ADBI Working Paper Series

APPROACHES TO MEASURE THE WIDER ECONOMIC IMPACTS OF HIGH-SPEED RAIL AND EXPERIENCES FROM EUROPE

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No. 946
May 2019

Asian Development Bank Institute

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The Working Paper series is a continuation of the formerly named Discussion Paper series; the numbering of the papers continued without interruption or change. ADBI's working papers reflect initial ideas on a topic and are posted online for discussion. Some working papers may develop into other forms of publication.

Suggested citation:

Rothengatter, W. 2019. Approaches to Measure the Wider Economic Impacts of High-Speed Rail and Experiences from Europe. ADBI Working Paper 946. Tokyo: Asian Development Bank Institute. Available: https://www.adb.org/publications/approaches-measure-wider-economic-impacts-high-speed-rail-experiences-europe

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Abstract

The European Union introduced the concept of Trans-European transport networks in 1996 and developed it from a set of projects into a comprehensive network plan in 2013. The high-priority components of this plan (for 2050) are a core network and nine core network corridors (CNCs), which the European Union intends to implement until the year 2030. The CNCs focus on improving connectivity, including harmonizing technology and organization as well as removing border resistance. Railways, in particular high-speed railways, are at the core of the CNCs. The evaluation of CNCs through conventional cost–benefit analysis (CBA) is too narrow and could lead to a patchwork of independent projects rather than an integrated network. Therefore, the European Commission has launched several studies on extending CBA with strategic approaches including wider economic impacts and long-term impacts on the environment, climate, and regional/social equity. As there has been no convention for a standard approach until now—contrasting CBA—this paper discusses several possible methodologies. The conclusion favors dynamic approaches that are well calibrated on the base of empirical observations, such as macro-econometric or system dynamics models, over theoretically more challenging general equilibrium models, although the latter are still the mainstream in the economic literature.

Keywords: Trans-European networks, core network corridors, cost–benefit analysis, wider economic impacts, computed equilibrium, econometrics, system dynamics approaches, integrated assessment

JEL Classification: H54, O22, R42

Contents

1. INTRODUCTION

Investments in high-speed rail (HSR) have a long life and generate impacts that often are not directly attributable to a specific project. Therefore, conventional cost–benefit analysis (CBA) is not sufficient to evaluate the overall impacts of HSR. Spillovers or wider economic impacts (WEIs) are identifiable on a micro-scale around stations, on a meso-scale for regions or corridors, and on a macro-scale for the whole economy—in the case of network-wide HSR plans. Micro-based evaluations are the most difficult, because HSR stations are in many cases integrated into urban development plans and it is almost impossible to separate the contributions of combined land use and transportation projects. On the meso- and macro-levels, it is possible to apply descriptive statistical analysis (before and after, again with problems of separating the effects), and with-without analyses using explanatory statistics, econometrics, or macro-simulation/optimization models, and to combine these with transportation, energy, and environmental modelling to prepare a quantitative base for an integrated assessment.

This paper starts in section 2 by presenting the plans of the European Commission to establish a comprehensive Trans-European Network for Transport (TEN-T) until 2050 and a core network until 2030. The heart of the core network consists of the nine core network corridors (CNCs). Section 3 discusses the existing European HSR network and the plans for its extension within the CNCs. The investment activity for HSR varies among countries, and scientists and auditors do not regard all HSR projects as success stories. One reason for appraisal failures with HSR plans is the very narrow assessment approaches through conventional CBA, which section 4 discusses. Such approaches can either lead to the rejection of beneficial projects because they do not consider the long-term strategic impacts, or they encourage promoters to predict overoptimistic figures for the short- and medium-term economic success to pass the CBA thresholds. Integrated assessment methods (IAMs), which section 5 presents, are intended to prepare a comprehensive picture of long-term wider economic impacts, regional equity, and environmental and climate effects. They make clear from the beginning the extent to which decision makers can expect an HSR project program to achieve financial returns or the extent to which environmental sustainability or regional equity are dominant, such that the public budget has to serve as the main source of finance. The section provides examples for the application of IAMs to the evaluation of CNCs and for their further development. Section 6 concludes by discussing the problem of determining the appropriate scope of an HSR network. This will require an opportunity cost calculus with the development and evaluation of alternative investment programs that may achieve comparable targets for efficiency, equity, and environmental protection.

2. TRANSEUROPEAN TRANSPORT NETWORKS AND CORE NETWORK CORRIDORS

The European Union (EU) developed the idea of establishing harmonized Trans-European networks for the transportation, energy, and communication sectors in the early 1990s and included it in the Maastricht Treaty of 1992.[1] It published the first concept of the Trans-European Network for Transport (TEN-T) in 1996 together with guidelines for its development. It consisted of 14 major projects. In the first revision of

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[1] The Maastricht Treaty founded the European Union (EU), replacing and reforming the former European Community. It established the constitutional basis of the EU and the pillar structure of its organizations.

2004, it replaced the project-based concept with a corridor-based concept, which in particular extended the scope of the network to the "accession countries" from Eastern and South-Eastern Europe. The second revision in 2011, modified in 2013 (European Commission 2013), foresaw a change from the corridor-based concept to a network-based concept consisting of two layers: a comprehensive network including all links of European importance, which the EU would finalize by the year 2050, and a core network consisting of all links of high priority, which it could finalize by the year 2030. The corridors forming the major part of the core network were called "core network corridors" (CNCs) and are now the focus of an implementation policy. Regarding implementation, one has to consider that the member states of the EU are competent in infrastructure planning and construction. This means that the EU institutions, in particular the European Commission, can motivate—but not enforce—the national institutions to follow the CNC planning. However, the European Commission has a powerful instrument to stimulate the member states to follow, which is the EU co-finance for CNC projects. A number of financial instruments for providing grants and special loans or bonds exist, which in particular support former accession countries and countries at the periphery of the EU in financing CNC projects. The following Table 1 exhibits some important characteristics of the CNC plans.

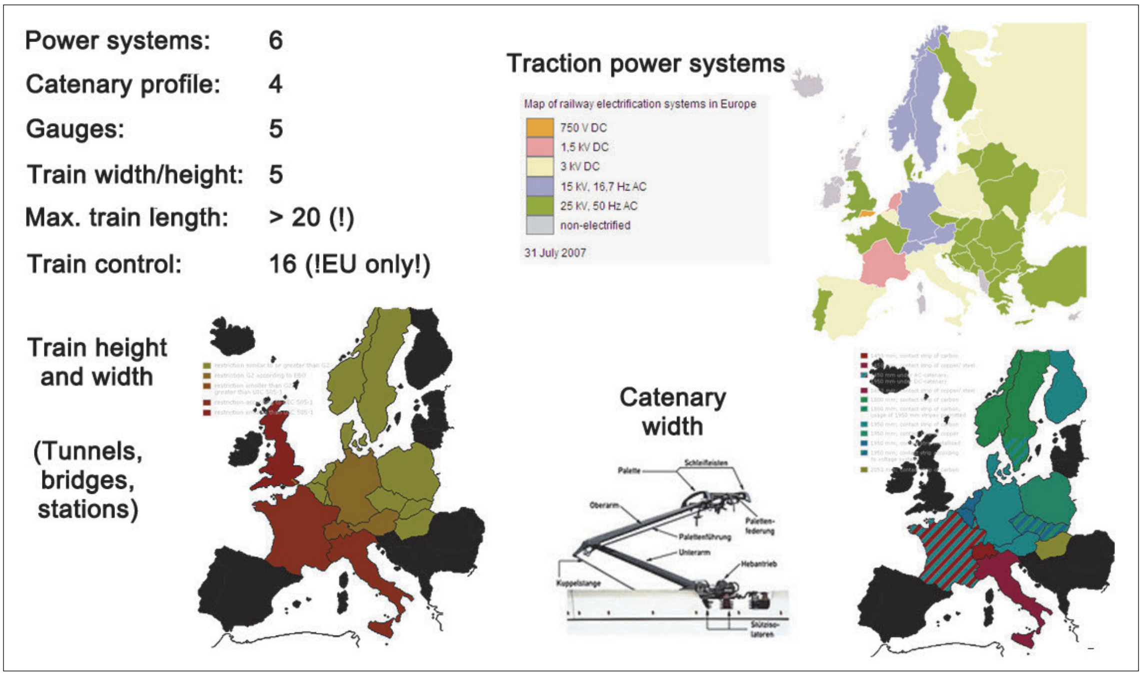
Table 1: Characteristics of the EU Core Network Corridors (CNCs)

Characteristics
Ten network types for modal infrastructure and related networks, e.g., motorways of the sea, networks for traffic control (ERTMS for railways, RIS for inland waterways, and SESAR for air transport)
Nine CNC axes with 34/51/16 thousand kms of road/rail/IWWs
CNC connecting at least three countries
Focus on rail and IWWs (more than two-thirds of investments)
Ten high-level coordinators (for 9 CNCs + ERMTS)
Interoperability issues are at the core of rail investments
High-speed rail is a substantial part of rail investments
Evaluation focusing on EU value: EU connectivity, overcoming border resistance, and contribution to reducing CO_2 emissions (60% by 2050 according to the EU White Paper of 2011)
Total investment costs of about EUR650 billion, financial support through grants (from CEF, ERDF, and EFSI funds), and loans/bonds with extended guarantees (EIB)

ERTMS = European Rail Traffic Management System, IWW = Inland Waterways, RIS = River Information System. SESAR = Single European Sky ATM Research Program, ATM = Air Traffic Management, CEF = Connecting Europe Facility, ERDF = European Regional Development Fund, EFSI = European Fund for Strategic Investments, EIB = European Investment Bank.

