Figure 24: HSR network - UK and Ireland

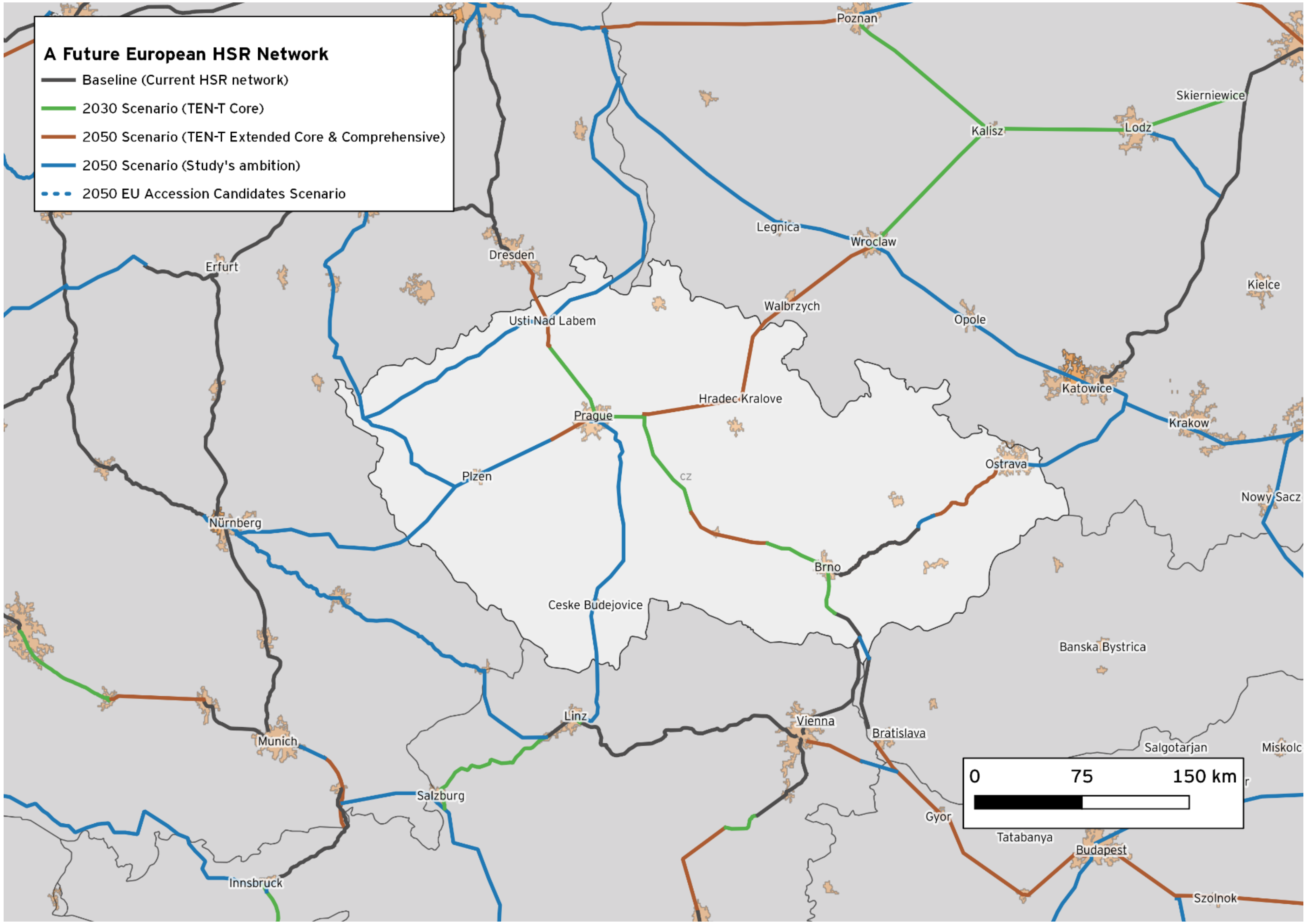


Figure 25: HSR network - Czechia

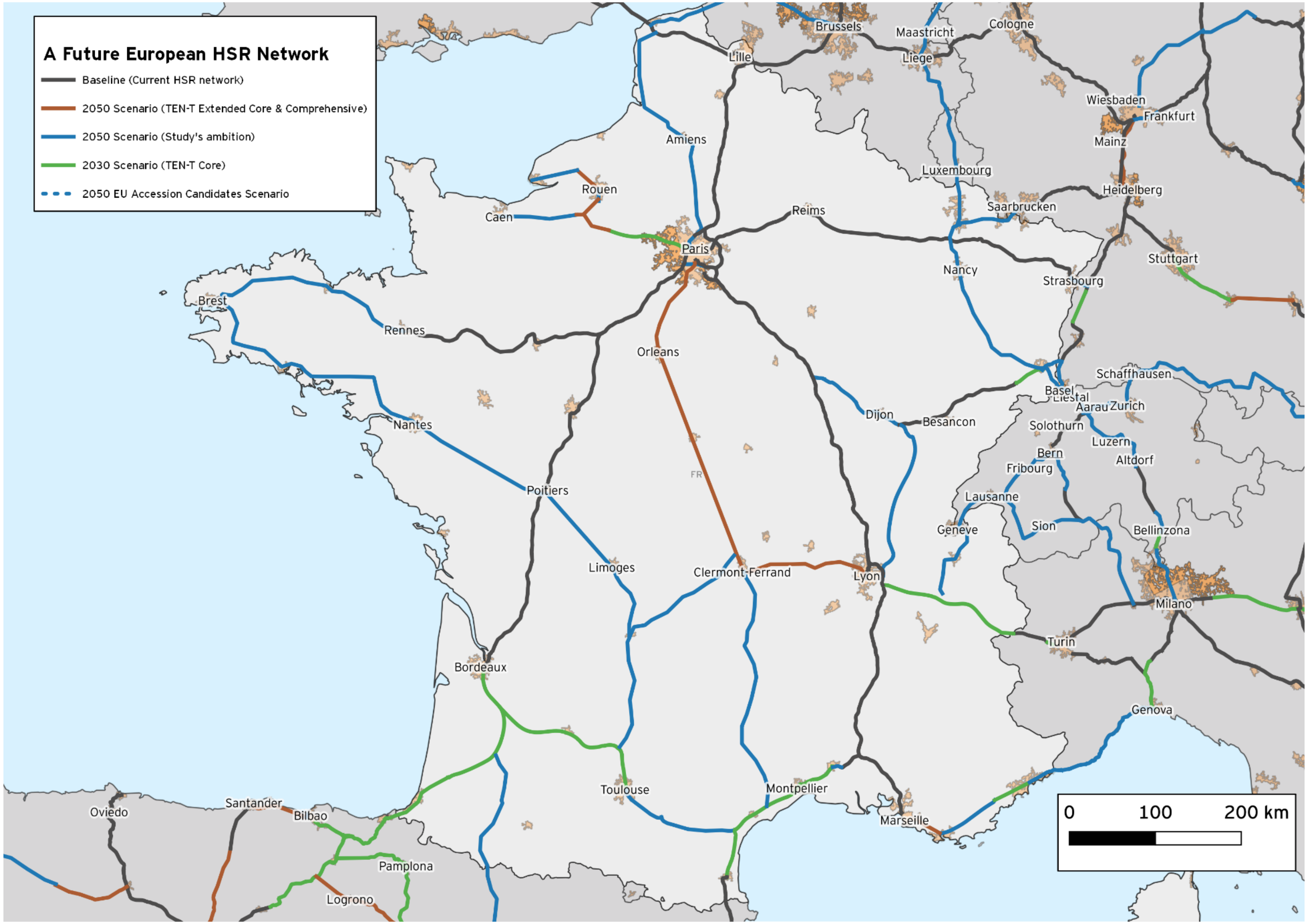


