EY

Building a better working world

Smart and affordable rail services in the EU: a socio-economic and environmental study for High-Speed in 2030 and 2050

Executive report. 23/01-2023

The better the question. The better the answer.
The better the world works.

Smart and affordable rail services in the EU: a socio-economic and environmental study for High-Speed in 2030 and 2050 – Executive Report

DISCLAIMER: This report based among other elements on information and conversations with CER/ALLRAIL/UNIFE on the basis of a common MoU was prepared by EY in collaboration with the Bocconi University (Green centre) and Blue Arches for the Europe's-Rail JU.
The information and views set out in this report are those of the author(s) and do not necessarily reflect the official opinion of the EU-Rail JU and Community of European Railways (CER)/ Alliance of Passenger Rail New Entrants (ALLRAIL)/Association of the European Rail Supply Industry (UNIFE).

Neither the Europe's-Rail JU and CER/ALLRAIL/UNIFE nor any person acting on their behalf may be held responsible for the use which may be made by third parties of the information contained therein.

Executive summary

This report presents the main findings[1] underpinning the establishment of a European High-Speed Rail (HSR) Network connecting the main European cities and regions, combining investments in constructing creating/upgrading new HSR lines and upgrading the digitalization and automation of existing ones, i.e. ERTMS. It confirms that investing in a comprehensive European HSR network will deliver added value to European society and massively reduce the environmental footprint of European passenger transport. **The report proposes a master plan for HSR network connecting all EU capitals and major cities** and calls for the Commission and Member States for a coordinated implementation with sufficient funding in the next decades. Such comprehensive network equalling at least tripling of the existing HSR network will certainly require high investment costs averaging to €550 billion but in return deliver a **net positive benefit in the range of €750 billion to society.**

HSR is often touted as a key lever to decarbonise the transport sector in the EU. Today, it is already a competitive alternative to both passenger road transport and short-haul aviation, on many inter-city routes—including cross-border routes such as Paris-Brussels. Some of the common reasons for passengers to choose HSR over alternative modes of transport include comfort, competitive travel time duration, comfort with more leg room, the comparative ease of boarding and the possibility of city-to-city connections relative to air travel, and the ability to carry out work or enjoy leisure time alone or with family or pets while onboard. Overall transport demand is expected to increase in the future, hereby leaving room for HSR to further grow albeit provided that the HSR network will expand.

On top of benefits to passengers, HSR has many broader societal benefits. It is many times less emissions-intensive — both in terms of greenhouse gases, and other air pollutants — than passenger road transport or air travel. It is a vital way to provide inter-city transport services to the growing number of EU citizens spurning private car ownership. And it helps stimulate regional economic development by connecting citizens and businesses across Europe. Furthermore, HSR is good for reducing EU's energy dependency thanks to the energy efficiency of rail compared to other modes.

Historical data from the opening of HSR lines in the EU and internationally shows that they can lead to significant reductions in the demand for air travel, by up to 80% in the case of the Paris-Strasbourg line, for instance[2]. In some parts of the EU, HSR developments are on track to delivering the transport alternatives required to reach the EU's overall decarbonisation objectives. These successes would suggest replication at large scale to build the future, sustainable pan-European passenger transport network.

[1] The study is presented in greater detail in the two Technical Reports (1 & 2), covering the market and impact assessments respectively.

[2] International Energy Agency (2019). *The Future of Rail*. Retrieved from https://iea.blob.core.windows.net/assets/fb7dc9e4-d5ff-4a22-ac07-ef3ca73ac680/The_Future_of_Rail.pdf

The EU's Smart and Sustainable Mobility Strategy[3] calls for doubling HSR rail traffic by 2030, and tripling it by 2050, relative to 2015 levels. Reaching these targets will require raising ambitions across the board in the rail sector, in particular regarding the development of new HSR lines, such as the Rail Baltica project, and the upgrade of existing ones[4]. While these increased ambitions have an investment cost, they have the potential to bring about significant benefits to passengers and to all Europeans.

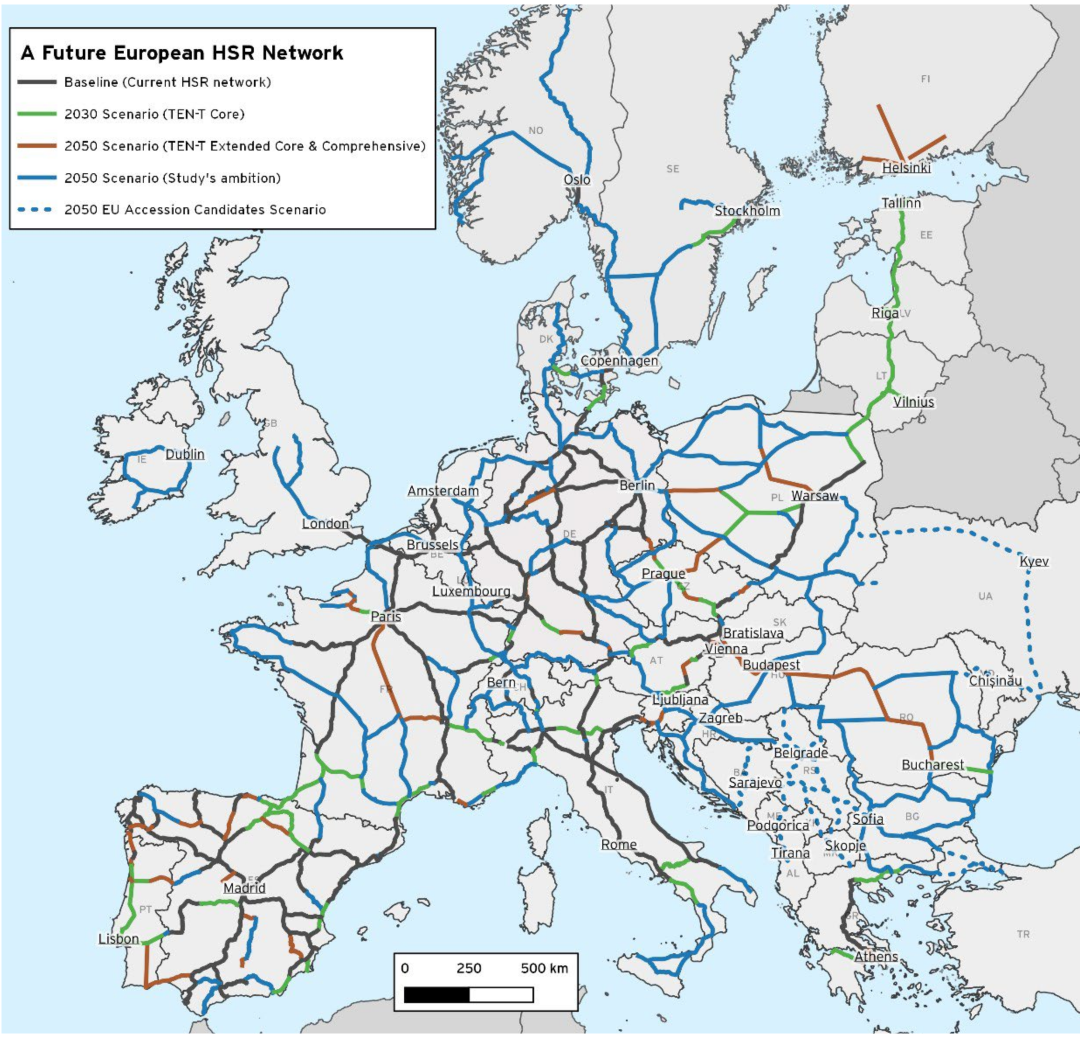

Figure 1: The HSR network proposed by the study

Quantifying the benefits of HSR traffic growth can help make the case for investments in HSR network development. This quantification calls for a comparative analysis between HSR and competing transport modes or new technologies[5],following a two-step approach. The

[3] 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 strategy and importance of HSR have been backed further in the Council of the EU's general approach to the TEN-T Network.
[4] Although the study applies a long-term perspective, the study has deemed any iteration of a "Hyperloop" too unrealistic currently to be considered.
[5] Railway technologies being the technologies included in the Shift2Rail program, excluding Hyperloop.

first step to size the possible market for HSR by 2030 and 2050[6]. The second step to assess the impact in terms of associated costs and benefits of the developing the HSR network.

The data for this two-step approach **is based on the current scientific and economic studies** on the impact of the considered shocks on passenger transport demand. The existing body of literature on the shocks remains limited. Therefore, future developments in cross-mode transport demand assessments would be useful for a revalidation of the findings of this report.

Market Assessment

- To forecast the future demand for passenger transport and HSR, a total of 10 demand shocks were applied to a baseline demand forecast based on previous demand growth and forecasted population and GDP growth. The 10 shocks were applied to simulate the impact of future possible policy measures and investments in new infrastructure and technologies. The shocks were based on several recent academic peer-reviewed studies and applied based on their likeliness to occur before either 2030 or 2050 in alignment with the respective scenarios. Figure 2 illustrates the effect of the most impactful shocks on the demand evolution.

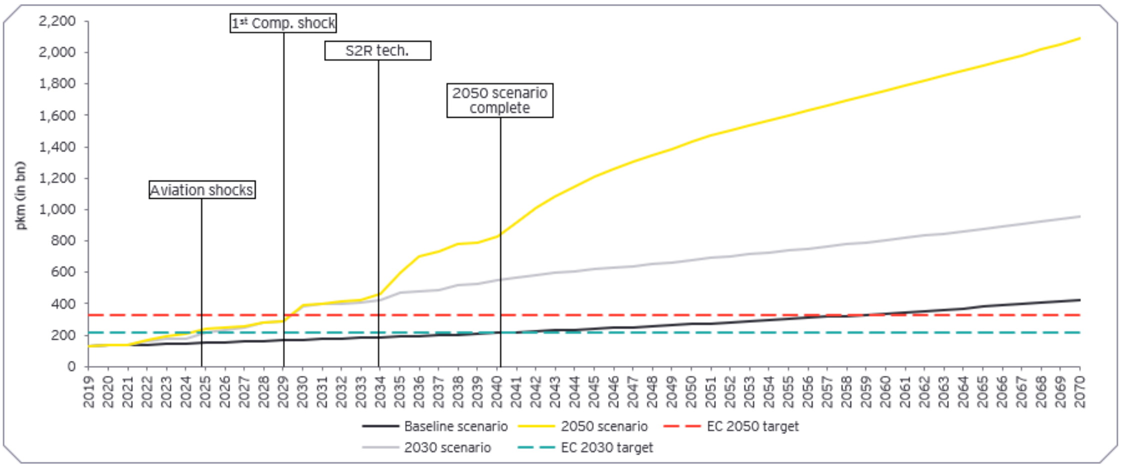

Figure 2: HSR passenger demand evolution in different scenarios

- Without new investment in HSR, demand and the modal share of HSR are expected to increase slowly and EU's targets unachieved. This is highlighted in figure 2 and 3.
- The 2030 Scenario, which includes the completion of the TEN-T Core Network[7] (5.300 km of HSR lines by 2030) will lead to a limited increase of about 16 percentage points in the modal share of HSR[8], which would be expected to more than double by 2030 despite the limited investment considered.
- An ambitious investment scenario for 2050 (Scenario) would encourage seeing all major urban agglomerations in the EU connected through a comprehensive HSR network, in addition to the TEN-T Extended Core (completion by 2040) and Comprehensive

[6] 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 (brown) 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 (blue). All lines in the 2050 scenario have been considered new construction, although some lines may be planned as upgrade of current lines.

[7] The completion of the TEN-T Core Network, which is targeted to be completed by 2030, constitute the 2030 Scenario together with the HSR lines currently completed.

[8] As compared to the Baseline Scenario.

Networks (completion by 2050)[9], with significant expansions especially in Eastern Europe compared to the baseline — see figure 1.

- Under this scenario, the full suite of demand shocks would make HSR the main transport mode in the EU beyond 2050. Notable, are the effects of railway market competition and further investments in railway technologies such as the ones promoted by Europe's Rail. The effect of these shocks is highlighted in Figure 2 above. This development is witnessed in figures 3-5 below.