A main problem of EU railway systems is their heterogeneity, which stems from their historical national and regional development. The aims of defense policy included preventing neighboring aggressors from using the domestic railway system for military logistics. International—and in some countries even national—railway transport in the EU suffers from different track gauges, electrical power supply, axle weight and speed design, vehicle dimensions, and train control systems (presently 16 systems, see Figure 1). The European Commission has taken initiative for defining interoperability standards and key performance indicators (in particular for the ERTMS), fostering their introduction through regulations, coordination of country specific planning procedures and provision of co-financing. Nine high-level coordinators for the individual CNCs and one coordinator for the ERTMS (former politicians and managers with a strong reputation) have the task of promoting the plans, removing the national barriers, and coordinating the implementation work in combination with the national authorities and the European Commission.

Figure 1: Technical Standards in the European Rail Network



Source: Doll, Rothengatter, and Schade (2015).

3. PLANNED DEVELOPMENT OF THE EU HIGH-SPEED RAIL NETWORK

3.1 EU-Wide Plans and Realizations

The high-speed rail (HSR) network in the EU consisted of 8,434 km in the year 2017, including all the links on which trains can travel at 250 km/h or faster; 1,676 km are under construction, which makes an HSR_{250} network of about 10,100 km. The first HSR links were built in France for the TGV Paris–Lyon and the TGV Atlantique.[2] Germany followed in 1991 and Spain in 1992 with their first lines.

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[2] TGV: Train à grande vitesse; the TGV Atlantique links Paris to Tours and Le Mans.

Table 2: Existing HSR Network in the EU and Lines under Construction

Length of Lines

	km (At End of Year)									
	BE	**DE**	**ES**	**FR**	**IT**	**NL**	**AT**	**PL**	**UK**	**EU**
1985	–	–	–	425	174	–	–	–	–	599
1990	–	90	–	717	194	–	–	–	–	1,001
1995	–	447	471	1,290	238	–	–	–	–	2,446
2000	72	636	471	1,290	238	–	–	–	–	2,707
2005	137	1,183	919	1,549	238	–	–	–	74	4,100
2010	209	1,272	1,866	1,912	238	120	–	–	113	6,348
2011	209	1,334	2,117	2,058	856	120	–	–	113	6,807
2012	209	1,352	2,117	2,058	856	120	–	–	113	6,825
2013	209	1,352	2,413	2,058	856	120	50	–	113	7,171
2014	209	1,352	2,413	2,058	856	120	50	–	113	7,171
2015	209	1,475	2,413	2,058	856	120	50	224	113	7,518
2016	209	1,475	2,413	2,180	896	120	50	224	113	7,680
2017	209	1,658	2,413	2,734	896	120	67	224	113	8,434

High-speed Lines Currently Under Construction

	Line	**Length** (km)	**Start of Operation**
DK	Copenhagen - Ringsted	56	2018
DE	Offenburg - Riegel (Basel)	39	2029
DE	Stuttgart - Wendlingen	57	2021
DE	Buggingen - Katzenberg tunnel (Basel)	12	2021
DE	Wendlingen - Ulm	60	2021
DE	Tunnel Rastatt	17	2022
ES	Monforte del Cid - Murcia	62	2018
ES	Vitoria - Bilbao - San Sebastian	175	2022
ES	León - Asturias Variante de Pajares	50	2019
ES	Bobadilla - Granada	109	2018
ES	Plasencia - Cacere/Badajoz	193	2019
ES	Venta de Banos - Burgos	91	2018
ES	Zamora - Orense	224	2019
FR	Counternement Nimes - Montpellier	80	2018
IT	Genoa - Milan (Tortona)	53	2020
AT	Graz - Klagenfurt (Koralmbahn)	122	2025
AT	Brenner - Basis - Tunnel	46	2027
UK	London - Birmingham	230	2026

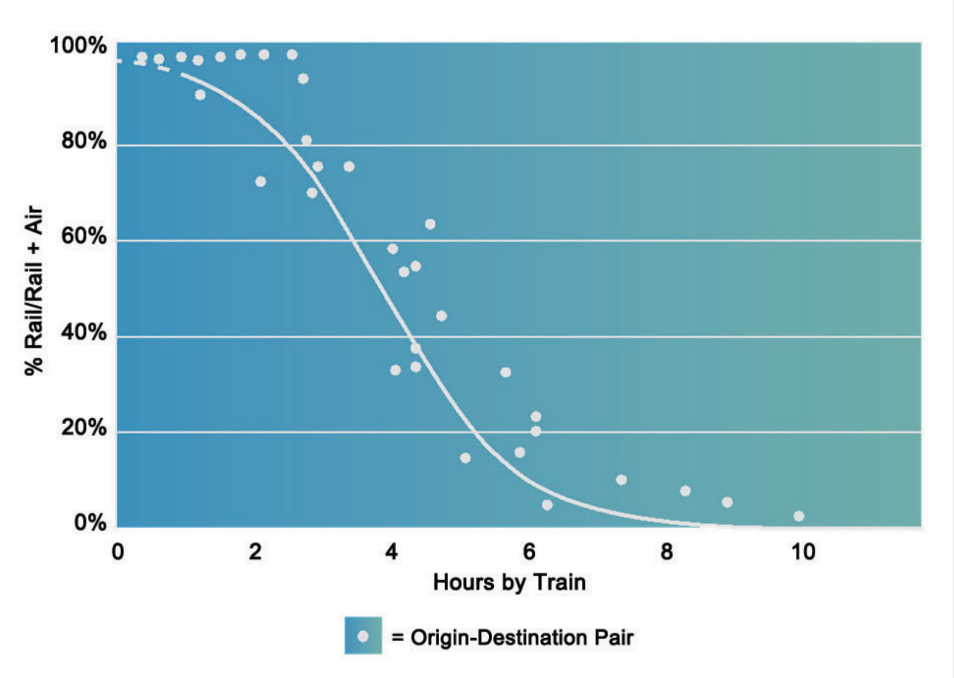
Note: Length of lines or of sections of lines on which trains can go faster than 250 km/h at some point during the journey.

Source: European Commission (2018).

The development of the HSR network in the EU has improved the competitiveness of railways and contributed to transnational connectivity. It is a crucial part of the EU transport policy and has achieved positive effects such as the following:

- Standardization of tracks, vehicles, and control systems;
- Internationalization of rail services (e.g., the TGV and ICE[3] for border-crossing connections between France and Germany; the ICE for connections between Germany and Switzerland; and Thalys for connections between France, Belgium, the Netherlands, and Germany);
- Significant diversion of air and car traffic to rail in corridors served by HSR (e.g., Paris–Lyon–Marseille; Madrid–Barcelona; Milan–Rome; Munich–Berlin); and
- Development of the regional economy in the environment of HSR stations.

Figure 2: Market Share of HSR Dependent on Hours of Travel



Source: International Union of Railways (2018).

The market success of HSR is strongly dependent on the duration of the trips and the performance of competitors (air for longer and cars for shorter distances). Rail is usually the dominant mode for travel times below 3.5 hours; see Figure 2. However, rail travel times of 4–5 hours can also be attractive to passengers if the access/egress times to and from airports as well as the processing times at airports are high. The ICE Munich–Berlin connection, which opened in December 2017, provides an example: for the 623 km link, the travel times reduced from 6 h to 4 h 25 min for the usual ICE and 4 h for the sprinter ICE.[4] Before opening, the modal split figures were 23%, 29%, 48% for rail, road, air, respectively, and these changed within one year to 46%, 24%, 30%, respectively. The number of rail passengers has doubled on this connection. The

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[3] ICE: Intercity Express in Germany.