Figure 26: HSR network - France

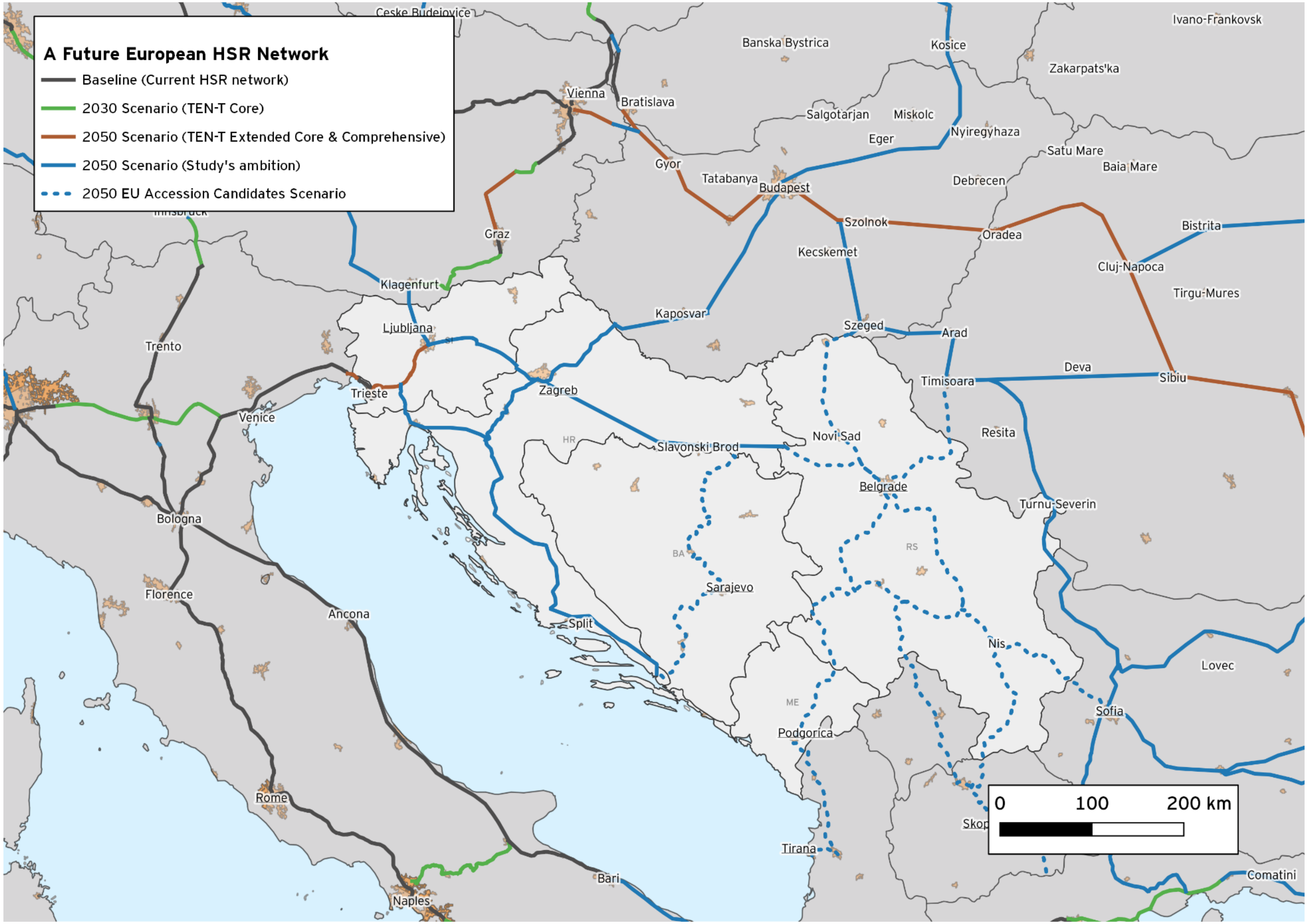


Figure 27: HSR network - Croatia, Slovenia, Bosnia, Montenegro and Serbia.