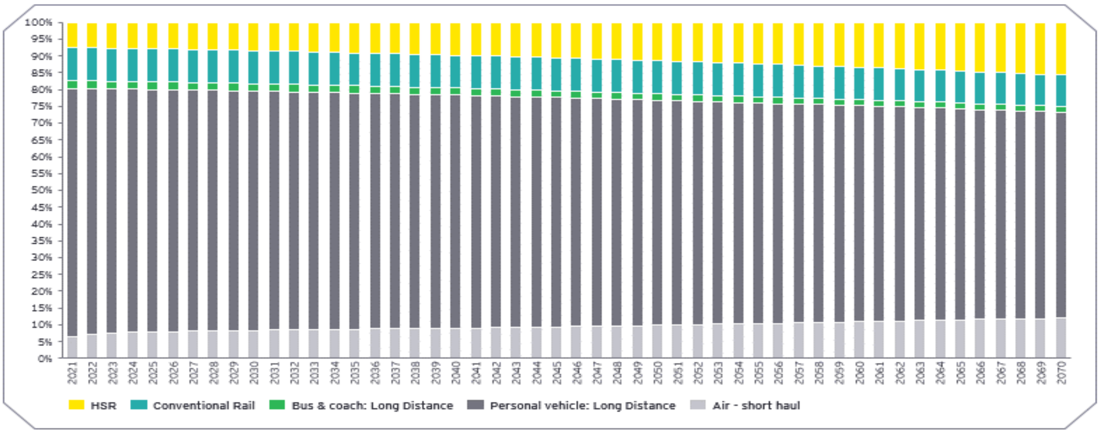

Figure 3: Passenger modal share evolution - Baseline scenario

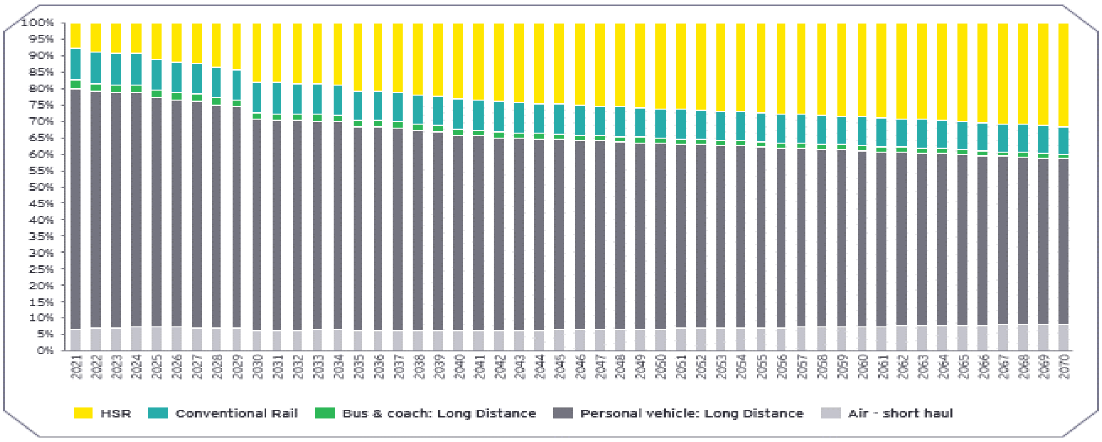

Figure 4: Modal share distribution - 2030 Scenario

[9] The TEN-T Extended Core and Comprehensive Networks are included in the maps by the brown line and as part of the 2050 Scenario.

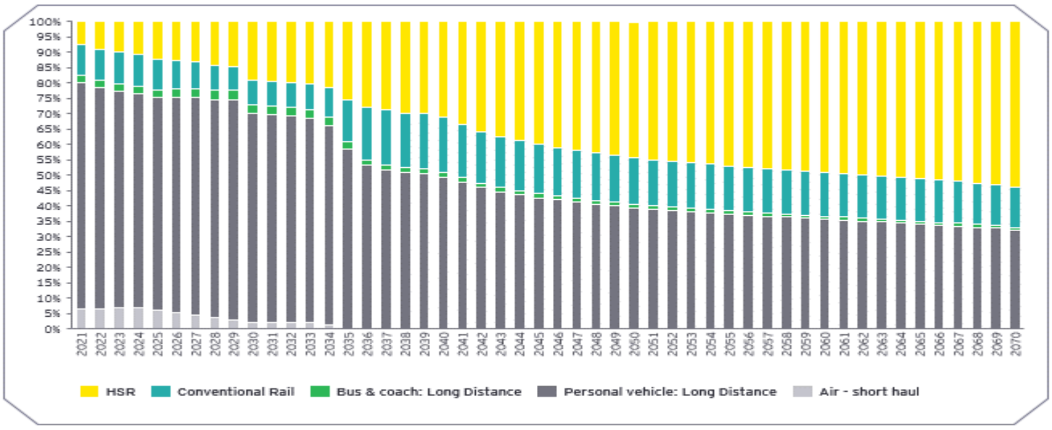

Figure 5: Modal share distribution - 2050 scenario

Impact Assessment

- The impact of the future trends in demand for passenger transport was estimated by applying a Cost-Benefit Analysis. It compares the economic benefits of a modal shift with the construction costs of the HSR networks in order to estimate the Net Present Value and the Benefit-Cost ratio. In addition, the CO2 emissions balance for the scenarios and the wider economic benefits of constructing and operating the HSR lines were estimated based on the latest *ex post* assessments available for HSR projects.
- Both the 2030 and 2050 scenarios see net positive benefits to society, of over nearly €400-447 billion, and €561-836 billion respectively. The ambitious, 2050, investment scenario requires almost a quadrupling in the size of the HSR network, leading to high investment costs — however, these are more than offset by the significant benefits generated with a comprehensive pan-European HSR network coupled with the implementation of sound policies and the deployment of state-of-the-art railway technologies.

Avg. construction costs	Scenario	Construction cost (bn €)	NPV (M€)	B/C Ratio
12 €M per KM[10]				
	2030	63	447.488	10
	2050	410	836.670	4
16.5 €M per KM[11]				
	2030	87	431.527	7,6
	2050	546	748.594	3
25 €M per KM[12]				
	2030	132	400.734	5
	2050	855	561.433	2

Table 1: Financial results of the CBA

[10] Based on the construction costs in 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)](2017852_E_web_light+c1.pdf)

[11] € 16.5 million per KM was also the completion cost per KM for the French LGV Est Européenne HSR line. See 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

[12] Average final construction costs audited by the ECA in European Court of Auditors (2018). Referenced in footnote 11.

- The 2030 scenario would lead to approximately 1.5 billion tonnes of CO2 emissions reductions, relative to the baseline scenario. The 2050 scenario would almost triple that amount as is highlighted by figure 6 below on the net saved CO2 emissions per scenario.

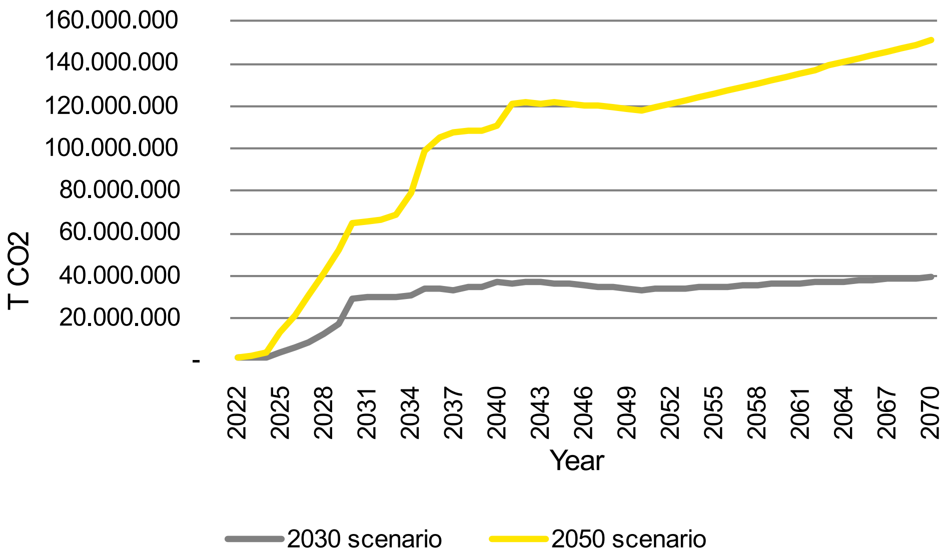

Figure 6: Net saved CO2 emissions per scenario

While it is clear that the figures produced in this study, considering the lengthy timeframe, cannot be seen as exact predictions and that specific feasibility studies are required before carrying out any infrastructure project, the study firmly establishes that **HSR can potentially become the dominating mode in its market**, and generate **considerable socio-economic benefits to the European society**. That is provided the current HSR network is expanded to cover the entire Europe and connect its major cities. Furthermore, the study highlights the critical role of supporting policies in favour of the most sustainable transport modes.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ALLRAIL	Alliance of Passenger Rail New Entrants
B/C Ratio	Benefit-Cost Ratio
CBA	Cost-Benefit analysis
CER	Community of European Railway and Infrastructure Companies
GDP	Gross Domestic Product
EU	European Union
EU-Rail	Europe’s Rail Joint Undertaking
EC	European Commission
ERTMS	European Rail Traffic Management System
UNIFE	Association of the European Rail Supply Industry
FUA	Functional Urban Area
GVA	Gross Value Added
HSR	High-speed rail
km	Kilometre
M	Million
MS	Member States
NPV	Net Present Value
pkm	Passenger Kilometre
S2R	Shift2Rail Joint Undertaking
SERA	Single European Rail Area
TEN-T	Trans-European Transport Network
UIC	International Union of Railways
UNECE	United Nations Economic Commission for Europe

1. Introduction

Recent years have seen the European Union (EU) and its Member States (MS) commit to concrete actions towards combatting climate change. Notably, under the European Green Deal, the EU has pledged to ensure no net emissions of greenhouse gases in the EU by 2050[13]. This commitment has resulted in rising pressure on European industries and economic sectors to decarbonise their activities. Serving as the backbone of European society and the internal market, the transport sector plays a critical role in enabling its citizens and goods to move sustainably, however it is the only sector in which emissions have risen at EU level since 1990 and that this is not compatible with the EU's climate targets.

The European Commission (EC) has proposed a series of measures to spur a green transition for the transport sector. One such measure is the Sustainable and Smart Mobility Strategy, in which the EC singles out High-Speed Rail (HSR)[14] as a key lever in delivering green long-distance passenger transport. In particular, the EC aims to double HSR traffic by 2030 and triple it by 2050[15].

HSR has been identified as a key lever in the transition due to its numerous societal benefits. First and foremost is the low carbon footprint of HSR thanks to its high energy efficiency, and the ability to power transport with increasingly sustainable electricity, HSR is many times less emission-intensive than aviation or passenger road transport. Secondly, HSR has the potential to stimulate regional economic development by connecting citizens and regional businesses through a fast and competitive alternative to aviation and passenger cars.

The EC HSR traffic targets can be fostered through constructing new dedicated tracks and through upgrading the current network by, for example, deploying a more performant traffic management system such as the European Rail Traffic Management System (ERTMS). Expanding the current network and delivering on the targets for HSR traffic will furthermore be a crucial step towards a Single European Rail Area (SERA), which will deliver additional synergies for the European transport system.

[13] European Commission (2022). *A European Green Deal. Striving to be the first climate-neutral continent.* Retrieved from A European Green Deal | European Commission (europa.eu)
[14] This study applies the definition of Directive 2016/797 on the interoperability of the rail system within the EU of what defines HSR. Pursuant to the Directive, this study defines HSR 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.
[15] 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)

This report, developed in close cooperation with the top-ranking Università Bocconi[16], presents the main findings[17] in terms of net benefits of a future European HSR network connecting the main European cities. It demonstrates how investing in a comprehensive European HSR network, while also deploying innovative railway technologies and adopting polices fostering a modal shift will deliver economic value besides a massive reduction of the environmental footprint of passenger transport in Europe. The geographical scope of the study covers the countries in the Trans-European Transport Network (TEN-T), the EU candidate and potential candidate countries[18] and the current and planned HSR lines in the UK.

The report is structured as follows:

- Section 2 provides a brief overview of the benefits of HSR as described by the literature, and the development of the European HSR network over time.
- Section 3 describes the methodological approach of the study.
- Section 4 presents the findings of the market and impact assessments.
- Section 5 concludes the study and its perspectives for HSR in Europe and for European passenger transport.

[16] Università Bocconi (2022). *Education quality rankings in the world.* Retrieved from Education quality rankings in the world - Bocconi University Milan (unibocconi.eu)

[17] The study is presented in greater detail in the two Technical Reports (1 & 2), covering the market and impact assessments respectively.

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

2. The case for HSR in Europe and the network developments

The European HSR network has witnessed a considerable development since the advent of HSR in the 1980s. The total HSR network length has grown considerably during the last two decades, thanks to a large expansion in some countries such as Spain in particular. The European HSR network currently consists of approx. 13-15.000 km of tracks[19], enabling sustainable high-speed transport for the European regions which are connected to the network where it is established.