[4] Sprinter services between large cities have fewer stops and save travel time.

company will extend the ICE sprinter service because it is unexpectedly well accepted. It is noticeable that the German rail service is still suffering from poor reliability and punctuality, which are still much worse than comparable figures in Japan, the People's Republic of China (PRC), France, or Spain. This is partly the result of many connecting stations along the lines, mixed train operations on the tracks, and, in recent years, increased repair and maintenance work. This indicates that the potential of HSR on well-connected corridors could be much greater than is presently observable.

Against the background of the positive experiences, the European Commission set very ambitious goals for developing HSR and published an HSR development plan in 2010, which included 30,000 km allowing for train speeds beyond 200 km/h. However, even with using a wide definition of the scope of HSR as rail speeds above 200 km/h, the reality of HSR investments is far behind the optimistic plans. The reasons for the comparatively slow progress—for comparison, the PRC has implemented around 25,000 km of HSR since 2008—are:

- Long planning times with many stakeholder interventions and complex approval procedures (in particular land acquisition and environmental legacy);
- Long implementation times (the average project implementation time is 16 years);[5]
- Comparatively high costs of infrastructure investment (in Europe $25 million–$39 million/km; in exceptional cases, for example, the Stuttgart–Ulm link, more than $75 million/km; for comparison, in the PRC, $17 million–21 million/km;[6]
- Lacking standardization of construction elements, treating every facility like a bridge or tunnel as a unique project (contrasting the Chinese construction principles);
- Problems of designing guideways through densely populated areas (declining acceptance by citizens); and
- Financial bottlenecks and limits to public deficit spending after the economic crisis in 2008.

Although the European Commission has tried to streamline the planning processes, to coordinate the planning legacy of member states, and to accelerate the implementation through attractive conditions for co-financing, the progress is modest. Furthermore, the barriers to HSR planning and implementation are growing. Several scientists have published warnings regarding the extremely high investment costs of HSR (e.g., Albalate and Bel 2010; Flyvbjerg 2014; Ansar et al. 2016). Environmental groups argue that high-speed mobility is causing high consumption of energy and CO_2 production compared with conventional rail and promote more slowness of mobility. Residents are concerned about the change in their environment and are organizing protest movements, although they may benefit from new HSR investments (e.g., the violent protests in Stuttgart, Germany, opposing the construction of a new central underground railway station and its HSR connection to Ulm/Munich).

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[5] According to a report of the European Court of Auditors (2018).

[6] See Ollivier, Jitendra, and Nanyan (2014); in Europe, meanwhile, these figures are substantially higher because of the exhausted capacities in the construction sector.

3.2 HSR Development in Some EU Countries

The result of the different national conditions and strategies is a patchwork instead of a network for HSR in the EU (see European Court of Auditors 2018). Two contrasting examples demonstrate the scope of the national investment strategies and their impact on the HSR network. First, we consider a country with a very low HSR density, the UK. Until now, the UK has only one HSR link, called HS1, connecting the Channel Tunnel to London St. Pancras station (108 km). The first section opened in 2003 and the second section in 2007. The travel times between London and Paris (Brussels) reduced to 135 (111) minutes, and the HSR market shares on these connections are higher than 80%.

The UK developed early plans to extend HS1 to the north for connecting the densely populated Midlands around Birmingham, Manchester, and Leeds, and further Edinburgh and Glasgow. These plans did not make progress because the results of financial and cost–benefit assessment were not promising. Finding appropriate guideways in the densely populated areas north of London was the most difficult task and resulted in high cost estimates. This gave opponents arguments to attack HSR projects in the UK from different sides. High-speed enthusiasts suggested visionary alternatives (the Japanese MAGLEV and the Hyperloop), while environmental groups were afraid of destroying biodiversity and fiscalists were concerned about the increase in public deficits. Finally, the UK Department of Transport enriched the quantitative assessment by including wider economic benefits and the prospects for strategic economic development (see the paper by R. Vickerman in this volume) and prepared the ground for a positive public discussion and final decision.

The Parliament approved the HS2 “Y-project” and the construction of phase 1 started in 2017. The plan is to complete phase 1 to Birmingham by 2026 and phase 2 (to Manchester and Leeds) by 2033. Unexpected constraints and barriers, together with updates to the construction design in densely populated areas, led to a drastic increase in the estimated construction costs; in the case of HS2, the early estimations of £32.7 billion (2010) rose to £56 billion at the beginning of the construction work. However, even after the completion of this most expensive extension, the UK will be the European HSR country with the lowest HSR density (9.7 km per 1 million capita).

Spain is a contrasting example. The country was among the first EU member states to introduce HSR on the link between Madrid and Seville, which was opened in 1992. The most important link, Madrid–Barcelona (625 km; 2 h 45 min), opened in 2008. In the following decade, Spain developed its HSR network rapidly, such that it consisted of about 3,300 km in 2018, making 71 km HSR per million capita. This is not only a top value for Europe but even exceeds by far the Japanese/Chinese figures of about 24/20 km HSR per million capita.

After finalizing the backbone corridor of Sevilla–Madrid–Barcelona, the political goals of regional connectivity and modal diversion mainly drove the HSR development in Spain (from air to rail) for environmental reasons; 90% of Spanish inhabitants should live within a distance of a maximum of 50 km from an HSR station, and the HSR network should connect all of the 47 provinces’ capital cities such that the maximum time needed for traveling from a province capital to the national capital Madrid will not exceed 4 h.

To achieve such goals, the Spanish Strategic Plan of Infrastructures and Transport (PEIT) foresees an extension of the Spanish HSR network to 5,000 km by 2030. This investment contributes to adjusting the Spanish rail network to the EU standards (a change from wide gauge (1668 mm) to standard gauge (1435 mm) and to the ERTMS, the future standard EU rail control system). Together with the special treatment of Spain as a “cohesion” country (on the periphery of the EU), EU funding sources like “cohesion,” "regional development," or "TEN-T" funding could provide high financial support: Spain received about one half of total EU co-finance for HSR. Economists (e.g., Albalate and Bel 2010) have criticized the HSR extension plans heavily for their weak economic foundation. In recent years, the European Commission and the EU Parliament have become increasingly skeptical and recommended tighter financial control of the PEIT plans (see Doll, Rothengatter, and Schade 2015). Against the background of low figures for the passenger volumes (see Table 3), the Spanish government has recently downgraded the plans partially as for instance reducing the track designs in less densely populated areas (maximum speeds and number of tracks).[7]

Table 3: High-Speed Rail Performance in EU Countries

High-speed Rail Transport (*)

	Billion pkm														%
	BE	**CZ**	**DE**	**ES**	**FR**	**IT**	**NL**	**PL**	**PT**	**SI**	**FI**	**SE**	**UK**	**EU-28**	**Change**
1990	–	–	–	–	14.92	0.30	–	–	–	–	–	0.01	–	15.23	
1995	–	–	8.70	1.29	21.43	1.10	–	–	–	–	–	0.42	–	*32.94*	7.2%
2000	0.87	–	13.93	1.94	34.75	5.09	0.11	–	–	–	0.07	2.05	–	*58.80*	11.2%
2005	0.98	0.01	20.85	2.32	43.13	8.55	0.69	–	0.49	–	0.31	2.33	*0.45*	*80.11*	5.3%
2006	1.00	0.15	21.64	2.70	44.85	8.91	0.73	–	0.51	–	0.44	2.49	0.90	*84.32*	5.2%
2007	1.02	0.33	21.92	2.59	47.97	8.82	0.80	–	0.51	–	0.58	2.78	1.39	*88.70*	5.2%
2008	1.08	0.25	23.33	5.48	52.56	8.88	0.87	–	0.53	0.01	0.62	2.99	0.99	*97.60*	10.0%
2009	1.06	0.25	22.56	11.51	51.86	10.75	0.92	–	0.53	0.02	0.60	3.05	1.01	104.10	6.7%
2010	1.06	0.27	23.90	11.72	51.89	11.61	0.29	–	0.52	0.02	0.65	*2.94*	1.01	*105.87*	1.7%
2011	*0.91*	0.29	23.31	11.23	52.04	12.28	0.31	–	0.47	0.01	0.71	2.83	4.36	108.74	2.7%
2012	*0.91*	0.27	24.75	11.18	51.09	12.79	0.32	–	0.46	0.01	0.71	2.95	*4.36*	*109.80*	1.0%
2013	*0.91*	0.25	25.18	12.74	50.79	*12.79*	0.36	–	0.47	0.01	0.76	3.06	*4.36*	*111.67*	1.7%
2014	*0.91*	*0.25*	24.32	12.79	50.66	*12.79*	0.24	–	0.54	0.01	0.65	3.23	2.90	*109.28*	–2.1%
2015	1.20	0.57	25.28	14.13	49.98	*12.79*	1.00	0.47	0.57	0.01	0.57	3.37	2.90	*112.82*	3.2%
2016	1.50	0.70	27.21	15.06	50.54	*12.79*	0.37	1.44	0.61	0.00	0.61	3.48	2.80	*117.12*	3.8%

Note: In this table, high-speed rail transport covers all traffic with high-speed rolling stock (incl. tilting trains able to run 200 km/h). This does not necessarily require high-speed infrastructure as defined in Table 2.5.4.