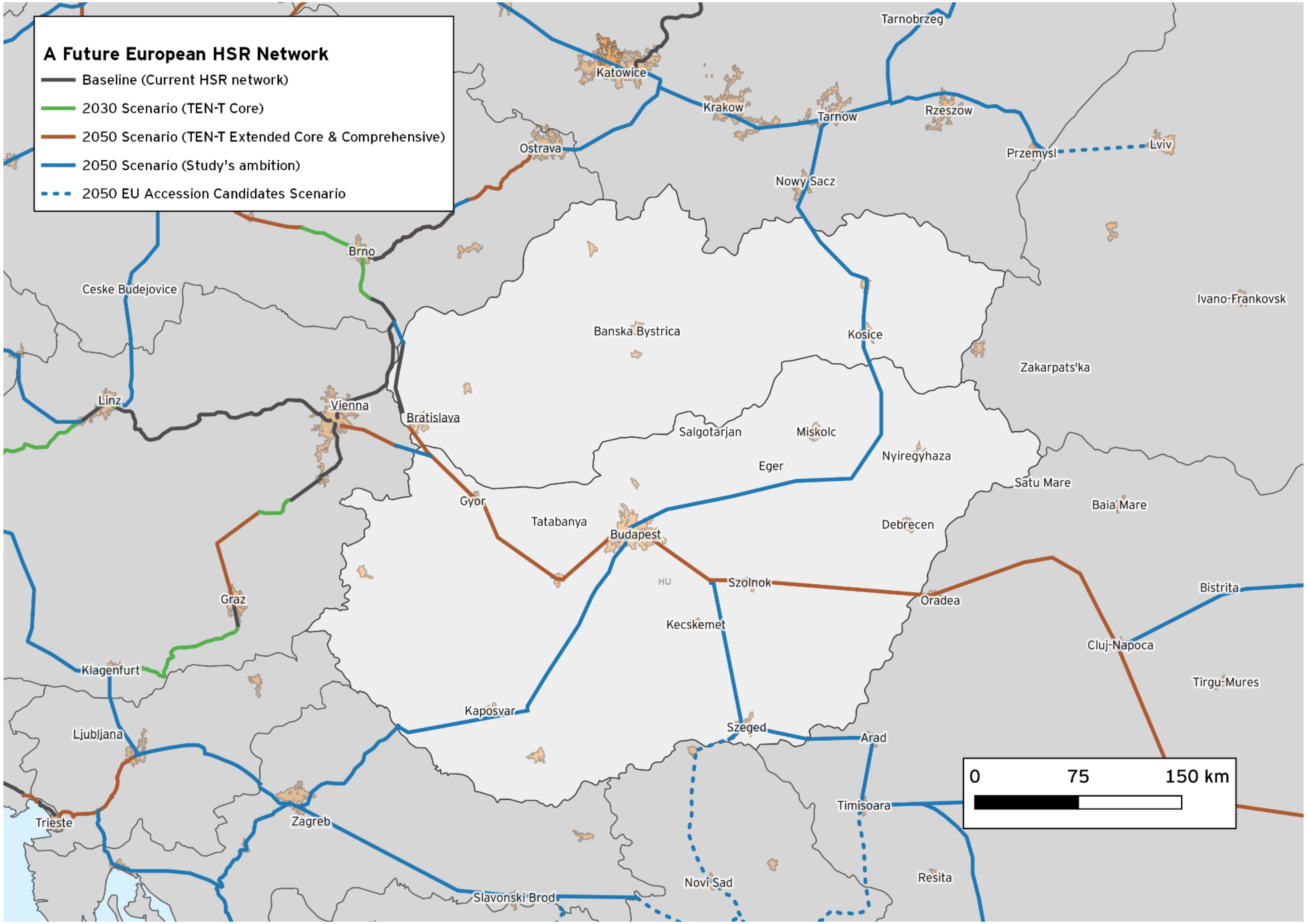


Figure 28: HSR network - Central Europe – Hungary and Slovakia

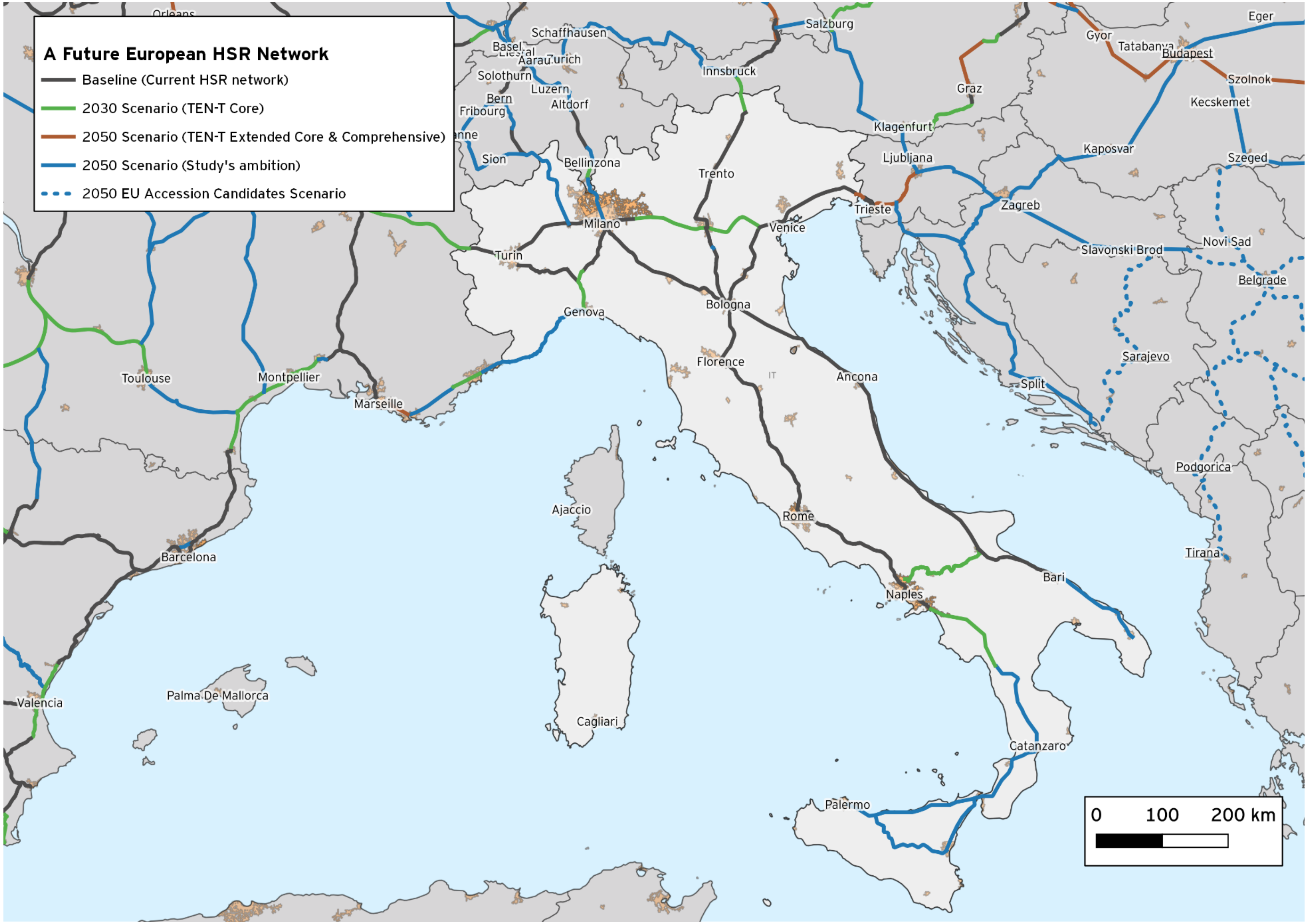


Figure 29: HSR network - Italy

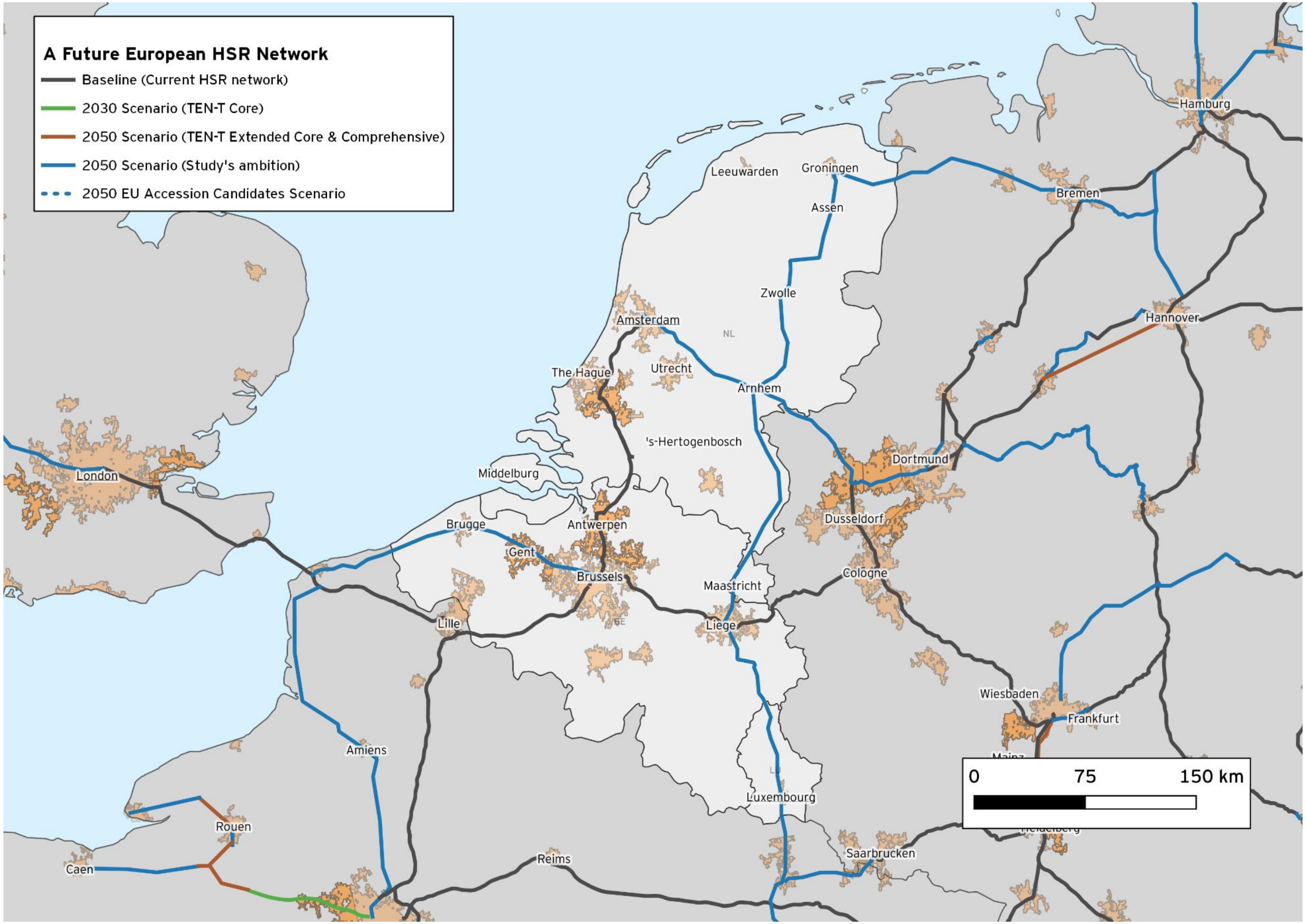


Figure 30: HSR network - Benelux countries

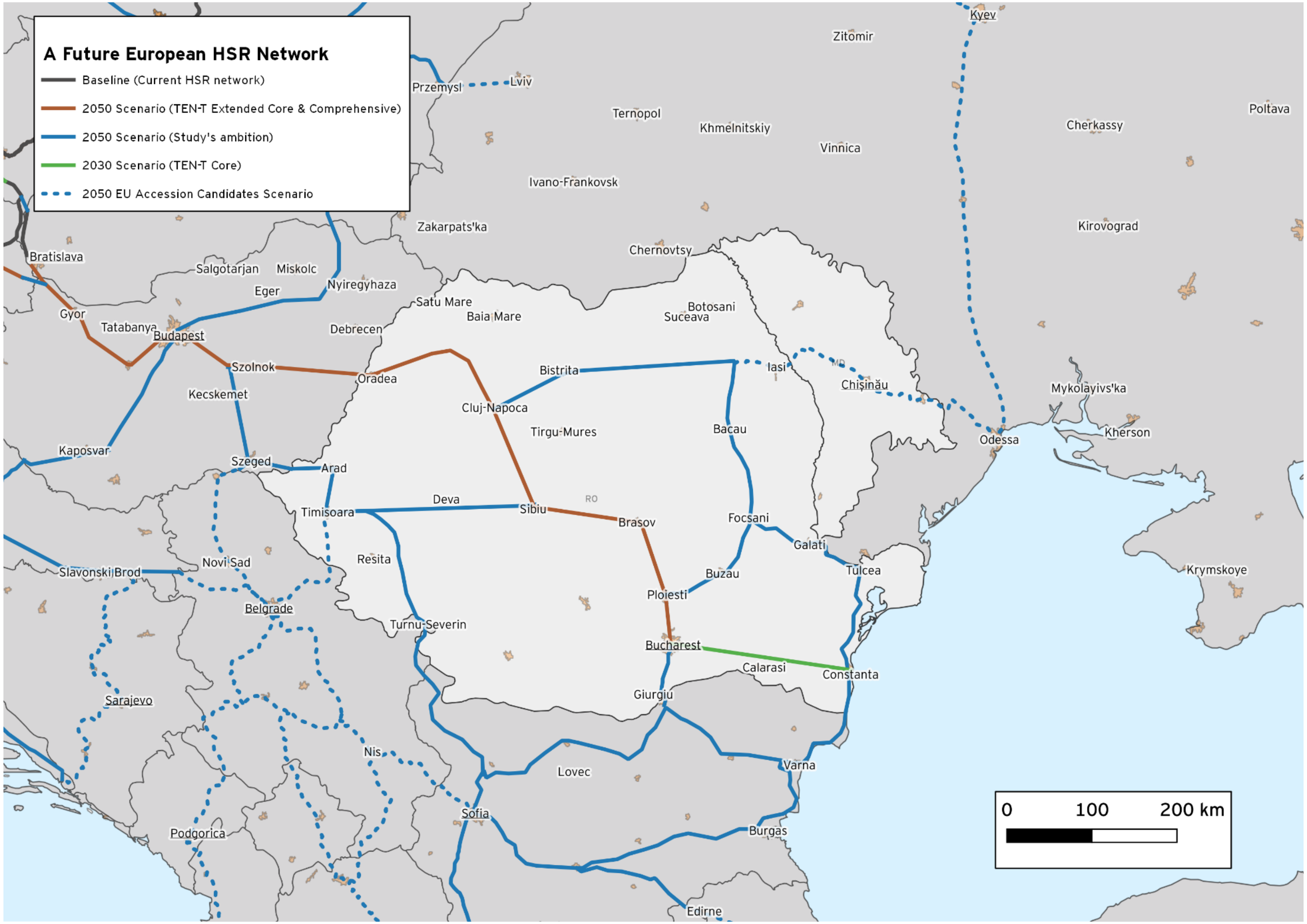


Figure 31: HSR network - Romania and Bulgaria

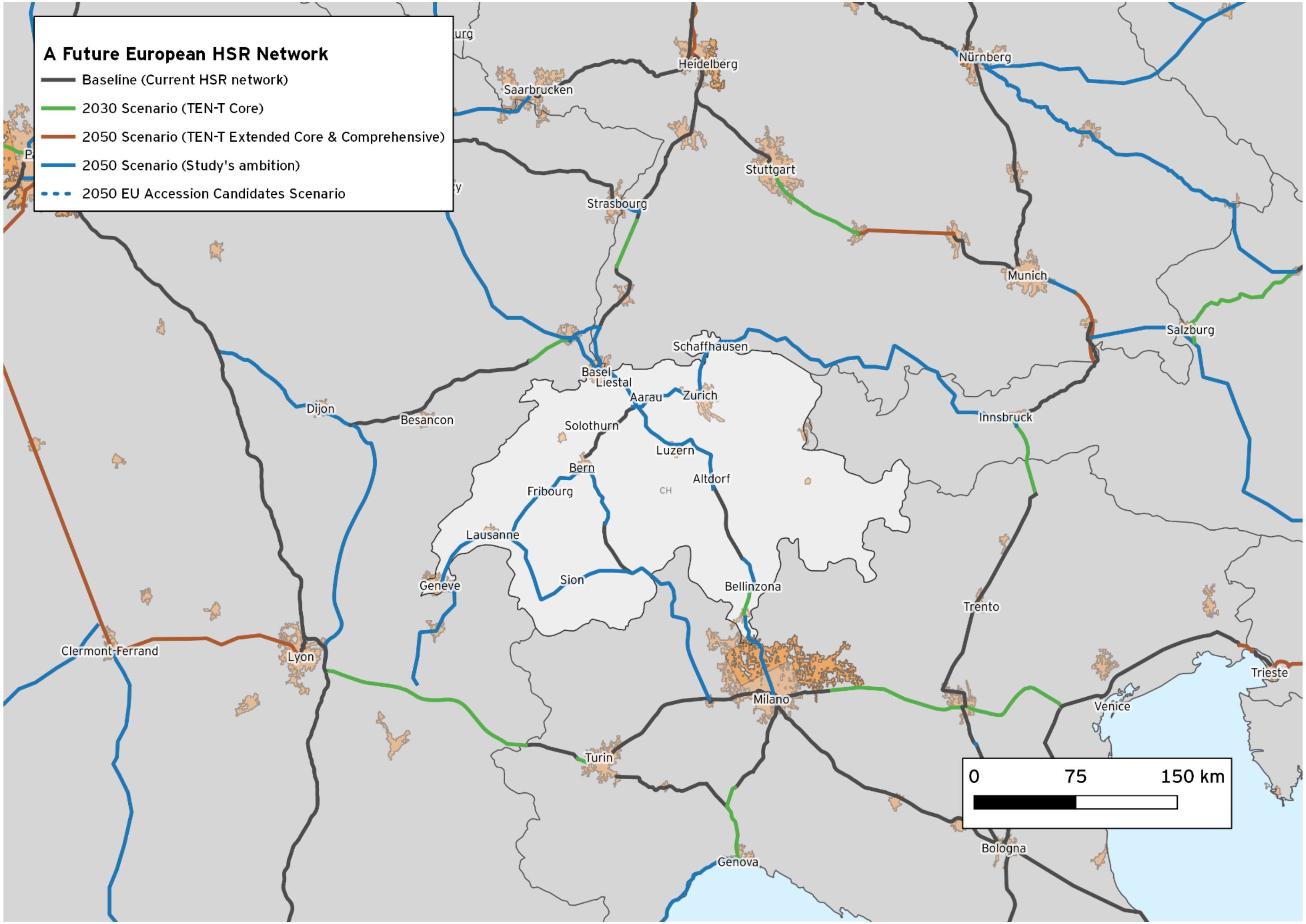


Figure 32: HSR network - Switzerland

Figure 33: HSR network - Ukraine

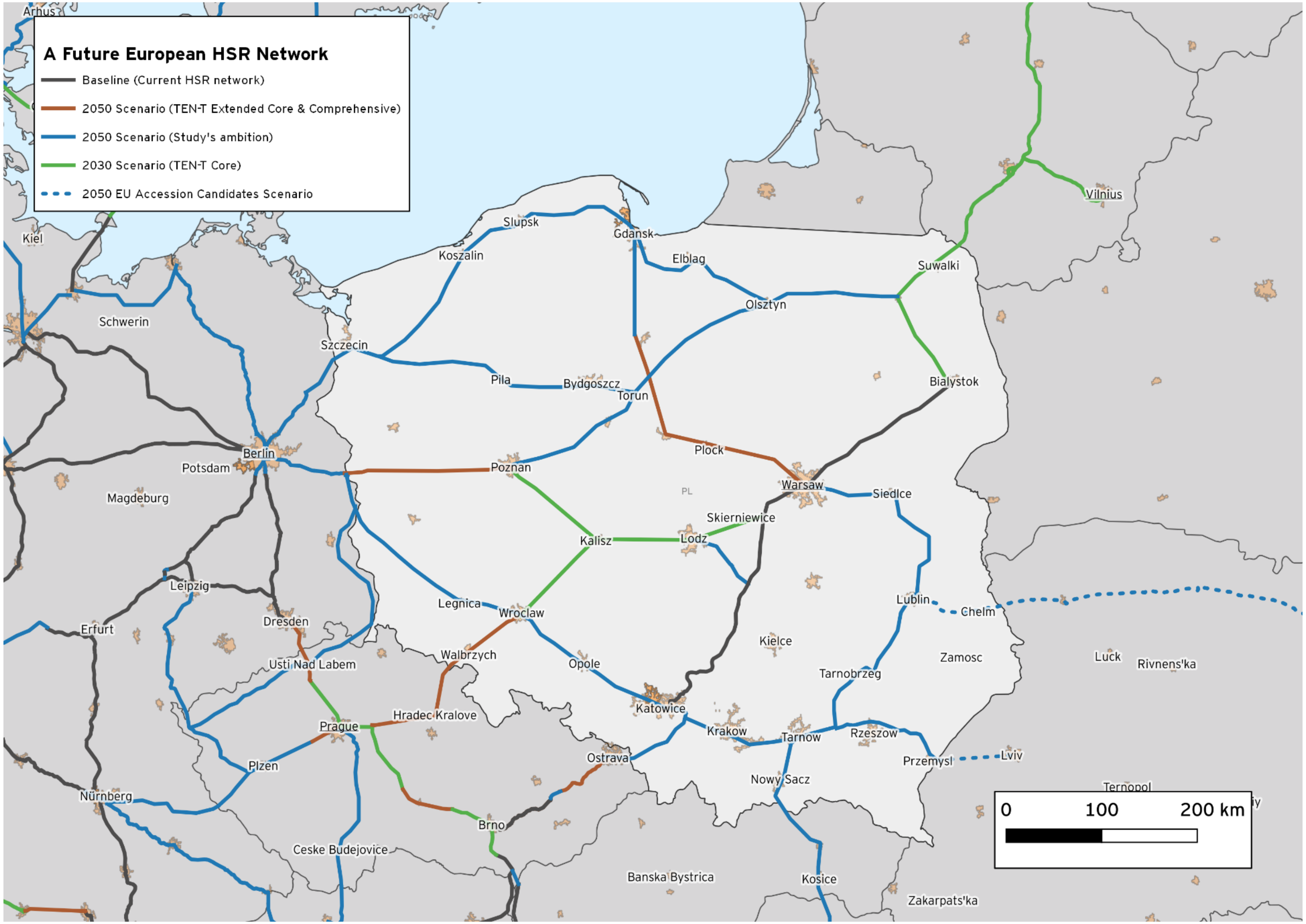


Figure 34: HSR network - Poland

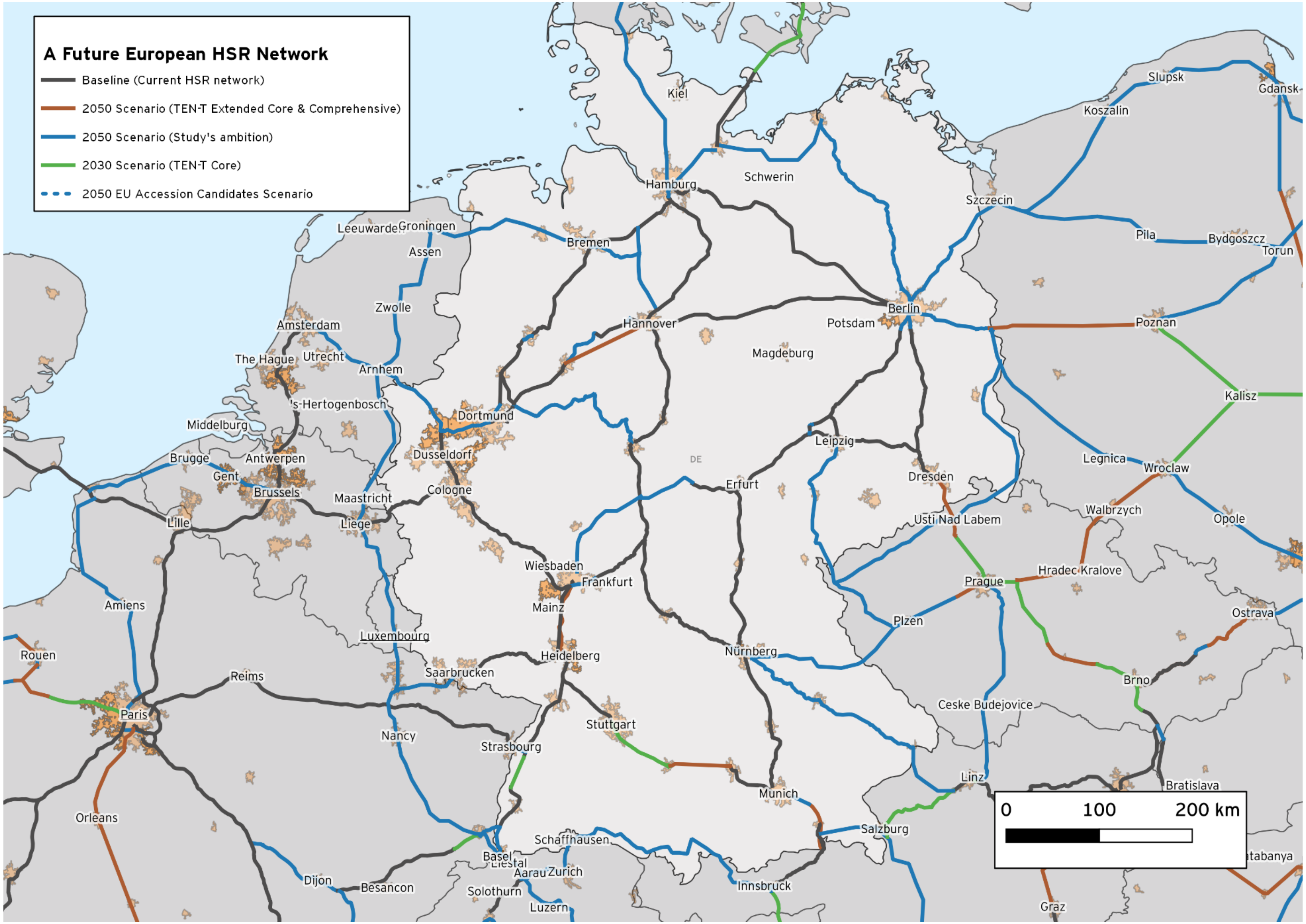


Figure 35: HSR network - Germanyy

Annex 5: Assumptions of the study

This section will briefly present and discuss the main assumptions applied in the study. These assumptions aim at