However, despite the significant engineering feats achieved across Europe, HSR in Europe remains scattered across Western Europe does not constitute a network yet and it is largely inexistent in Central-Eastern Europe. Indeed, there is currently almost no HSR infrastructure in the Member States (MS) that joined the EU in the recent enlargement waves. Central and eastern Europeans therefore lack a sustainable high-speed alternative to passenger road or airplane transport in their respective countries and are effectively excluded from enjoying the benefits of HSR[20].

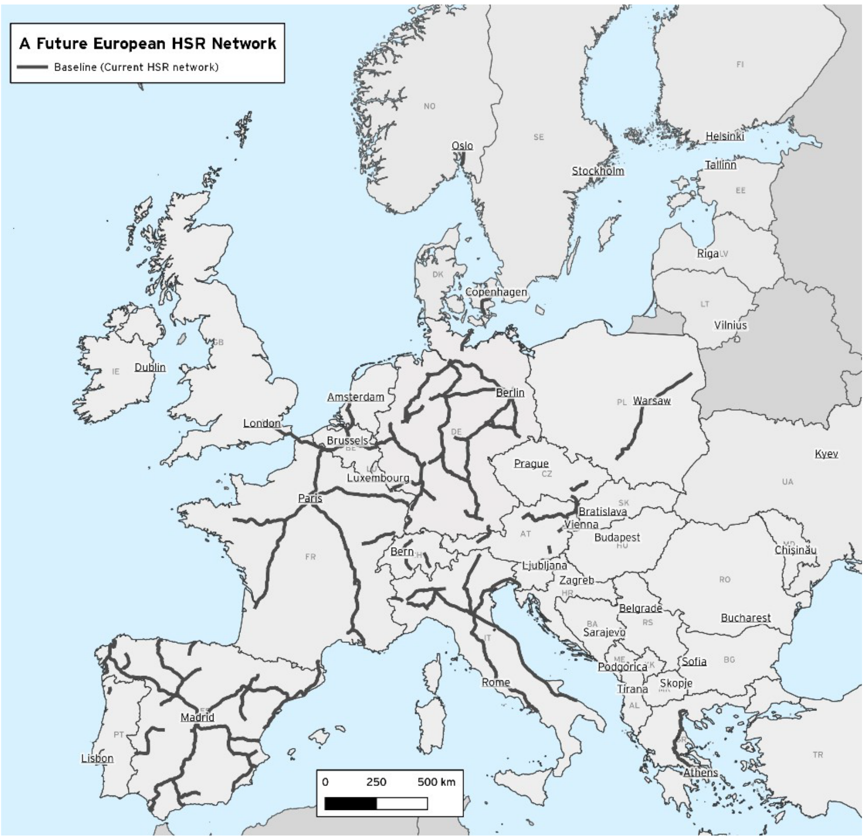

Figure 7: HSR network in Europe (2022)[21]

[19] Based on the International Union of Railways (2022). *Atlas High-Speed Rail 2022.* Retrieved from High-Speed Databases and Atlas | UIC - International union of railways and the TEN-T completed HSR network. The baseline of this study is slightly higher than the UIC as this study includes some additional lines. The total distance of the network varies depending on the HSR definition and hereby the lines included.

[20] Potential costs and benefits associated to the development of the HSR network in the EU accession countries is provided in Annex 6.

[21] Based on 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)

Moreover, bottlenecks and gaps exist in the current network, impeding a seamless HSR transport experience across Europe. These constitute a barrier to shifting traffic from less performing modes such as personal vehicles and aviation to HSR[22]. As a result, investments in expanding the European HSR network presents a golden opportunity for Europe.

Potential benefits of HSR are many and tap into the EC vision of a future sustainable European transport system in conjunction with other measures such as alternative fuels infrastructure for vehicles. In particular, HSR is associated with low negative externalities of its operation, in comparison to alternative modes. Externalities such as reduced CO2, as witnessed by Figure 8, and air pollutants per passenger kilometre (pkm) as well as increased safety[23] make it by far the most sustainable transport solution. Moreover, HSR improves local productivity and accessibility whilst at the same time, if successful in shifting traffic from the road, lowers congestion on the highways[24].

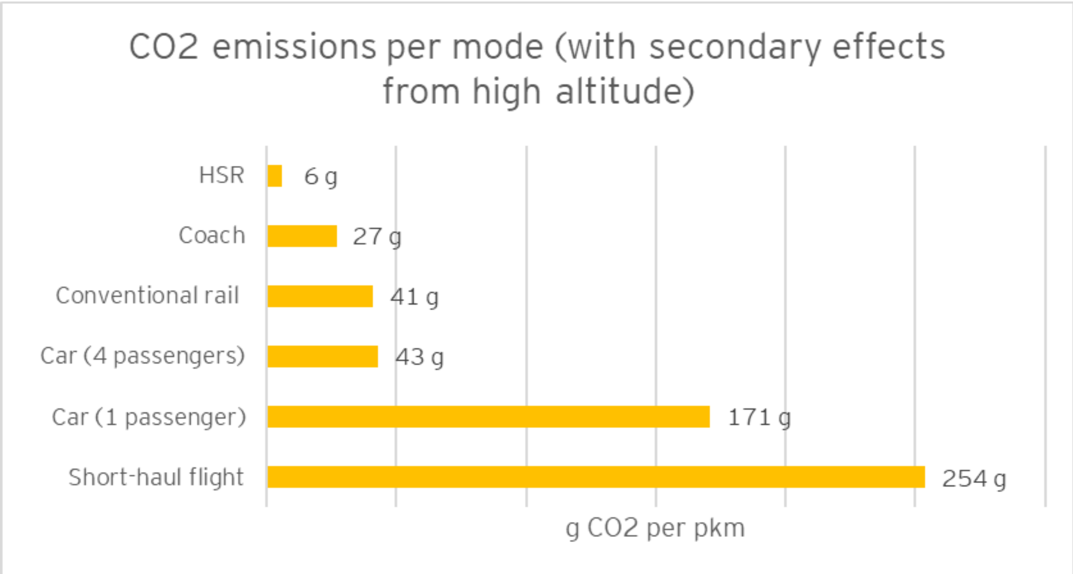

Figure 8: CO2 emissions from operations per mode and pkm. 2019 figures.[25]

Furthermore, the development of HSR lines generates productivity increase, according to current academic literature[26]. Faster and more accessible transportation decreases the travel time and promotes the exchange of knowledge and skills among people and businesses. Improved access to intermediate commodities and consumer markets,

[22] 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)
[23] European Commission (2019). *EU Handbook on the external costs of transport*. Version 1.1. Retrieved from Handbook on the external costs of transport - Publications Office of the EU (europa.eu)
[24] Idem.
Blanquart, C., & Koning, M. (2017). The local economic impacts of high-speed railways: theories and facts. *European Transport Research Review*, 9 (12), pp. 1-14. Retrieved from https://doi.org/10.1007/s12544-017-0233-0
[25] Greenhouse gas reporting: conversion factors 2019 - GOV.UK (www.gov.uk).
[26] Blanquart, C., & Koning, M. (2017). The local economic impacts of high-speed railways: theories and facts. *European Transport Research Review*, 9 (12), pp. 1-14. Retrieved from https://doi.org/10.1007/s12544-017-0233-0
Fouqueray, E. (2016). Impact économique de la construction de la LGV SEA Tours-Bordeaux sur les régions traversées. *Revue d'Économie Régionale & Urbaine*, 2, pp. 385-416. Retrieved from https://doi.org/10.3917/reru.162.0385
Ahlfeldt, G.M. & Feddersen, A. (2015). From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail. *SERC Discussion Paper,* 172, p. 1-20, Retrieved from From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail (repec.org)

knowledge dissemination, labour market pooling, and consumer markets are the key avenues to enhance throughout Europe, remote locations included.

3. Methodology

Four key principles underpin the study:

1. **Comparative analysis amongst HSR and the competing transport modes, by assessing the market potential and impact of investments in HSR.**
2. **Differential approach** including three network scenarios:
    a. A baseline scenario, only including those HSR lines currently in operation[27],
    b. a 2030 scenario incorporating the additional HSR lines planned to be completed by 2030[28], and
    c. a comprehensive 2050 scenario, connecting all major European cities, additional and complementary to lines already planned to be completed by 2050[29].

Competing transport modes:

- HSR.
- Conventional long-distance rail.
- Long-distance passenger car (above 100 km per trip).
- Passenger coach (above 100 km).
- Short-haul aviation (up to 3 hrs).

3. **Societal perspective,** focussing on the socio-economic and environmental benefits of expanding the European HSR network.
4. **Academically founded methodology, therefore** based on robust evidence from recent and relevant academic studies.

These four principles were applied consistently throughout:

- **the market assessment**, driven by a demand-shock model; and
- **the impact assessment**, driven by a cost-benefit analysis[30].

Figure 9 below provides an overview of the two assessments and how they are connected.

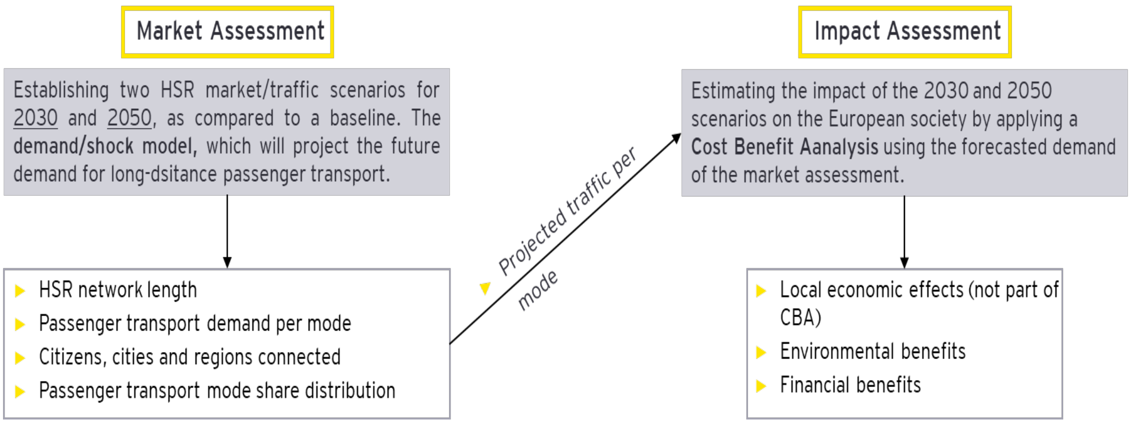

Figure 9: Methodological overview

[27] 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)]
[28] Idem. The TEN-T Core Network.
[29] Idem. Lines planned are the lines in the Extended Core and Comprehensive TEN-T Network.
[30] For a more detailed presentation, see Technical Report 1 (market assessment) and 2 (impact assessment).

3.1 Market Assessment

The demand- "shock" model has been applied to forecast demand for the market in which HSR competes. It defines a baseline scenario of the total transport demand until 2070, expressed in pkm and differentiated per mode[31], on the basis of Gross Domestic Product (GDP), and population growth forecasts and the historic development in traffic levels for the included modes. A combination of 10 individual demand "shocks" were applied to simulate the effects of future regulatory and technological developments on the passenger demand by mode of transport[32]. The shocks and the respective effects are based on peer-reviewed academic articles or high-level studies and have been tested through a sensitivity analysis indicating robust results[33]. It is presented in detail in the technical report 1.

Demand shocks:

1. HSR infrastructure.
2. Competition (HSR and LD rail)
3. Shared mobility (cars)
4. LD bus competition.
5. Aviation ticket tax.
6. Aviation fuel tax.
7. Short-haul flight ban.
8. Highway toll tax.
9. Shift2Rail railway technologies.
10. Gasoline price increase.

HSR traffic has been forecasted based on three network scenarios, as defined in table 2 below.

Scenario	Description
Baseline (15.200 km)[34][35][36]	**Network comprised of lines in operation as per the revised TEN-T Network maps[37]** ▶ 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, which means that the current use rates of the infrastructure of these modes will be conserved.
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. ▶ Additional population connected: ≈86 million.