Source: European Commission (2018).

Other European countries with significant HSR are France, Germany, and Italy. France was the first country to introduce HSR on longer distances and to achieve higher average operation speeds than 200 km/h.[8] The first links were Paris–Lyon and Paris–Tour/Le Mans. Until 2017, France was the EU country with the largest HSR network, and Spain recently surpassed it (see Table 2). The French HSR system still attracts the most passengers and shows the highest passenger turnover of the EU countries (see Table 3), three times as high as that of Spain with a similar network length. However, the passenger performance figures also show that the growth of patronage in France stopped after 2008.

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[7] See International Union of Railways (UIC) (2018) for details.

[8] Italy had already introduced HSR with 250 km/h on part of the connection between Rome and Florence in 1977. The average speed was about 200 km/h.

This reduced the financial expectations and changed the most ambitious HSR development plans, which the "Grenelle Environment Round Table" sketched out in 2007.[9] This meeting developed a concept for reducing the CO_2 emissions of transport, partly by shifting traffic from road and air to rail and extending the HSR network in France by another 2,000 km. After the economic crisis in 2008, on the one hand, the railway company SNCF increased its demand for public co-finance because of lower passenger volume expectations while, on the other hand, the public budget problems had grown and needed consolidation. In the end, the HSR extension plan suffered drastic reductions. Even trans-border connections to Spain on the Atlantic and the Mediterranean coasts were suspended for financial reasons.

Only one major HSR project of the Grenelle agreement has materialized, which is the 300 km link between Tours and Bordeaux, connecting Bordeaux to Paris (540 km) in 2h 4 min, which opened in 2017. The complex public–private partnership (PPP) constructed reflects the increasing difficulties of HSR finance: a private consortium (LISEA) of nine partners under the lead of VINCI, a big construction and infrastructure operation company, received a concession for 50 years. The consortium finances EUR3.8 billion (49%) of the investment budget of EUR7.8 billion from six different sources (own capital, bank credits, and loans). The European Investment Bank (EIB) contributes EUR1.2 billion with a loan guarantee on TEN-T projects. The public subsidies from the French state and the EU total EUR3 billion or 39%. The French public rail infrastructure company RFF contributes EUR1 billion (12%) and pays for additional investment costs of EUR1 billion to link the new stretch to the network and to the stations. It will also be responsible for the refinancing of the private part of the debt, which it will achieve through track charges to be paid by the rail operator SNCF. The consortium has implemented the project on time and without cost overruns, which is a big achievement compared with other European HSR projects, which have shown high cost overruns and contributed to creating a negative image of megaprojects, which Flyvbjerg (2014:11) summarized as the "iron law of megaprojects: over budget, over time, over and over again."

Germany (with about 1,700 km HSR) will stick to its concept of constructing mixed HSR and conventional links, which will not exploit the full potential of HSR but aims at improving the connectivity of the network in a country without a main corridor (such as the Honshu corridor in Japan) or a main orientation toward a major centrality (such as the Paris agglomeration in France). Presently the repair and maintenance works are very intense after decades of neglect, and the operator, Deutsche Bahn AG, is experiencing problems recruiting qualified personnel for driving and vehicle maintenance and servicing. As a consequence, the punctuality and reliability of the train service has dropped to a record low level (about 70% punctuality in November 2018). The plans for the future are, in the first instance, oriented toward improving the reliability and punctuality, particularly at connecting stations, increasing the frequency of services on main corridors, and reducing the energy consumption as well as the climate footprint through the use of renewable energy. These goals do not make it necessary to increase the maximum speeds on domestic connections with relatively short distances between stations; therefore, the new ICE 4 train generation is designed for only 250 km/h. The average speeds can be increased through sprinter services with fewer stops between bigger agglomerations.

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[9] This Round Table brought together federal and local government authorities, trade unions, and NGOs in Grenelle, a suburban location in Paris.

The negative experiences with the big HSR projects under construction have reduced the appetite of policy makers and of the infrastructure manager, Deutsche Bahn AG, for starting further expensive projects. First, the combined HSR and regional transit Stuttgart–Ulm project is the most expensive European railway project, with estimated costs of more than EUR10 billion, including the construction of a heavily debated new underground station in Stuttgart, already decided in 1996. Construction started in 2010 after long processes of legal permission, coordination of public authorities, and financial negotiations with the infrastructure manager, Deutsche Bahn. Furthermore, citizens' protests and the following mediation processes interrupted the project's start, ending after a people's referendum in 2011 in favor of the project. The plan is to open the project for operation in 2023, that is, 27 years after making the decision. The second example is the most important international north–south Karlsruhe–Basel rail corridor link, which is showing slow progress paired with a high cost increase (costs estimated in 2015 at EUR7.1 billion plus at least EUR1 billion damage costs because of a severe breakdown of the existing track during the underground construction of the new one). The expectation is that this major connection, which Germany designed not only for HSR but also for efficient rail freight transport (on a separate track), will not be accomplished before 2035. These examples illustrate the low planning efficiency in Germany and people's fading willingness to accept new technologies that bring changes into their living environment, a phenomenon that is often apparent in wealthier societies and that the economic literature describes through the Kuznets curve (see Uchiyama 2016).

Italy owns less than 1,000 km of HSR, which the public Trenitalia, a 100% subsidiary of the public Ferrovie dello Stato Italiane (FS), and the private NTV Italo operate partially. Four industrials established NTV Italo in 2012, and it operates on four HSR connections (e.g., Turin–Milan–Naples; Rome–Florence–Venice) at maximum speeds of 300 km/h. After years of financial difficulties and major restructuring, NTV Italo is profitable, and a US equity fund[10] took it over early in 2018. The Italian example is interesting in two respects: it shows first that HSR services can be profitable on backbone corridors and second that competition on HSR networks is possible, beneficial for the customers, and useful for improving the quality and efficiency of the service. The European Court of Auditors (2018) therefore argued in favor of expanding the competition and fostering liberalization to push the incumbent former public national railway companies.

The following sections will focus on the further development of assessment methods to improve the decision support for European HSR projects in the planning and procurement phases.

4. CONVENTIONAL COST–BENEFIT ANALYSIS (CBA)[11]

CBA is obligatory in most EU countries for large transport investments and an element of fiscal legacy with standardized methodology. CBA measures the direct impacts of infrastructure projects on users and on non-users. It measures the economic user benefits through the consumers' and producers' surpluses, which it calculates with the generalized transport cost savings for existing traffic and the gained net surpluses from diverted and induced traffic.[12] It adds environmental and safety benefits to the amount, which it can measure economically through cost savings. When applying conventional

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[10] Global Infrastructure Partners, a fund investing in energy, water, waste, and transport and managing infrastructure facilities like the airport of London Gatwick (UK) or the Port of Melbourne (Australia).

[11] A brief description from Rothengatter (2018).

[12] It measures this approximately using the "rule of the half."

CBA, one presumes that it is sufficient to look at the transport sector only while neglecting the possible impacts on other sectors. This is theoretically only consistent if all the other markets are in equilibrium and the structural changes that a project or program induces are marginal. However, very large transport projects and network developments will generate stepwise changes for mobility and logistics, which may produce substantial feedback loops through other sectors of the economy. Therefore, conventional CBA can contribute only part of a comprehensive assessment of HSR projects.