simplifying the already complicated process of estimating long term market evolutions and calculating the subsequent economic and socioeconomic costs and benefits. The main idea is to present a case for high-speed rail as a wholistic purpose, where the society (represented by different public institutions) decide to actively opt in favour of HSR (through infrastructure investment and policies and reaps the corresponding benefits.

- No capacity constraints on the network.

To simplify the models of the market and impact assessment, the study assumes that there are no capacity constraints on the HSR network. Given that the 2030 and 2050 scenarios will be entirely new construction on dedicated HSR lines there will be more capacity than in the baseline, where certain lines are shared with freight and conventional rail.

The next four assumptions are all based on the underlying consideration that, according to regulation[61], European railway undertakings will operate in an open market. This means that the theoretical rules that apply for open market competition can be applied here:

- Railway undertakings operate at equilibrium between revenue and costs.

The railway undertakings are assumed to operate at equilibrium. Meaning that any surplus is redistributed back to the passengers through a lower price.

- The study does not take into consideration the procurement of vehicles, airplanes or rolling stock to match the growth in demand.

While the study forecasts traffic growth for all modes dependent on the scenario, the study does not take into account the procurement of rolling stock, purchase of passenger cars and airplanes. This assumption is strongly linked to the previous one, as, in the open market situation, railway undertakings (and other transporters) are supposed to cover their investment-related costs through their revenue.

- Track access charges completely cover infrastructure maintenance.

Infrastructure maintenance for all modes is assumed to be covered fully by track access charges. This is also included to align with European Regulation.

- The study makes no assumption on the evolution of the fares.

While an important part of increasing the demand for HSR, the study does not take into account the evolution of fares. The study behind the competition shock took into account the evolution of