[31] HSR, non-HSR long distance rail, short-haul aviation, coaches and passenger cars.
[32] Annex 1 details the shocks included in the model.
[33] For all the policy-related shocks, a variation of +/- 25% of the impact results into a variation of +/- 5% at most on the results in terms of market share and overall traffic. For infrastructure, arguably the most impactful effect on future traffic, the elasticity of results is still under 1 (15%-20% for a 25% variation).
[34] The length of the networks per scenario were measured using the Geographic Information System software, QGIS. Some differences with other sources may appear.
[35] Baseline forecast based on 2015 prices and 2% inflation rate.
[36] The Baseline is based on the EU's definition of HSR set out in Annex 1 of Council Directive 98/48 EC. It defines HSR as: specially built HS lines equipped for speeds generally equal to or greater than 250 km/h, specially upgraded HS lines equipped for speeds of the order of 200 km/h and specially upgraded HS lines which have special features as a result of topographical, relief or town-planning constraints, on which the speed must be adapted to each case. The same definition is applied in the TEN-T Revision Council General Approach. This 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.
[37] 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)]

Scenario	Description
2050 scenario (49.400 km)	**Network comprised of lines connecting all Functional Urban Areas (FUAs) (above 250.000 inhabitants) in Europe, in addition to the HSR lines forming part of the Extended Core TEN-T Network (2040) and the Comprehensive Ten-T Network (2050)** ▶ FUAs are defined as a city core and its commuting zone[38][39]. ▶ FUAs can either be departure and destination cities or stops along the line. FUAs are considered connected if a HSR line passes within a 20 km 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. ▶ Population connected to the network: ≈216 million.
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. ▶ Some lines, particularly in Serbia, will be completed before 2030. ▶ Assumed completed by 2050. ▶ Population connected to the network: ≈40 million.

Table 2: HSR network scenarios

3.2 Impact Assessment

The main methodological component of the impact assessment is the CBA. It computes the net benefits of the construction of the 2030 and the 2050 network scenarios. The methodological approach of the CBA is based on the EC's guidelines on transport CBAs[40]. The net benefits are computed based on the travel times savings and saved external costs[41] due to the traffic shifted against the costs of constructing the network[42]. Lastly, the study estimates the local economic effects covering the construction and operation of the new HSR lines, based on previous *ex post* estimations of the impact of HSR[43].

[38] 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
[39] For a full list of the FUAs, see Appendix_all_fuas.pdf (oecd.org).
[40] European Commission (2021). *Economic Appraisal Vademecum 2021-2027*. Retrieved from https://ec.europa.eu/regional_policy/sources/docgener/guides/vademecum_2127/vademecum_2127_en.pdf
[41] Based on European Commission (2019). *EU Handbook on the external costs of transport*. Version 1.1. Retrieved from Handbook on the external costs of transport - Publications Office of the EU (europa.eu)
[42] Based on 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 and 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)
[43] Fouqueray, E. (2016). Impact économique de la construction de la LGV SEA Tours-Bordeaux sur les régions traversées. *Revue d'Économie Régionale & Urbaine*, 2, pp. 385-416. Retrieved from https://doi.org/10.3917/reru.162.0385 Ahlfeldt, G.M. & Feddersen, A. (2015). From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail. *SERC Discussion Paper,* 172, p. 1-20, Retrieved from From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail (repec.org)

Methodological component	Description	Output
CBA	The socio-economic cost-benefit analysis of the proposed HSR networks provides a monetary valuation of the societal impact. **Costs:** ▶ Construction of the network. **Benefits:** ▶ Travel time benefits. ▶ Saved external costs (CO2, air pollution, noise, safety, congestion) due to shifted traffic.	▶ The **Net Present Value (NPV)** is the sum of discounted total social benefits and costs, valued at shadow prices and expressed in monetary values. ▶ The **Benefit-Cost Ratio (B/C ratio)** is the ratio between discounted economic benefits and costs.
Local Economic Effects	The local economic effects estimate the effects of the construction HSR lines and operating HSR services. **Effect:** ▶ 8.5% GDP increase from operation 6 years after start of operations. ▶ Multiplier effects from HSR construction: 1,96 for production, 0,91 for Gross Value Added and 2,44 for jobs created.	▶ Regional GDP increase. ▶ Regional jobs created. ▶ Regional Gross Value Added. *Due to uncertainties on the actual local economic effects related to major infrastructure projects[44] and the risk of overestimation, this additional impact has not been considered in the CBA.*

Table 3: Methodological overview - Impact Assessment

[44] This is line with the methodological approaches of the European Investment Bank: European Investment Bank (2013). *The Economic Appraisal of Investment Projects at the EIB.* Retrieved from [The Economic Appraisal of Investment Projects at the EIB]

4. Findings

This section presents the main results of both the market assessment and the impact assessment for the considered HSR network configurations, as illustrated in the map below. Illustrated by the full blue lines, the 2050 scenario will close the gaps and bottlenecks present in the current network in operation as per the TEN-T Network.

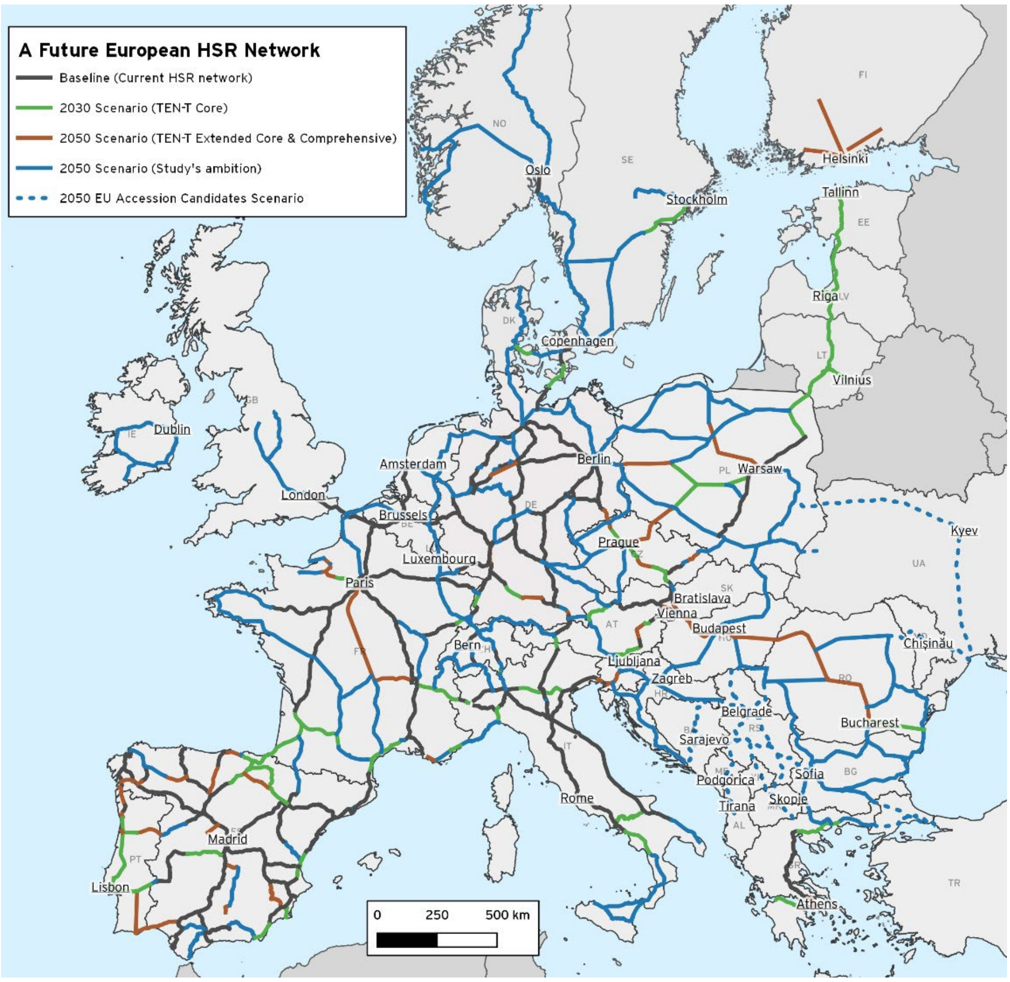

Figure 10: The HSR network proposed by the study

4.1 Market assessment

The application of the 10 shocks to the scenarios, illustrated in Figure 11, yield three main conclusions. The first is that without new investment in HSR, demand for HSR will only increase slightly, as Figure 11 indicates. This will leave other, more polluting, forms of transport as the only alternatives for travellers across the continent. 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[45]. As it, HSR expansion coupled with the measures proposed by this study will meet these targets well in advance, while the baseline scenario (of continuing current efforts) indicate that the 2030 and 2050 European targets will only be reached by 2040 and 2058 respectively.

[45] 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)

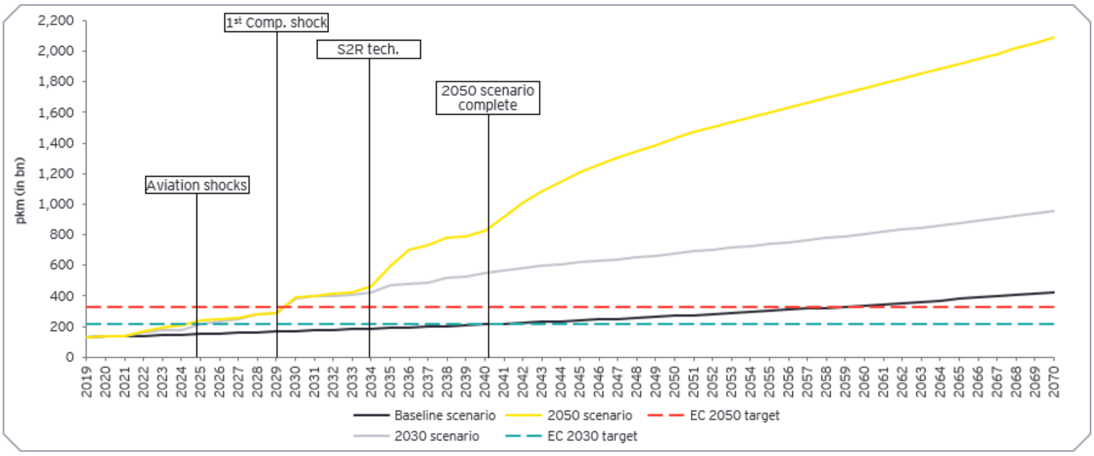

Figure 11: Evolution in HSR demand (in pkm)[46]

Secondly, a limited investment in HSR as represented by the 2030 scenario foresees a future which only will spur a limited growth in HSR traffic compared to the baseline (reaching 958 billion pkm in 2070). This increase in traffic would result in a market share for HSR of 32% by 2070, while, more crucially for the environment, demand for short-haul aviation would reach an 8% share by 2070. Figure 12, Figure 13, and Figure 14 illustrate the evolution of the passenger modal share in the three scenarios.

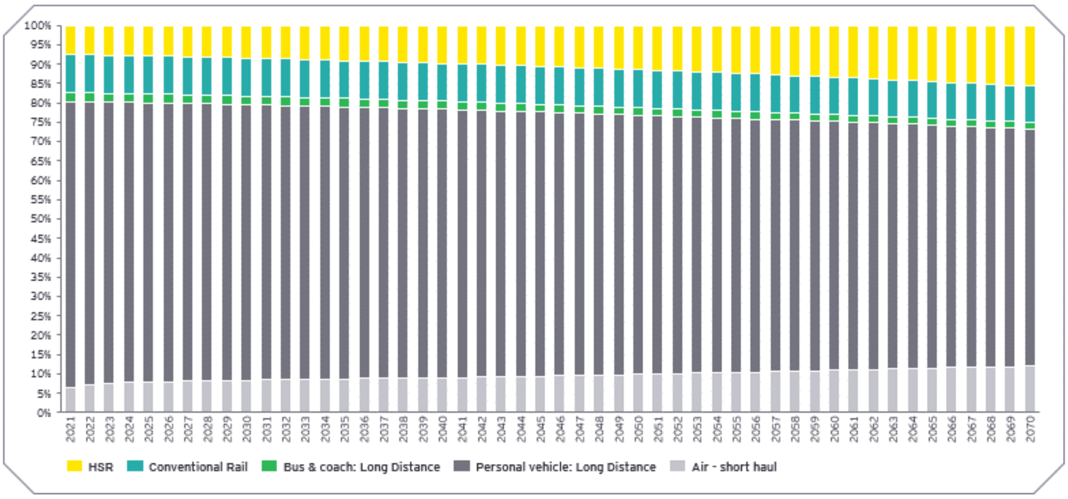

Figure 12: Passenger modal share evolution - baseline

[46] 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.