As the CBA approach is widely standardized, it has gained broad acceptance and its outcomes serve as a dominating criterion for project evaluation (see e.g., European Commission 2014; Quinet 2013. If a megaproject with a low benefit–cost ratio is favored to a set of smaller projects that show a higher ratio for the same budget, then clear arguments will be necessary to support this decision. Such arguments can stem from the analysis of wider economic impacts and/or high strategic environmental or regional equity advantages in the context of an integrated assessment, which the following sections present.

5. WIDER ECONOMIC IMPACTS (WEIS) AND INTEGRATED ASSESSMENT METHODS (IAMS)

5.1 Scope of the Methodological Approaches

5.1.1 Background and Terminology

The two prominent examples for the UK and Spain that section 3 provided characterize the wide scope of economic assessment for HSR projects in Europe, although all the cases applied standard methods of CBA. Countries like the UK have followed narrow financial and economic assessment criteria for a long time and postponed promising projects with the consequence that the challenges for finance and stakeholders' acceptance have grown exponentially. Countries like Spain have focused on regional and environmental benefits and applied soft economic assessment, with the consequence that a number of projects are not financially viable despite the generous EU co-financing and now require operation in such a way that the regional and environmental advantages are diminishing. This gives rise to change in the assessment of large projects or project plans in two directions: first, restricting CBA to benefits that a project company, at least theoretically, can capture and, second, assessing all the economic impacts beyond this narrow approach through a wider economic impact analysis. This should include or be extended by a strategic environmental and regional equity analysis, resulting in an integrated assessment method (IAM). It is possible to carry out CBA and IAM in parallel to provide the decision maker with the necessary comprehensive decision support.

The secret founder of CBA, the French engineer-economist Jules Dupuit (1844), was also apparently the originator of the idea and of the basic concept of WEIs. Contrasting the partial utility approach of Alfred Marshall (1920), who developed the surplus concept about 50 years after Dupuit, the relevant surplus is not the reduced generalized transportation costs rather than the reduced costs (prices) on the markets influenced by new or improved transport facilities. It is the reduced payments of consumers (following cost reductions) and increased willingness to pay for goods (following higher quality of service) that increase their "relative utility" (translating the wording "utilité relative" of Dupuit), which Marshall later called consumers' surplus in his narrow partial market approach.

Dupuit illustrated the basic idea by taking the example of the market of stone for which it is necessary to consider the reduced price (cost) of stone as the relevant measure[13] and not the reduced costs of transport from the quarry (see Ekelund and Hébert 1999, 83; illustrated in Rothengatter 2018). If a (public) company constructs a new canal to explore an unexploited quarry, then the transport costs may rise compared with the situation without investment, because the stone has to travel over a greater distance (100 instead of 4 length units; see Table 4). Therefore, it would be wrong to compare the transport costs with and without the canal and use the difference as a benefit measure. Assuming that the new quarry would be linked by a road and comparing the costs of road transport with the costs of canal transport (a fictive with–without comparison) would also be misleading, because it would lead to a huge overestimation of the benefits (for 100 length units, the costs of road transport would be 100 and the costs of canal transport 13, such that the cost difference (benefit) would be 87 fr). Comparing the total costs of *transport and production* leads to the correct measure of 5 fr for the reduced costs of a ton of stone, which makes the "relative utility" (benefit) presuming that the market price for stone will drop accordingly.

Table 4: Dupuit's Example of Comparative Costs of a Canal Investment

Old route: a road	Costs per ton of stone
Extraction from the quarry	16 fr
Transport over a short distance (say 4 leagues)	4 fr
Total former costs of production (without a canal)	20 fr
New route: a canal	
Extraction from the quarry	2 fr
Transport over a long distance (say 100 leagues)	13 fr
Total present costs of production (with a canal)	15 fr

Fr = French francs.

League = distance metric used in France around 1850 ~ 4 km.

Source: Ekelund and Hébert (1999) following Dupuit (1844).

This simple example allows for a first set of conclusions:

- As soon as transport projects lead to a change in technology and organization of production, a benefit measurement based only on comparative transportation costs implies under- or overestimations depending on the definition of the compared constellations.
- The relevant measure is the change in the total costs of transport and production, which are presumably equivalent to a similar reduction in the market price or an increase in the willingness to pay.
- It is necessary to analyze the impacts on the total costs and market prices for all the markets that the transport facility under evaluation influences.
- Marshall's partial approach of benefit measurement through surpluses on the transport market is restricted to the special case of a static total equilibrium on all markets except for transport and therefore only appropriate for the evaluation of small projects in an equilibrium environment.

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[13] Dupuit used this example to contradict strongly the suggestion of his engineer colleague Navier to measure the economic advantage of a canal by the cost differential between road and waterway shipment; see Ekelund and Hébert (1999).

Following this basic idea, one can easily conclude that the canal can induce additional businesses and activities, which today we would call secondary benefits. Dupuit recognized and partly described such effects, for example the impact on equity, but he argued that it is a matter of public policy to take account of them. This means that he made a clear distinction between the project-related (direct) utility (which already includes a substantial extension of Marshall's consumers' surplus) and the second-round effects, which the project management cannot capture or even the project users cannot enjoy (see Poinsot 2018). This becomes understandable against the background that Dupuit favored privatized management of the transport infrastructure, that is, the project managers should be able to finance the project by partly exploiting the willingness to pay of the users, but he left the possibility open for increasing state governance in the case of high market imperfections.[14] However, it would be a matter of state governance and not of the project management to take account of secondary impacts.

The conclusions above highlight important issues for the assessment of large transportation projects and HSR project plans.

- Long-term impacts on productivity, costs, and product/service quality through the change in technology and organization are in general likely to result from large transportation projects and HSR network plans. These require a sector-specific productivity analysis including the subsequent impacts on (endogenous) growth, industrial interchange, and trade activity.
- Market imperfections prevail in many economic sectors. On the labor market, underemployment is not an exception but the rule for many countries. Therefore, medium-term analyses of multiplier and accelerator effects are important, because they can determine the future path of economic growth.
- It is possible to regard regional and personal equity as hidden production factors, because undiscovered potential is exploitable and social conflicts avoidable. Therefore, impacts on equity (regional and personal) are not beyond a wider economic impact assessment.
- The reaction times to changes in the transport system vary by consumer groups and industries. Therefore, a dynamic analysis is needed that can identify the time profiles of fast (e.g., output and demand adjustments) and slow (e.g., technology adjustments) feedback mechanisms and their interactions.
- The comprehensive assessment should clearly differentiate the impacts that project management can capture and the impacts that the state has to consider. This provides the base for the appropriate allocation of managerial and financial responsibilities in the procurement phase (see Stillman 2018; Yoshino and Stillman 2018).

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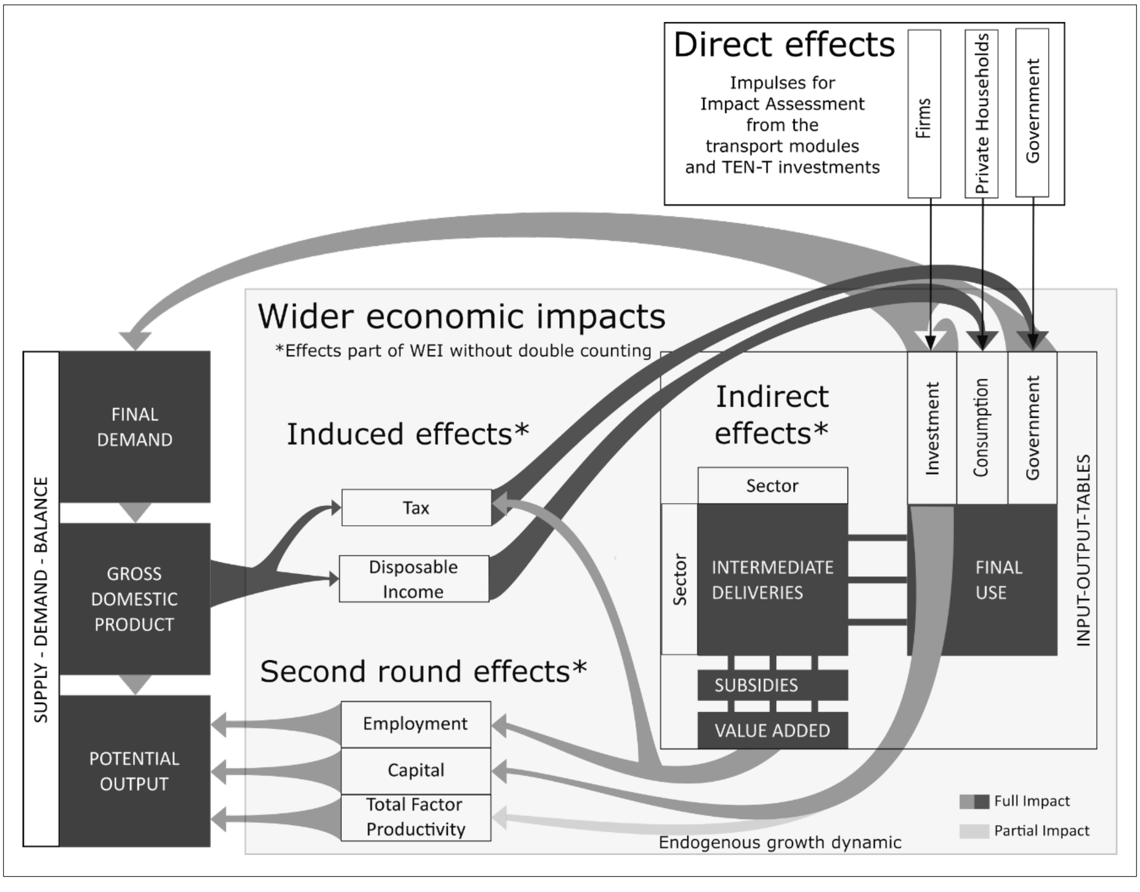
[14] This holds for instance for railways, for which some parts of Dupuit's work show a clear insight into the imperfection of this market (natural monopoly) and the need for state governance, while in other parts he showed his preference for a liberal market structure; see Poinsot (2012).