prices due to competition. As seen on other lines, where open-access competition exists, prices decrease as a result of competition[62][63].

These assumptions, while strongly theoretical, do not jeopardize the study robustness as they are:

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[61] 4th Rail package, noticeably, Directive 2016/2370/EU

[62] Tomeš, Z., Kvizda, M., Jandová, M., & Rederer, V. (2016). Open access passenger rail competition in the Czech Republic. *Transport policy*, *47*, 203-211.

[63] Antoniazzi, F., Giuricin, A. & Tosatti, R. (2019). Introducing competition in Italian high-speed rail. *L'Espace géographique*, 48, 329-349. https://doi.org/10.3917/eg.484.0329

- Consistent with the regulatory and market evolutions already observed, and assumed to continue in the next decades
- Consistent with the objective of the study, which is a case for the railway as a whole, not a case for specific actors

Annex 6: EU Accession Candidate Countries Scenario

This section will present the results of the traffic forecast for the EU accession candidate scenario. This scenario will be presented by itself and is for the accession candidate countries only due to uncertainties related to the estimations as there is very limited available data. As is witnessed by the figure below, upon completion of the HSR network in the countries, the modal share of HSR will increase until reaching a modal share of 14% by 2070.

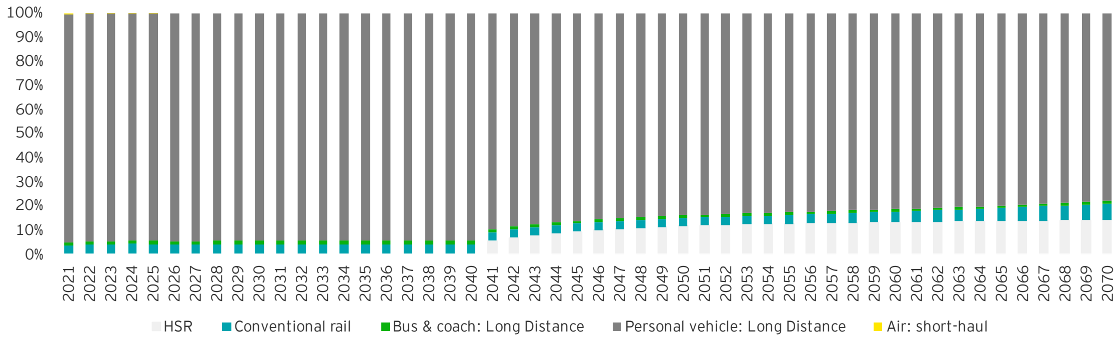

Figure 28: Modal share evolution - 2050 EU accession candidates scenario