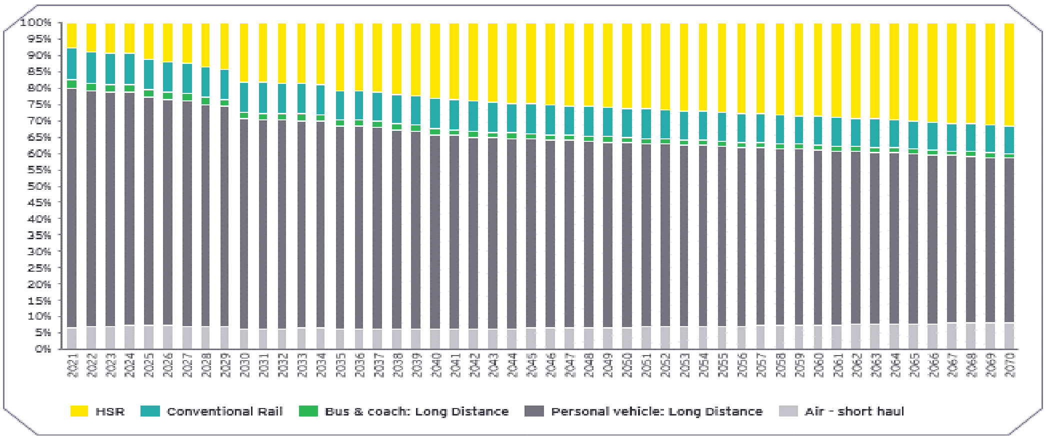

Figure 13: Passenger modal share evolution – 2030 scenario

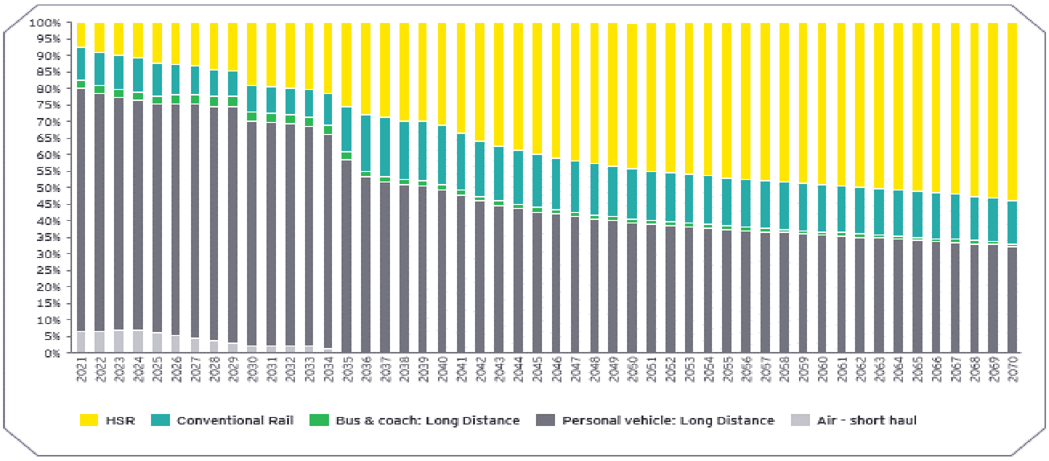

Figure 14: Passenger modal share evolution – 2050 scenario

Crucially, however, is that the third conclusion indicates, that an accelerated investment in a complete European HSR network will elicit a considerable response from travellers (more than 2089 billion pkm and 54% modal share in 2070). This result indicates economies of scale for both the traffic by HSR and the associated economic and environmental benefits.

The four figures (11-14) above highlight the impact and therefore the importance of the “shocks” identified for this study. Firstly, it can be seen that infrastructure, not surprisingly, has a considerable effect on the pkm travelled and the modal choice of passengers. Secondly, the return on investments in future rail technologies can be seen in the significant increase in modal share and pkm around 2030, which is where the S2R technological program is expected to be deployed. The potential positive effects of S2R technologies indicates that increased investments in railway research & development is needed to deliver a modal shift. Thirdly, increased competition in the railway market has a positive effect on demand, due to the increase in service quality and decrease in prices. As illustrated in Figure 11, demand for HSR in the 2050 scenario increases with close to 40% around the year 2030 where the first competition shock is applied along with a completion of the 2030 Scenario. Two additional competition shocks are considered over the following years and will combine demand increase with other shocks that are occurring. Lastly, policies disincentivising travelling by plane will virtually eliminate short-haul aviation. As mentioned above, the positive features of HSR in terms of travel quality, door-to-door travel time and low environmental impact outcompete the alternative modes when all European regions are serviced with HSR[47].

The HSR network expansion will, in addition, create spill-over benefiting the entire rail network. Where non-HSR would account for 9% of the market in the baseline scenario, it would account for 13% in the 2050 scenario. The increase may not seem noteworthy but compared to the share developments of competing modes, the spill-over effects are considerable. Non-HSR rail services can be part of an integrated ticketing system and therefore help connect smaller cities with the HSR network.

4.2 Impact assessment

The impact assessment estimates the impact of the investment in the networks on the European society. The main component is the CBA, which estimated the impact of the investment in the proposed networks.

Table 4 outlines the key economic results of the investment in the HSR network scenarios with different construction costs per km. The NPV is significantly positive in both scenarios. The 2050 scenario generates € 561-836 billion for the European society and economy in saved external costs and travel time benefits. The Benefits/Costs (B/C) ratio is positive in both network scenarios. The lower B/C ratio for the 2050 scenario compared to the 2030 scenario is due to the significantly higher construction costs needed to build the longer 2050 network[48]. Nevertheless, the B/C ratio even in the costly scenario remains at levels similar to previous HSR appraisals, and it has to be noted that these results exclude the wider economic benefits[49]. The high B/C can be explained by the long-term perspective of the study and hereby the ability to shift a great share of traffic to HSR and offset the investment in the networks.

Avg. Construction costs	**Scenario**	**Construction cost (bn €)**	**NPV (M€)**	**B/C Ratio**
12 €M per KM[50]				
	2030	63	447.488	10
	2050	410	836.670	4

[47] The results and demand forecast have been deemed robust, through a sensitivity analysis of the application of the shocks. The analysis is presented in depth in the technical report 1.

[48] An in-depth discussion on this can be found in Annex 1.

[49] The wider economic benefits have been left out due to uncertainties on the actual local economic effects related to major infrastructure projects and the risk of overestimation, this additional impact has not been considered in the CBA.

[50] Based on the construction costs in 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)](2017852_E_web_light+c1.pdf)

Avg. Construction costs	Scenario	Construction cost (bn €)	NPV (M€)	B/C Ratio
16.5 €M per KM[51]				
	2030	87	431.527	7,6
	2050	546	748.594	3
25 €M per KM[52]				
	2030	132	400.734	5
	2050	855	561.433	2

Table 4: Financial results of the CBA per scenario

Figure 15 below depicts the evolution of the externalities saved for the 2050 scenario due to the modal shift in traffic to HSR. The construction of the HSR infrastructure and its related effects are visible through the increase in saved external costs from 2036 and forward. Notably, the increase in HSR traffic and decrease in demand for competing modes leads to considerable time savings. The decrease from 2040 and onwards is both due to the increasing modal share of HSR and the gradual decarbonization of the transport system.

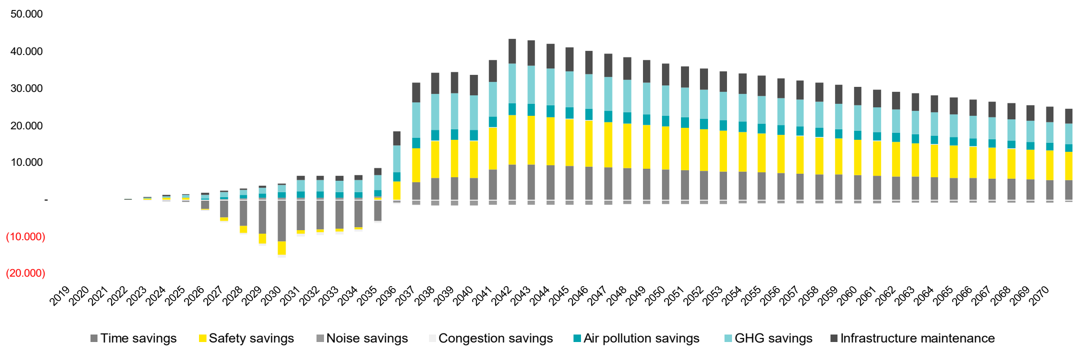

Figure 15: Externalities saved in M € - 2050 scenario

4.2.1 Wider/local economic benefits of the HSR networks

As explained further above, the investment in large infrastructure projects such as a HSR network, and the subsequent operation of the HSR services yield considerable economic benefits to the regions on the network. The benefits come mainly through increased GDP and added jobs. Table 5 below highlights the total wider economic effects per scenario[53]. While there is a considerable difference in the results based on the multipliers applied, it remains clear that the return on investment in the HSR networks will outweigh the construction costs greatly. The results below are summed up from all the local economic effects per NUTS 3 region and the first row depicts the results of the two scenarios together. As can be witnessed by Table 5 the 2030 and 2050 scenario may create around 1.8 million job-years due to construction of the network, while generating 85 bn in gross value added

[51] € 16.5 million per KM was also the completion cost per KM for the French LGV Est Européenne HSR line. See 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

[52] Average final construction costs audited by the ECA in 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

[53] Sum up from the estimations per NUTS 3 region.

(GVA) in the 2050 scenario. Moreover, the EU accession candidate countries stand to gain considerably by the investment in the network.

Scenario	Incremental production from construction (€ BN)[54]	Incremental GVA from construction (€ BN)[55]	Incremental job-years from construction ('000)	Incremental GVA from operations (€ BN)[56]
2030	29	13	264	115-174
2050 scenario	184	85	1549	313-484

Table 5: Total wider economic effects per scenario

4.2.2 CO2 emissions saved

As can be seen from the figures below, the increased shift to HSR in the 2030 and 2050 scenarios coupled with a rapid decarbonization of the power supply for rail, will be key in decarbonizing the European transport system. By 2070, compared to the baseline scenario, a total of 1.5 and 5[57] billion t CO2 will be saved in the 2030 and 2050 scenarios respectively.

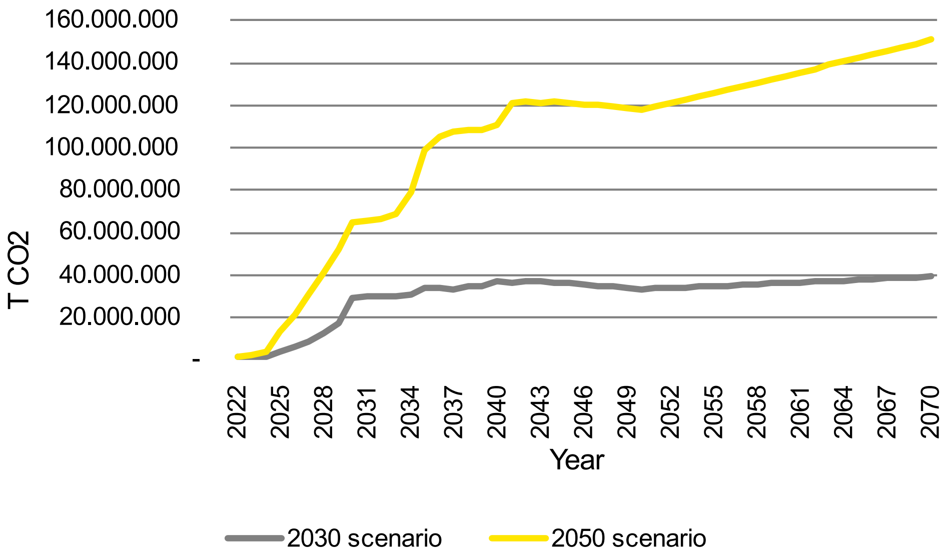

Figure 16: tonnes CO2 emissions – net saved per scenario

[54] Based on Fouqueray, E. (2016). Impact économique de la construction de la LGV SEA Tours-Bordeaux sur les régions traversées. *Revue d'Économie Régionale & Urbaine*, 2, pp. 385-416. Retrieved from https://doi.org/10.3917/reru.162.0385.
[55] Idem.
[56] High range based on Ahlfeldt, G.M. & Feddersen, A. (2015). From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail. *SERC Discussion Paper,* 172, p. 1-20, Retrieved from From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail (repec.org) and low range based on Cascetta, E., Cartenì, A., Henke, I., & Pagliara, F. (2020). Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: ten years ex post evaluation and future perspectives. *Transportation Research. Part A, Policy and Practice, 139*, 412 - 428.
[57] Set at 60 tonnes CO2 emitted per km of track constructed per year.

Figure 17 below provides an insight into the benefits of the 2050 scenario compared to the 2030 scenario as it delivers a more CO2 efficient transport market. By 2070, in fact, the CO2 emission intensity of the European transport system will decrease, compared to the baseline scenario, by a factor of approximately:

- 1.3 for the 2030 scenario, and
- 4.5 for the 2050 scenario.