The above considerations lead to a pragmatic definition of WEIs for applied assessment work: WEI assessment includes all direct and indirect/second-round economic effects, in particular those impacts that occur beyond the conventional benefit measurement based on the Marshallian welfare surpluses that transport cost differentials induce. This definition takes into account the fact that CBA and WEI results in general are not separable and not additive. Figure 3 illustrates the concept of WEIs (comprising all the economic impacts stemming from a project or action plan) and the different scopes for the often-used terms of direct, indirect, induced, and second-round effects.

Contrasting CBA, it is possible to base the analysis of WEIs closely on indicators of social account. This holds in particular for the macro-economic approaches that section 5.1.2 describes, which deliver data on the GDP and employment as well as on the induced tax revenues of the state. The latter can provide a rationale for the state co-finance in PPPs. Wider economic assessment has followed such approaches in the context of large HSR projects, for example the project Stuttgart–Ulm/Munich in Germany (mentioned in section 3.2) and developed proposals for their institutionalization by “tax-kicker bonds” (Stillman 2018).

Figure 3: Terminology of Economic Impacts Stemming from Mega-projects or Action Plans



Source: Schade, W., J. Hartwig, W. Rothengatter, and S. Welter (2017).

5.1.2 Methodologies for the Measurement of WEIs

The bullet points in section 5.1.1 set out a framework of issues for the measurement of WEIs beyond conventional CBA. Contrasting CBA, there is no standard procedure or widely agreed theoretical foundation for WEI measurement. Possible approaches are:

- Spatial computed equilibrium models (SCGEs), which start from a total equilibrium environment in which monopolistic competition occurs in a few sectors, leading to spatial concentration in agglomerations (Krugman's theory of economic geography; Krugman 1991). Venables (2007) and Bröcker et al. (2011) developed models that aim at practical implementation.
- Elasticity models based on SCGE theory, as Graham (2006) developed and applied on behalf of the UK Department of Transport (2006), for example for the assessment of HS2 (see the paper by R. Vickerman in this volume).
- Integrated regional land use and transport infrastructure models (LUTI [Échénique et al. 1990]); regional potential factor models (Biehl 1991); and regional simulation models (Vickerman 1995, 2013; SASI model 2008).[15]
- Macro-economic integrated models including input–output analysis, energy, and the environment (e.g., the E3ME model of Cambridge econometrics; the E3MLAB model of the University of Athens).[16]
- System dynamics models integrating input–output analysis (SDM, e.g., the ASTRA model that the consultancies M-Five and TRT or the Fraunhofer Institute ISI, Karlsruhe, further developed).[17]

The following brief characterizations refer to only one model example representing each category. The description of SDM is more detailed, as an integrated CNC assessment recently applied it.

SCGEs and their simplifications through elasticity models are based on the micro-economic equilibrium and welfare philosophy. These models involve the strict assumptions of neo-classical economic theory (e.g., user- or profit-maximizing behavior, perfect foresight, convex preferences and technologies, and almost-perfect price equilibria). They assume that most markets work perfectly according to these requirements while there are a few markets (in the model of Bröcker and Mercenier (2011) only the transport market) that show imperfections. In this case, spatial concentrations at agglomerations can develop (the Krugman theory of economic geography) with a higher level of productivity than in low-density regions. HSR investments connect agglomerated with lower-density regions such that they induce mobility of the workforce toward regions with higher productivity and wages (migration or commuting). The elasticity approach of Graham (2006) makes this model philosophy transparent: the HSR connection of a region leads to a higher-weighted population density (population weighted with an accessibility measure), and this result is multiplied by the elasticity of productivity with respect to the weighted population density. This approach is differentiated by economic sectors such that the elasticities have to be estimated on a sector base (see the paper by R. Vickerman in this volume).

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[15] http://spiekermann-wegener.com/mod/pdf/AP_0801.pdf.

[16] Descriptions of E3ME, E3MLAB, and ASTRA are available on the Internet.

[17] https://wwwb.vito.be/ghgprojection/documents/workshop_1/day2/Schade_DE_Astra.pdf; the PhD thesis of Schade (2004) originally developed ASTRA.

The elasticity model of Graham is an exception to the general rule that CBA and WEIs are not separable and are not additive. The empirical application, for example in the UK and in Australia, shows an extremely high variance of estimated elasticities (see Rothengatter 2017) such that the degree of confidence in the results is low, a comparison is very difficult, and the transfer of results to other project areas is impossible. However, the main problem with these approaches is that the technology as such remains a constant over time so that the positive growth impact only stems from a spatial shift of production to agglomerations and not from the dynamic change in sector technology. The approach focuses on the agglomeration density increase, which at the same time implies that the lower-density regions will lose. While this impact can be observed on some corridors served by HSR (the areas around stations benefit while the areas between stations stagnate), it appears to be too narrow to treat it as a general and always-predominant effect. Furthermore, such effects may conflict with a regional policy aiming at reducing regional imbalances.

The ***macro-economic CGEs***, like the economic module of E3MLAB,[18] are also based on the neo-classical assumptions, modeling the behavior of representative agents according to the homo oeconomicus principles in an almost-perfect economic environment. They also generate price equilibria and their change through infrastructure investments. Contrasting the micro-economically based SCGEs, they introduce more relaxations from the neo-classical world, making it easier to model real phenomena like unemployment. CGEs are highly appropriate for applying comparative statics to quantify the impacts of exogenous changes, and macro-economic theory has widely accepted them as the most sophisticated tools for assessment. The theoretical development toward stochastic dynamic equilibria is challenging, and the practical solution methods have also developed with the GAMS software. However, the heart of the method, the equilibrium approach, is also a weakness, because it prevents the model from achieving a close approximation to real observations (optimization dominates calibration) and it presents difficulties in modeling technological and behavioral changes endogenously over time.

Macro-econometric models, like E3ME,[19] use long time series for testing econometric functionals and composing them into equation systems for approximating the development of macro-economic indicators of social accounting. As in the case of E3MLAB, the “E3” means the integration of “economy,” “energy,” and “environment” into one model context, while adding transportation data exogenously. E3ME does not aim to model equilibria, which the developers (Cambridge Econometrics) argued to be an advantage, because it intends to simulate real developments and not theoretical ideals. As the computational tasks are much easier to solve than equilibrium models, the supporting sub-models can show a high level of detail. For instance, the input–output sub-model differentiates 69 sectors for Europe and 43 for the rest of the world as well as 53 regions. The dynamic simulations presently extend until the year 2050. The principal model philosophy is Keynesian; that is, the demand side is dominant and the supply side is following the aggregate demand. Contrasting the CGEs, prices and interest rates are not results of equilibrium processes, but aggregate figures are used to estimate them, for instance the gap between the aggregate demand and the potential output.

J. Forrester (1962) at MIT developed **system dynamics modeling** (SDM) in the 1960s, and it consists of four basic components: cybernetics, numerical simulation, decision theory, and mental creativity (see Milling 1974). Cybernetics provides the modeling principle for dynamic systems through feedback loops that link state variables (levels)

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[18] http://www.e3mlab.eu/e3mlab/.

[19] https://www.camecon.com/wp-content/uploads/2016/09/E3ME-Manual.pdf.

for which flow variables (rates) influence or control the magnitude of changes. The mathematical representation results in a set of difference equations that can include different degrees (time lags between reactions). Numerical integration methods approximate this system of dynamic equations.[20] It is possible to use the model for simulation, control, and optimization to provide decision support. Mental creativity can help to fill gaps in quantitative modeling, because SDM intends to model systems comprehensively with all the endogenous components and not partially. With these properties, SDM is an appropriate instrument for constructing scenarios that may include visionary elements for long-term development. One of the first applications consisted of preparing the world scenarios for the "Limits to Growth" project of D. Meadows et al. (1972). This study for the Club of Rome made SDM popular but also open to attacks from economic theorists. The reason was that the study used the component of "mental creativity" extensively to model the thinking of the team of modelers and their value judgments. As a strict set of assumptions on technology and behavior, comparable to CGEs and SCGEs, does not constrain SDM, it is necessary to fill an SDM as far as possible with empirically observed, econometrically proven, and sound data. Using the "mental creativity" component in a restrictive and controllable manner, in particular making value judgments transparent or supporting them with expert ratings, can increase the confidence in the independence of the results from the modeler's preferences.[21]

If SDM approaches are based on observed relationships and feedback mechanisms, it is possible to calibrate them at different levels: the functional level (parameters for single equations), module level (e.g., transport data for a country), and system level (EU-wide indicators). Therefore, the modeled dynamic profiles of variables can come very close to observations, even in the case of breaks of trends. The SDM ASTRA, exhibited in Figure 4, includes modules for macro-economics (MAC) with input–output tables for 28 countries, regional economies on the NUTS 2 level (REM),[22] population (POP), foreign trade (FOT), infrastructure (INF), transport (TRA), vehicle fleet technology (VFT), environment and safety (ENV), and comprehensive welfare measurement (WEM). ASTRA includes a simplified transportation model (without geographical modeling of networks). Comparable to the other models for measuring WEIs, it is possible to combine it with a detailed transportation model.

The most important theory element of the macro-economic supply side is endogenous technical progress, for which P. Romer (1990), the winner of the 2018 Nobel Prize for economics, in particular developed the economic theory in the 1990s. Romer explained the endogenous growth dynamics by the knowledge economy, that is, investing part of human and material resources in generating knowledge, which can then act as blueprints for innovations. This drives the total factor productivity (of labor and capital) and affects the long-term growth path of the economy. Figure 5 illustrates the basic idea of Romer, showing how the knowledge economy influences the total factor productivity in the production function. Investing part of human resources in research and development produces blueprints for inventions that creative entrepreneurs can use to develop innovations. These innovations increase the total factor productivity (productivity of capital and labor, A in Figure 5) and push economic growth

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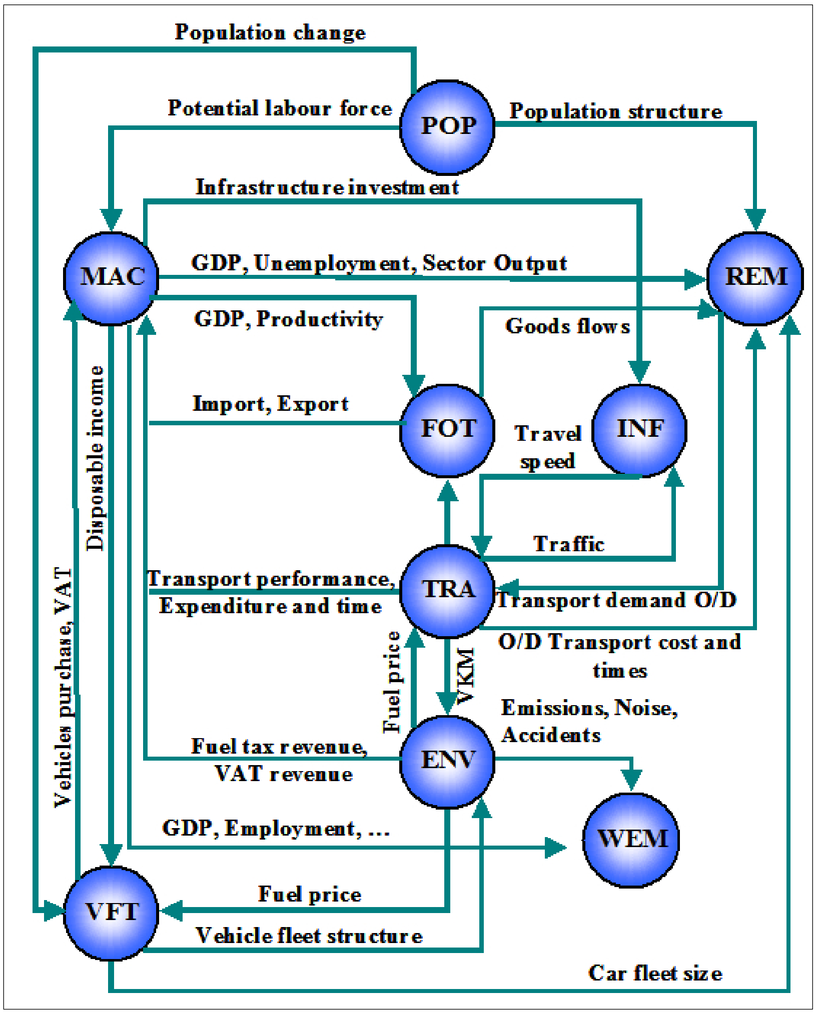
[20] Forrester developed the DYNAMO compiler, which is still the heart of software packages like ITHINK and STELLA.

[21] Mentioning this issue in the context of SDM does not mean that other assessment approaches are immune to manipulation risk. However, the aspiration of the early applicants to use the instrument as a quantitative representation of human thinking still influences the image of SDM. The first commercial software package including Forrester's DYNAMO compiler was called "ITHINK."

[22] NUTS is an abbreviation for regional classification: NUTS 0: country; NUTS 1: macro-region; NUTS 2: province; NUTS 3: county level.

endogenously. This idea is extendable to the development of infrastructure for transport and communication networks, which—analogously to the knowledge stock—can also contribute to improving the total factor productivity over time (see Rothengatter 2017). It is possible to integrated this into SDM through the production functions on the supply side such that major improvements in the transport infrastructure, which lead to a stepwise change in service quality, contribute endogenously to the long-term growth of the economy.

Figure 4: Structure of the SDM ASTRA

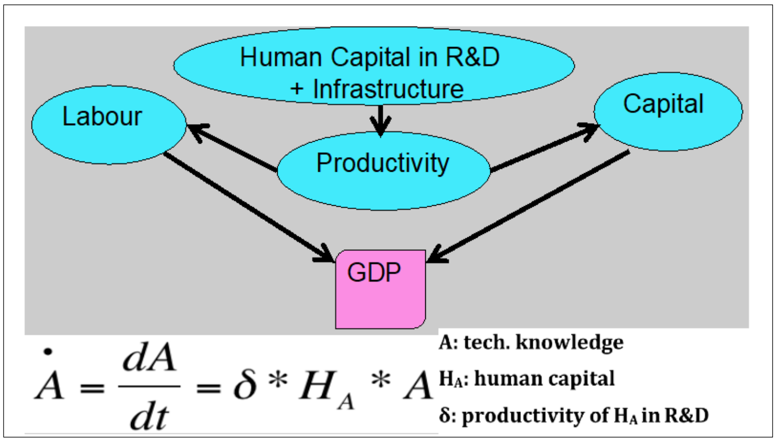


Source: http://www.astra-model.eu/structure-overview.htm.

Yoshino and Nakahigashi (2018) presented other growth accounting and production function approaches for measuring total factor productivity impacts and quantified them for Thailand and Japan. According to the results of time series analysis, the influence of transport infrastructure on output growth is dominant in the secondary (production) sector. This means that the main productivity impacts occur through improved freight transport and trade conditions. However, the share of GDP contribution of this sector is declining in highly industrialized countries. Therefore, it will be a challenge for future research to analyze the total productivity impacts on the third sector (services). Attempts to prove a positive correlation between the education level, the growth of high-tech industries, including services, and HSR produce promising results, but researchers have not generalized them until now (e.g., the WEI assessment of the Stuttgart–Ulm/Munich project; see section 3.2).