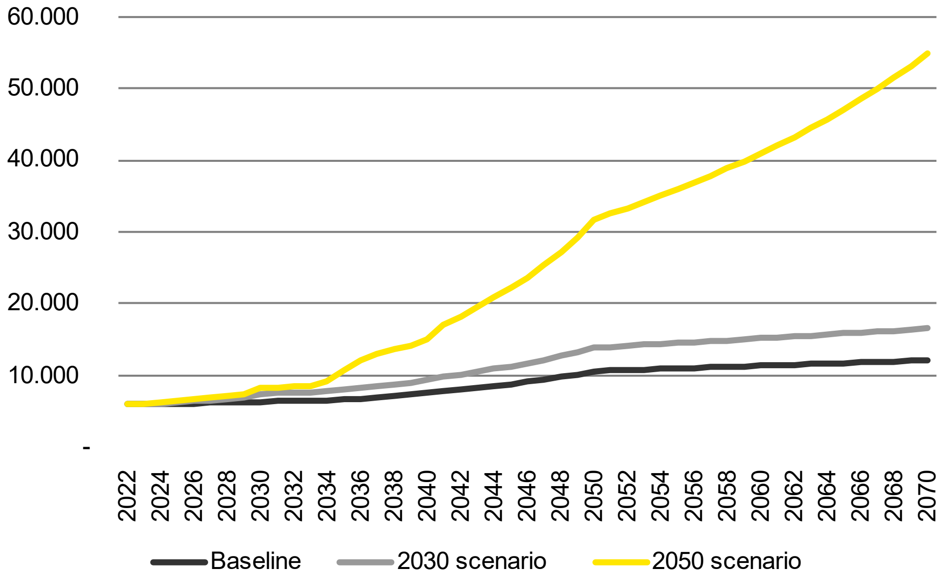

Figure 17: pkm travelled per T CO2 emitted (per scenario) for all modes

5. Conclusion

This study can conclude that expanding the current European HSR network to cover the main European regions and cities, while implementing a series of other measures, will result in considerable benefits for the European society and economy.

The results of both the market and the impact assessments were highly positive and supportive of an expansion of the European HSR network. According to the 2050 scenario, approximately 49.400 km of HSR lines would be in operation in Europe already by 2040. This, in conjunction with the demand "shocks", such as increased HSR competition or investing in railway technologies, would result in HSR accounting for 54% of passenger transport by 2070. While the 2030 scenario, differently, would limit the HSR share to 32% only.

An increased HSR traffic would be highly beneficial to the European society and economy:

- The investments in the network would generate € 400-447 billion, for the 2030 scenario, and € 561-836 billion, for the 2050 scenario, of value added. Meaning that benefits outweigh the costs by at least a factor of 2.
- Moreover, HSR would also considerably contribute to fighting climate change. The 2030 scenario will have saved 1.5 billion tons CO_2 and the 2050 scenario 5 billion tons of CO_2 by 2070.

Therefore, while the 2030 scenario delivers considerable economic benefits, the 2050 scenario will also make passenger transport much more environmentally sustainable overall.

The results of this study shed light on where to focus future efforts and which policies to adopt if a modal shift to HSR and resulting decarbonisation of transport is to be obtained. There is a need for an extension of the current HSR network to cover the entire European connect the major European cities. Nevertheless, it should be coupled with series of sound policies regulating the entire transport sector and support in the harmonised EU-wide deployment and development of railway technologies to support further growth of HSR.

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. Lastly, it is recommended that future HSR lines should be followed an individual appraisal.

6. Annex

Annex 1: Limitations of the study

The following section will discuss the limitations of the study and its applied methodology. Firstly, the market assessment and then secondly the impact assessment.

Market assessment:

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 estimating the effects 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.

Impact assessment:

Uncertainties are related to the estimates of costs and benefits in this study are built on the results of other reports and assumptions that jointly contribute to a level of uncertainty around the CBA results. Overall conducting appraisals of large construction projects is difficult and estimations of the costs and benefits are often over and underestimated, respectively. The overestimation of costs has been partly taken into account by providing the results at different avg. costs per km based on *ex post* construction costs. The economic benefits of construction or operations have inherent uncertainties since it's difficult to single out the effect of construction or operation from other factors which have an effect on economic indicators. This has to some extent been taken into consideration by applying different estimations of economic effects. Moreover, there are uncertainties related to monetising the externalities of transport[58]. Lastly, given this study's European geographical scope it has been difficult to take into account local specificities which may affect the results. Hence, more detailed studies per country are suggested.

A note on the findings of the 2030 scenario in comparison to the 2050 scenario. The potential economic impact of the 2030 scenario may appear large relative to the impact of the 2050 scenario. There are multiple reasons for this. Firstly, the 2030 scenario is completed earlier

[58] For a full discussion see the EU Handbook on External Costs in footnote 77.

than the 2050 scenario leaving more time for the impact of the HSR lines to settle in. Secondly, there may be diminishing marginal returns for every newly added line, since the economic impact of a line is highly dependent on its geographic surroundings. Thirdly, and related to point number 2, the lines included in the 2030 scenario are already under construction and have received financing, thus one can assume they represent the most impactful lines in economic terms. However, this does not entail that lines included in the 2050 scenario are not economically sound. This is so for two reasons: the decision to construct HSR lines is politically influenced and decisions may not rest solely upon economic rationales. Secondly and more importantly, our study and the specific feasibility studies use the same economic impact assessment techniques, thus sharing the same biases and errors. Thus, if a line is erroneously deemed economically profitable by a feasibility study (hereby included in the 2030 scenario), our study will also over/underestimate its economic impact.

Annex 2: List of shocks

Shock	Main effect	Source	Traffic shifted to HSRHSR	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.
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

Shock	Main effect	Source	Traffic shifted to HSRHSR	Timing
Shared mobility	+ 2,8 % 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 % 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[59]	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 increase in travel time Avogardo et al., (2021).	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[60]: 10% ▶ From rail: 80% ▶ From road: 10%	From 2025
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%[61] ▶ 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

[59] A similar ban is being introduced in France EU approves France's short-haul flight ban — but only for 3 routes – POLITICO.
[60] 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.
[61] 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.

Shock	Main effect	Source	Traffic shifted to HSRHSR	Timing
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 by 2034.
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 6: List of the shocks including their main effects and traffic shifts

Annex 3: Externalities included in the study

Externalities are referred to as "the effect of production or consumption of goods and services imposing costs or benefits on third-parties which are not reflected in the prices charged for the goods and services being provided"[62]. In the context of transport, six types of externalities are considered: climate, air pollution, noise, accidents, infrastructure wear, time savings linked to road congestion.

Climate Impact. Due to the fact that the effects of climate change are global, long-term and have risk patterns that are difficult to anticipate, identifying the costs associated with these effects is rather complex. Transport results in emissions of CO_2, N_2O and CH_4 (methane), all of which are greenhouse gases contributing to climate change. Therefore, the climate costs of transport need to be included[63].

Air Pollution. The emission of air pollutants can lead to different types of damages. Most relevant and probably best analysed are the health effects due to air pollutants. However, other damages such as building and material damages, crop losses and biodiversity losses are also relevant.

- **Health effects**. The inhalation of air pollutants such as particles (PM_{10}, $PM_{2.5}$) and nitrogen oxides (NO_x) leads to a higher risk of respiratory and cardiovascular diseases. These negative health effects lead to medical treatment costs, production loss at work (due to illness) and, in some cases, even to death.
- **Crop losses**. Ozone as a secondary air pollutant (mainly caused by the emission of NO_x and VOC) and other acidic air pollutants (e.g. SO_2, NO_x) can damage agricultural crops. As a result, an increased concentration of ozone and other substances can lead to lower crop yields (e.g. for wheat).
- **Material and building damage**. Air pollutants can mainly lead to two types of damage to buildings and other materials: a) pollution of building surfaces through particles and dust; b) damage of building facades and materials due to corrosion processes, caused by acidic substances (e.g. nitrogen oxides NO_x or sulphur oxide SO_2).
- **Biodiversity loss**. Air pollutants can lead to damage to ecosystems. The most important damages are the acidification of soil, precipitation and water (e.g. by NO_x, SO_2) and the eutrophication of ecosystems (e.g. by NO_x, NH_3). Damages to ecosystems can lead to a decrease in biodiversity (flora & fauna) [63].

Noise Pollution. Traffic noise is generally experienced as a disutility and is accompanied by significant costs. Noise emissions from traffic pose a growing environmental problem due to the combination of a trend towards greater urbanisation and an increase in traffic volumes. Whilst the increase in traffic volume results in higher noise levels, the increase in urbanisation results in a higher number of people experiencing disutility due to noise. As a result, the costs of traffic noise are expected to grow in the future despite potential noise-reducing improvements in vehicles, tyres and roads[63].

Accidents. Accidents occur in all forms of traffic and result in substantial costs, consisting of two types of components: material costs (e.g. damages to vehicles, administrative costs and

[62] OECD (2021). *Glossary Of Industrial Organisation Economics and Competition Law*. Retrieved from https://www.oecd.org/regreform/sectors/2376087.pdf

[63] European Commission (2019). *EU Handbook on the external costs of transport*. Version 1.1. Retrieved from Handbook on the external costs of transport - Publications Office of the EU (europa.eu)

medical costs) and immaterial costs (e.g. shorter lifetimes, suffering, pain and sorrow). The EU Handbook on External Costs of Transport has laid out monetary value of each life, light injury and serious injury alike that occurs and modelled this as € per pkm for each transport mode. This is thus taken as the most appropriate source[63].

Congestion. Congestion is a condition where vehicles are delayed when travelling. In particular, a congestion cost arises when an additional vehicle reduces the speed of the other vehicles of the flow and hence increases travel time. Road congestion cost can be defined on the basis of a speed-flow relationship in a given context, for example at an urban or inter-urban level[64]. Road congestion automatically determines increased levels of air and noise pollution.

Infrastructure wear. The cost of infrastructure wear is not covered in the EU Handbook on External Costs of Transport, although it is covered in the socio-economic Impact of the Transport Sector by the Swedish Transport Administration[65]. It is defined as deterioration of infrastructure and is directly related to maintenance costs. There is a non-negligible difference between modes in their footprint on the general infrastructure that is maintained with public funds[65]. While the study assumes the infrastructure maintenance covered by track access charges for railway actors, it includes infrastructure maintenance costs at modal level.

[64] Externality descriptions taken from European Commission (2019). *EU Handbook on the external costs of transport*. Version 1.1. Retrieved from Handbook on the external costs of transport - Publications Office of the EU (europa.eu)

[65] Swedish Transport Administration (2020) *ASEK - Guidelines for cost-benefit analysis in the transport sector* https://www.trafikverket.se/for-dig-i-branschen/Planera-och-utreda/Planerings--och-analysmetoder/Samhallsekonomisk-analys-och-trafikanalys/asek-analysmetod-och-samhallsekonomiska-kalkylvarden/ (retrieved from IMPACT-2)

Annex 4: Cost assumptions of the study

This section breaks down the assumptions on the costs of constructing the HSR lines.

Maintenance costs: The study assumes that operators run at equilibrium (between cost and revenue) and that track access charges are efficiently set to offset maintenance costs. Nevertheless, the CBA includes the infrastructure maintenance savings over the period of the study. Thus, infrastructure maintenance is included at macro level but not micro level.

Construction costs: The construction of HSR lines is cost-intensive due to requirements of the infrastructure in terms of earthworks and construction of tunnels or bridges. The construction cost assumption applied for this study is based on previous studies and assessments of the construction of HSR networks. The accounts only for the construction of new dedicated HSR lines.

The associated to the construction of entirely new dedicated HSR lines includes everything from planning to earthworks and the construction of tunnels and viaducts. This study applies the costs identified in two previous studies: the European Court of Auditors report on HSR[66] and the UNECE study on a Trans-European HSR network[67]. The ECA report has identified 10 HSR lines with an average *ex ante* cost of €10 M per km and an average *ex post* cost of €25 M per KM, while the UNECE study assumes construction costs to be €12.4 M per km. To account for any differences between initial and completion costs, this study assumes construction costs to be €16.5 M per km. The results takes into account both the estimation by the UNECE and the average post construction costs per km from the ECA report (€25 M per KM).

[66] 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

[67] 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)

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)

Annex 5: CO2 emissions calculations and assumptions

The assumptions regarding the CO2 emissions from the different transport modes have been based on the CE Delft study on the external costs of transport[68]. The study both include the emissions from the production of energy (well-to-tank) and the operation of the modes (climate change, CO2 emissions), which was done to account for any emissions related to the energy mix and hereby the emissions of powering electric transport.

The energy mix (well-to-tank) has been assumed to gradually decarbonize over time as based on the forecast of the International Energy Agency in their World Energy Outlook 2021[69]. The energy mix needed to power electric vehicles is thereby assumed to be net zero by 2050. Based on the recent trend in partnerships between energy providers and infrastructure managers, it has been assumed that the energy mix for rail will be CO2 net-zero as of 2030[70] [71]. The delay in decarbonisation the energy mix of EVs is due to the larger supply of energy needed to power the future EV fleet in Europe.

The CO2 emissions related to the construction of the HSR network are based on a study of the UIC on the Carbon Footprint of HSR[72]. The study estimated the CO2 embedded emissions of HSR construction (entire construction phase including planning) over the 100 years lifetime of HSR infrastructure. The construction and maintenance of HSR lines has been estimated at emitting 58 t CO2 per km per year while an additional sensitivity analysis have been made for 200 t CO2 per km per year. The emissions depend greatly on the course of the lines. Additional bridges, tunnels and earthwork increase the CO2 emissions significantly. The two emission estimates (58 t and 200 t) hereby reflect a low and high estimate.

The study has, moreover, included estimations on the future CO2 emissions from constructing the other modes infrastructure (airports and highways). Future infrastructure construction was modelled after the forecasted demand developments in the baseline scenario. Meaning that the forecasted increase in demand for road and aviation will elicit an expansion in infrastructure capacity.

For road transport the following approach was applied: Based on a regression of Eurostat data on highway length in Europe and the increase in pkm in the same time period (2011-2019), it was estimated that a total of 14.375375 lane-km of highway will be constructed until 2070. Lane-km was chosen as studies suggest that widening the existing highway network is more likely then extending the current length of the network[73]. The CO2 emissions from constructing one lane-km of highway has been set at 43 tons of CO2 per year[74].

---

[68] European Commission (2019). *EU Handbook on the external costs of transport*. Version 1.1. Retrieved from Handbook on the external costs of transport - Publications Office of the EU (europa.eu)

[69] International Energy Agency (2021). *World Energy Outlook 2021.* Retrieved from World Energy Outlook 2021 (windows.net)

[70] Network Rail (10 August 2022). *Network Rail signs solar power agreement with EDF Renewables UK in milestone step towards a cleaner and greener railway.* Retrieved from Network Rail signs solar power agreement with EDF Renewables UK in milestone step towards a cleaner and greener railway - Network Rail

[71] Moreover, studies indicate that even when decarbonizing the energy mix, the negative externalities of EVs are higher than for rail, see Boulouchos, K. & Ducrot, V. (2022). The Swiss experience to support modal shift Performance-based road-charging and efficient rail infrastructure. *The CER Essay Series.* Retrieved from CER Essay_SBB_FINAL.pdf

[72] International Union of Railways (2011). *Carbon Footprint of High Speed Rail*. Retrieved from HSR_Sustainability_carbon_footprint_FINAL_5_(dot.gov)

[73] Ossokina, I.V., van Ommeren, J. & van Mourik, H. (2022). Do highway widenings reduce congestion? *Tinbergen Institute Discussion Paper*. Retrieved from Ossokina_et_al2022_Highways.pdf

[74] Williams-Derry, C. (2007). Increases in greenhouse-gas emissions from highway-widening projects. *Sightline Research Backgrounder*. Retrieved from Memorandum (ubc.ca)

For aviation: The expansion of the main European airports has been estimated in similar fashion. Based on airport extensions of the largest European airports in the last 20 years[75] and the historic data on passenger carried from Eurostat, it was estimated that there would be 22 runway expansions by 2070 to follow the increased demand. The CO_2 emissions related to expanding an airport are based on data from the assessment of an extension of London Gatwick Airport, which estimates a total of 3.016.218 tonnes of CO_2 emitted in the 60-year appraisal period[76].

[75] Dray, L. (2020). An empirical analysis of airport capacity expansion. *Journal of Air Transport Management,* 87. Retrieved from https://doi.org/10.1016/j.jairtraman.2020.101850

[76] Jacobs (2014). *8. Carbon: Baseline*. Retrieved from Carbon: Baseline (publishing.service.gov.uk)

Annex 6: Methodology behind the local economic effects

The local economic effects of HSR are based on two *ex post* assessments of the effect of constructing and operating HSR lines[77][78]. As stated in the methodological approach section of the report, the local economic effects have not been included in the NPV and B/C ratio due to the risk of double counting and the difficulties in estimating the local economic effects. Moreover, due to the limited *ex post* studies available on the local economic effects produced by new HSR lines, these findings provide some uncertainties when applied over the catchment areas surrounding the entire HSR network.

The local economic effects of having aa HSR line in operation for the given regions was identified by Ahlfeldt & Feddersen (2015) to be 8.5% GDP increase in comparison to having no HSR line operation. This increase was observed over a 6-year period. The local economic benefit has been applied to the FUAs and NUTS 3 regions covered by the proposed HSR network. The GDP per FUA and NUTS 3 regions was sourced through Eurostat datasets.

The regional economic effects of constructing a HSR network are based on the findings of Fouqueray (2016)) for the HSR line between Tours and Bordeaux. The study estimates the multipliers as being 1,96 for production, 0,91 for Gross Value Added and 2,44 for jobs created. The latter has been rescaled to replicate the effects on jobs created by € 1 invested in the network. The multipliers have been applied to number of kilometres constructed per NUTS3 region.

Annex 7: 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[79], 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.

---

[77] Ahlfeldt, G.M. & Feddersen, A. (2015). From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail. *SERC Discussion Paper,* 172, p. 1-20, Retrieved from From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail (repec.org)
Fouqueray, E. (2016). Impact économique de la construction de la LGV SEA Tours-Bordeaux sur les régions traversées. *Revue d'Économie Régionale & Urbaine*, 2, pp. 385-416. Retrieved from https://doi.org/10.3917/reru.162.0385
[78] For an in-depth presentation of the methodology applied to the local economic effects, please see Technical Report 2 of the study.
[79] 4th Rail package, noticeably, Directive 2016/2370/EU

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 regulations. The underlying assumption is that, thanks to market efficiency, companies (both infrastructure managers and railway undertakings) operate at equilibrium: which means that the evolution of maintenance and operating costs (both increasing or decreasing) is directly translated into an evolution of prices (customer prices and track-access charges).

- 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[80][81].

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

  - 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 8: The EU accession candidate countries scenario

This section presents the results of the traffic forecast for the EU accession candidate scenario. This scenario is a standalone one for the accession candidate countries only, due to the very limited available traffic data for the region. As 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.

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

[81] 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

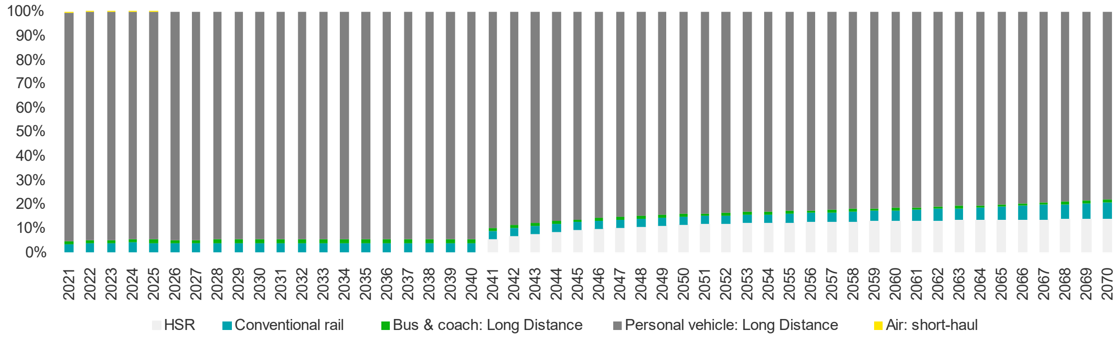

Figure 18: Modal share evolution - 2050 EU accession candidates scenario

Due to the limited data the results below have had no shocks applied to them[82], the traffic is uncertain and hence less benefits arise and the overall results are negative. The local economic effects on the other hand, since they depend on the constructed kilometers of network, show positive results and able to offset the infrastructure investment costs with an infrastructure cost of 12 M per KM. With shocks applied it can be assumed that the B/C ratio would be above 1.

Avg. Construction costs	Scenario	Construction cost (bn €)	NPV (M€)	B/C Ratio
12 €M per KM[83]				
	2050 EU	41	-9614	0,69
16.5 €M per KM[84]				
	2050 EU	71	-20.992	0,51
25 €M per KM[85]				
	2050 EU	107	-42.483	0.35

Table 7: CBA results for the EU accession countries

[82] See the attached sensitivity analysis for a comparison with the 2030 and 2050 scenarios without any shocks applied.

[83] Based on the construction costs in 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)](2017852_E_web_light+c1.pdf)

[84] € 16.5 million per KM was also the completion cost per KM for the French LGV Est Européenne HSR line. See 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

[85] Average final construction costs audited by the ECA in 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

Scenario	Incremental production from construction (€ M)[86]	Incremental GVA from construction (€ M)[87]	Incremental job-years from construction ('000)	Incremental GVA from operations (€ M)[88]
2050 EU Accession scenario	12402 (-30%) 15517 (100%) 23032 (130%)	5767 (-30%) 7039 (100%) 10711 (130%)	138	18591-29050

Table 8: Local economic effects - 2050 EU accession

[86] 100% based on Fouqueray, E. (2016). Impact économique de la construction de la LGV SEA Tours-Bordeaux sur les régions traversées. *Revue d'Économie Régionale & Urbaine*, 2, pp. 385-416. Retrieved from https://doi.org/10.3917/reru.162.0385. The two other serve as a range of 70% or 130% of the impact.

[87] Same as above.

[88] High range based on Ahlfeldt, G.M. & Feddersen, A. (2015). From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail. *SERC Discussion Paper,* 172, p. 1-20, Retrieved from From Periphery to Core: Measuring Agglomeration Effects Using High-Speed Rail (repec.org) and low range based on Cascetta, E., Cartenì, A., Henke, I., & Pagliara, F. (2020). Economic growth, transport accessibility and regional equity impacts of high-speed railways in Italy: ten years ex post evaluation and future perspectives. *Transportation Research. Part A, Policy and Practice, 139*, 412 - 428.

Annex 9: HSR network per scenario

As referred to in the methodological section, this annex presents the HSR network per scenario.

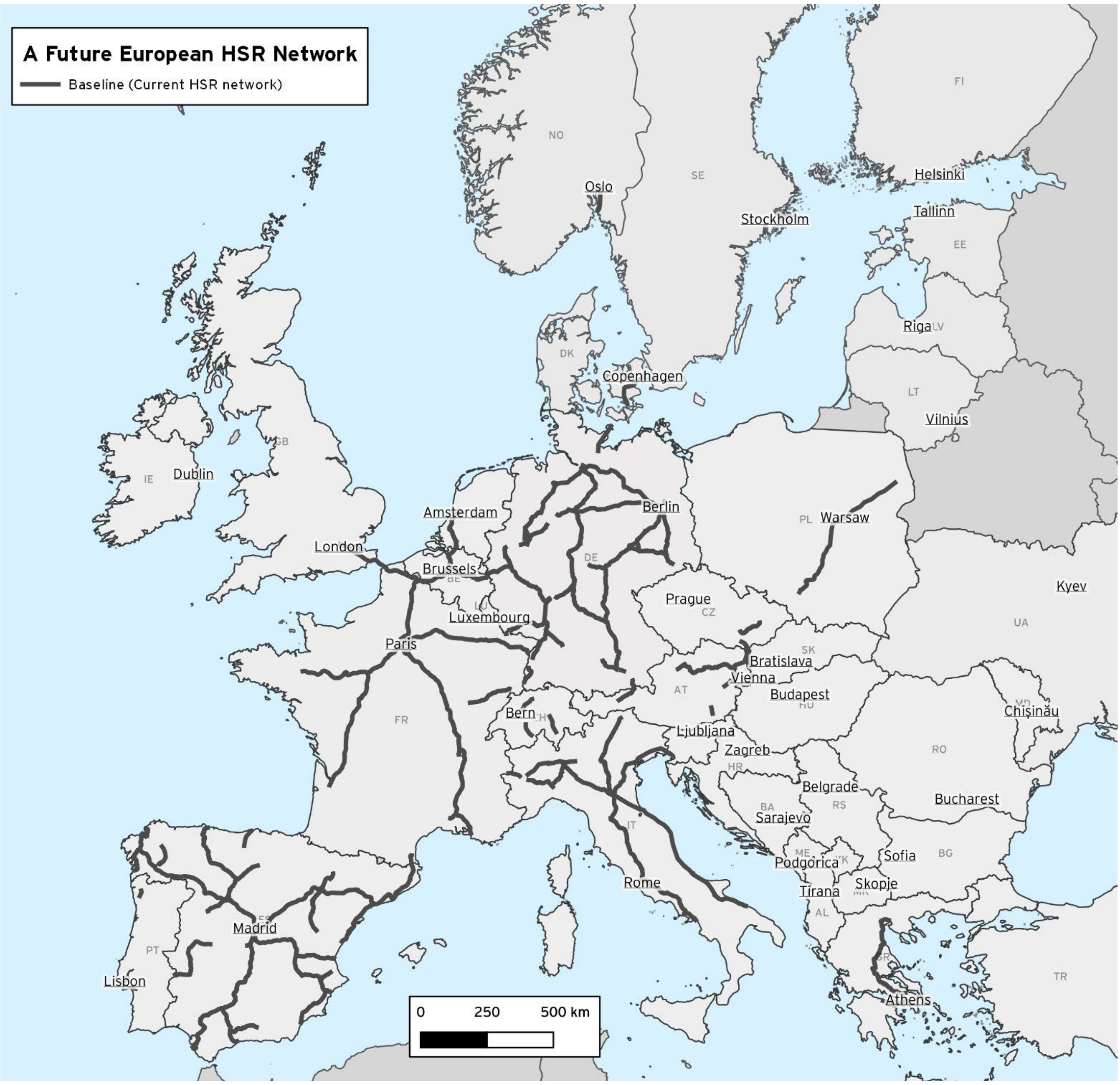

Figure 19: Baseline scenario

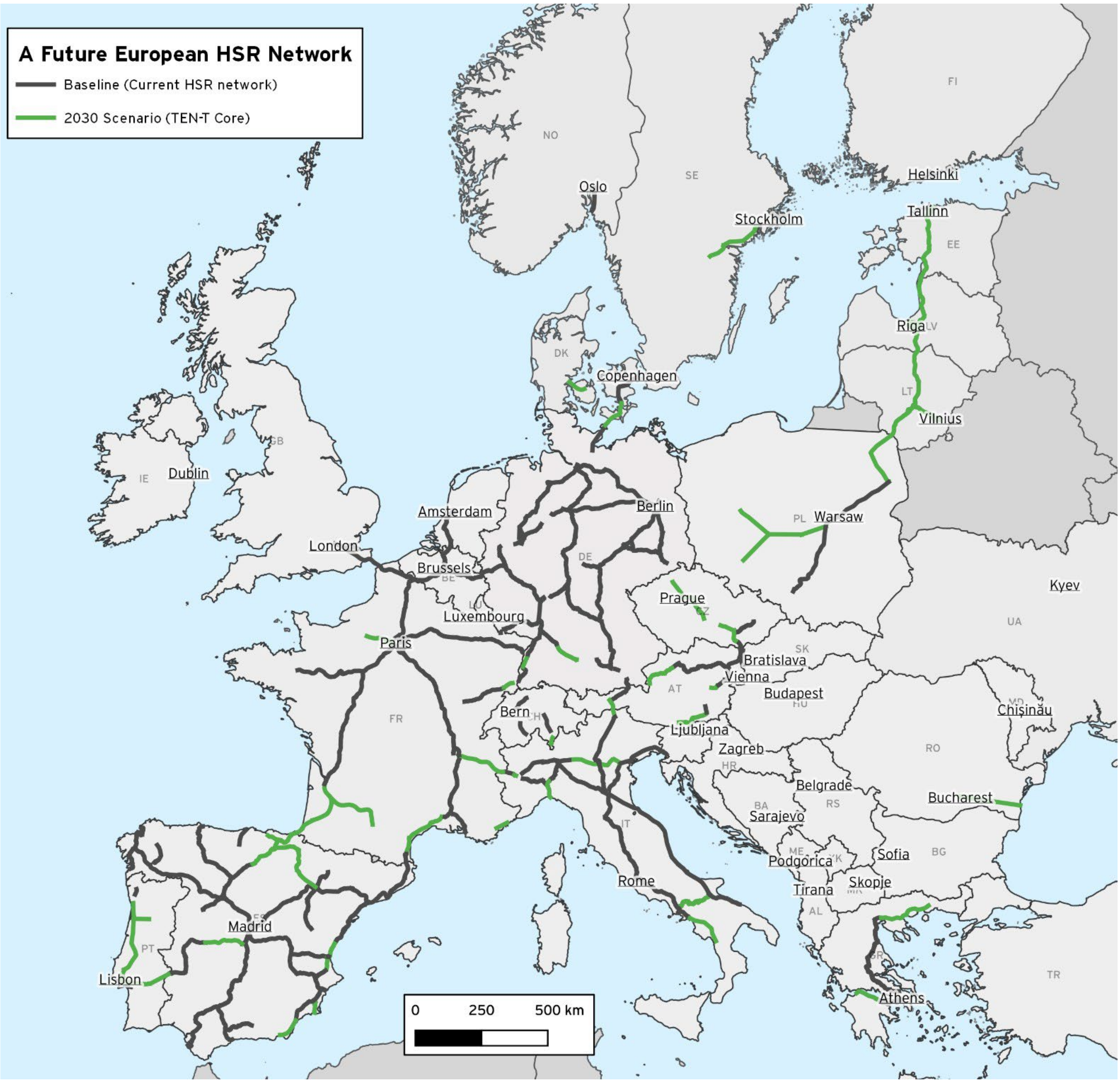

Figure 20: Baseline and 2030 scenario

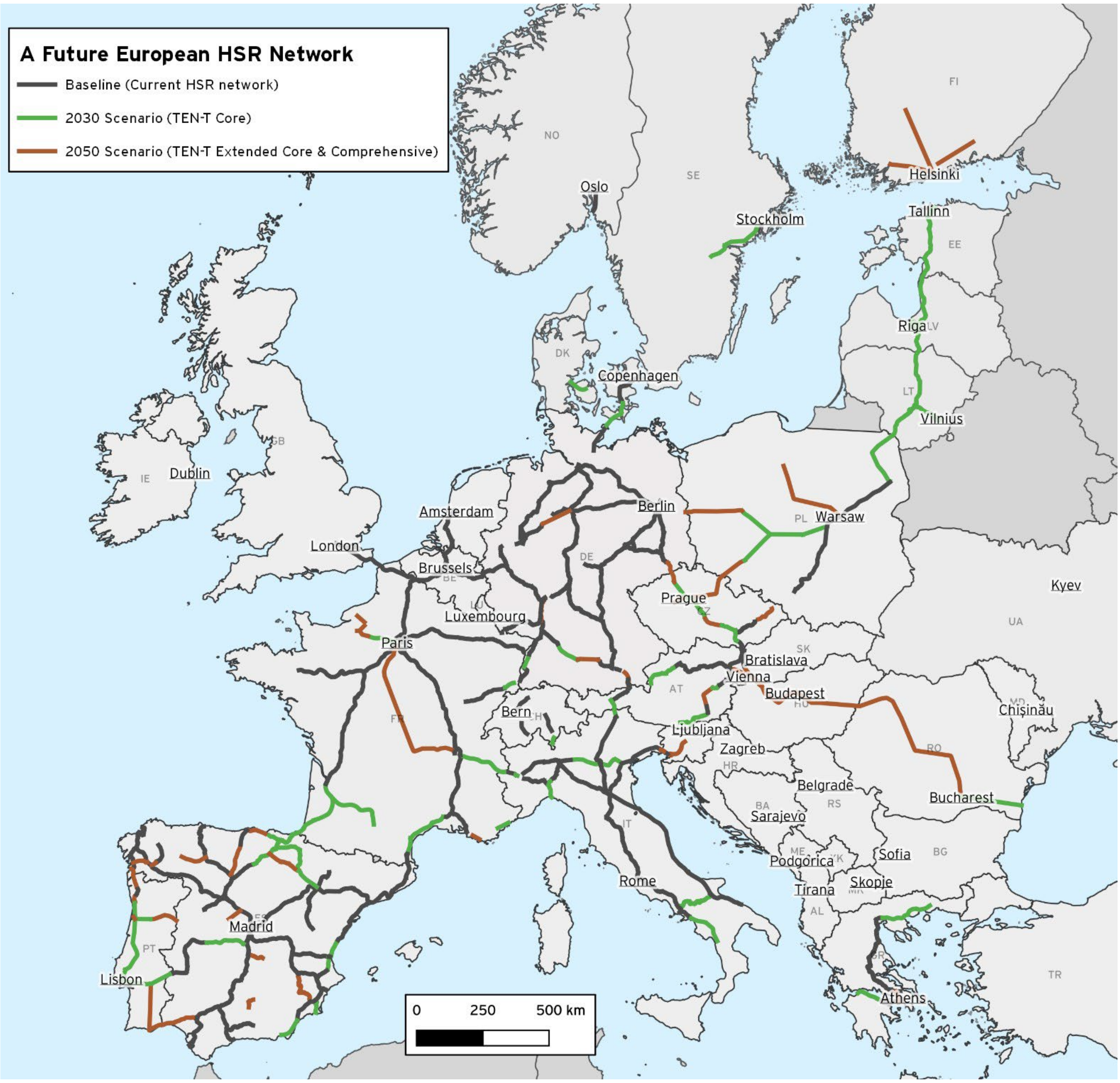

Figure 21: Baseline, 2030 scenario and 2050 scenario (planned lines)

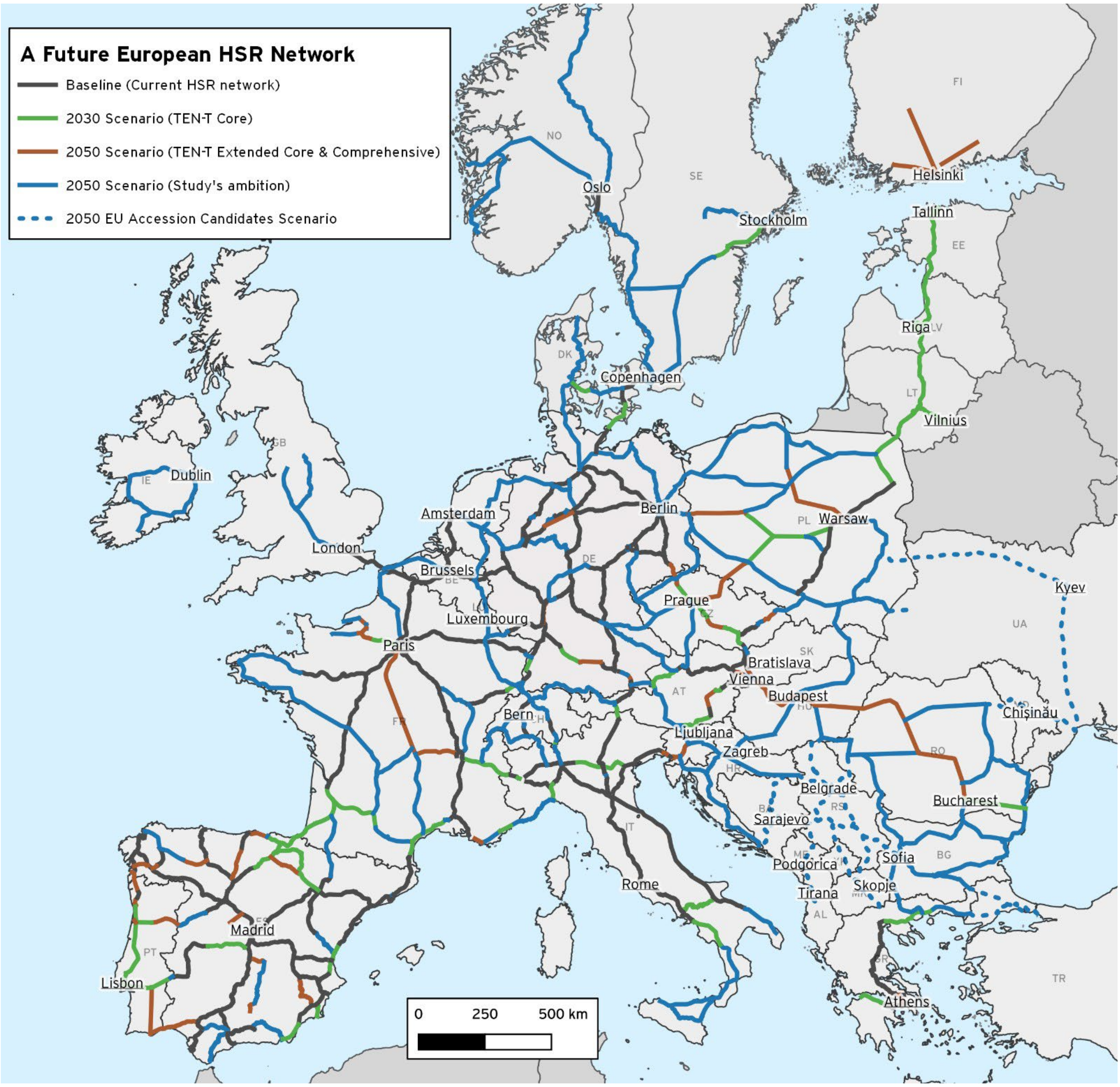

Figure 22: Full HSR network