The idea behind the hypothesis of such a relationship is that highly qualified people prefer working locations with good accessibility of high-speed transportation modes—for business as well as for private travel purposes. Therefore, the improvement of accessibility through HSR can attract high-quality human capital, which induces the Romer effect that Figure 5 depicts.

Figure 5: Endogenous Growth Impacts



Source: Rothengatter (2017) following Romer (1990).

The model contains further interfaces between transport and the economy for the final demand. The Keynesian multiplier and accelerator impacts can stimulate the economy in the case of underemployment and foster foreign trade through a change in the terms of trade following reduced transportation costs. These demand-side effects weaken as soon as the gap between the supply (potential output) and the demand decreases. This demonstrates that an SDM can model the macro-economic reactions according to the prevailing and expected economic regime (in the sense of Malinvaud 1977) and is not bound to a particular philosophy (neo-classical, Keynesian, or monetarist).

5.2 Application to the Assessment of EU Core Network Corridors

The SDM ASTRA has estimated the wider economic impacts as well as the environmental impacts of the CNCs (see section 2) until the year 2030 (FhG-ISI et al. 2015; M-Five and TRT 2018). ASTRA in combination with the transport model TRUST[23] delivered the inputs for modeling the changes in passenger and freight transport, in particular regarding the modal split (Figure 6). The results underline that the influence on the modal split is in the desired direction. However, the impact of the pure infrastructure policy is limited, which means that the infrastructure policy is necessary but not sufficient and that it needs further policy measures like pricing, regulation, and improved vehicle/control technology to achieve substantial impacts on modal shift.

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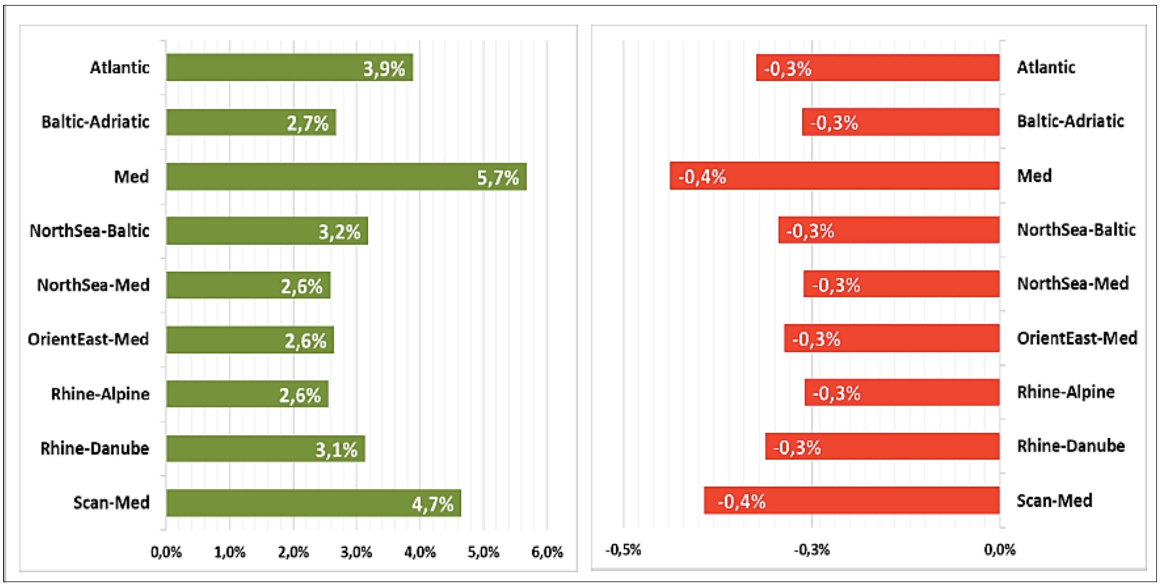
[23] http://www.trt.it/en/tools/trust/.

Figure 6: Impacts of CNCs on the Modal Split

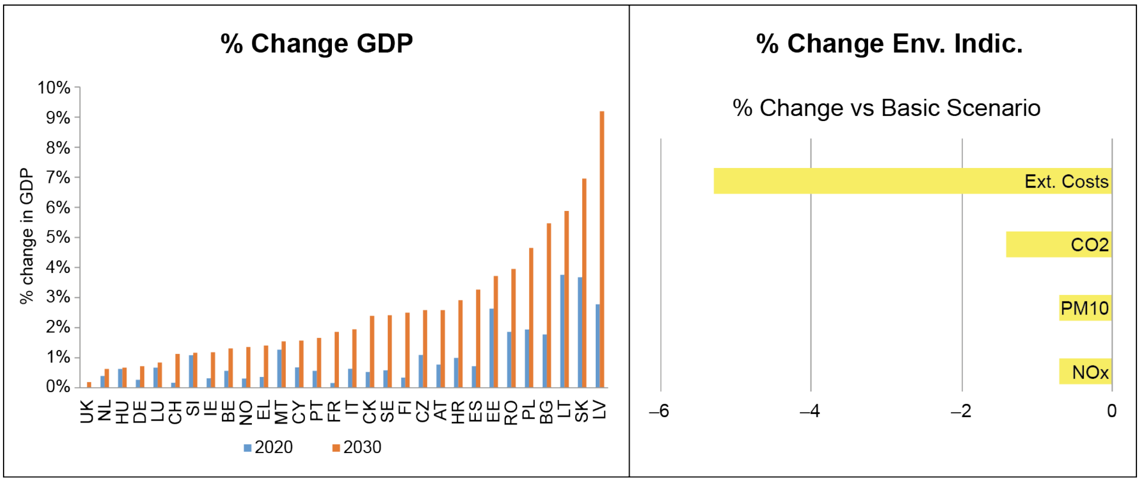


Left = rail, right = road.

Source: M-Five and TRT (2018).

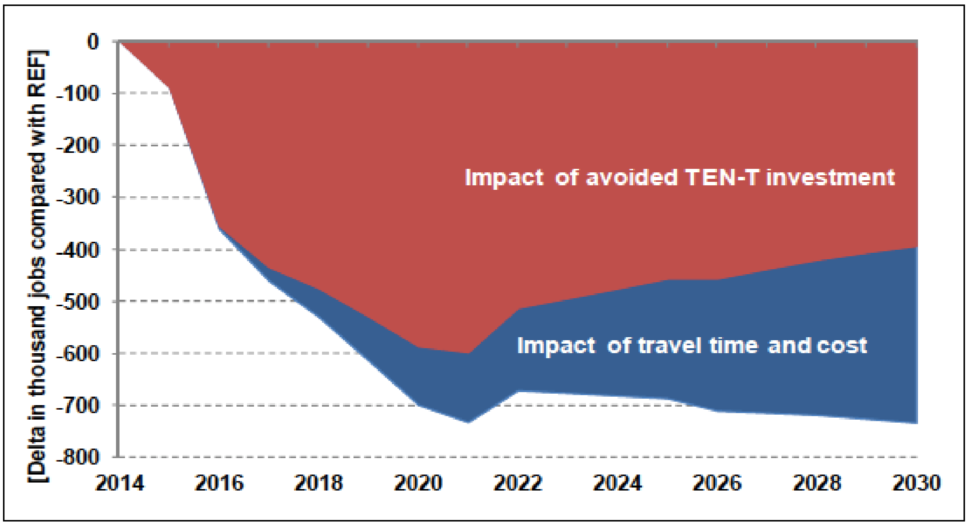
Figure 7 illustrates the impacts on the GDP differentiated by EU member states and on external diseconomies (environment, climate, and safety). As the figure exhibits the impacts as percentage changes, they appear to be comparatively high in small countries, particularly in the former "accession" countries that joined the EU after 2007. Because the time horizon of the simulation is short, ending in 2030, the multiplier and accelerator effects in the initial phase are dominant (Figure 8). However, it is apparent that the share of the impacts of time and cost reductions or quality improvements will grow over time; in particular, the improvements of border crossings and their impacts on transnational connectivity will become evident in a later phase of CNC projects' life. Furthermore, the endogenous growth impacts will become apparent after the planning horizon defined for this study.

Figure 7: Impacts of CNCs on the GDP and on External Diseconomies



Source: M-Five and TRT (2018).

Figure 8: Employment Impacts of CNCs

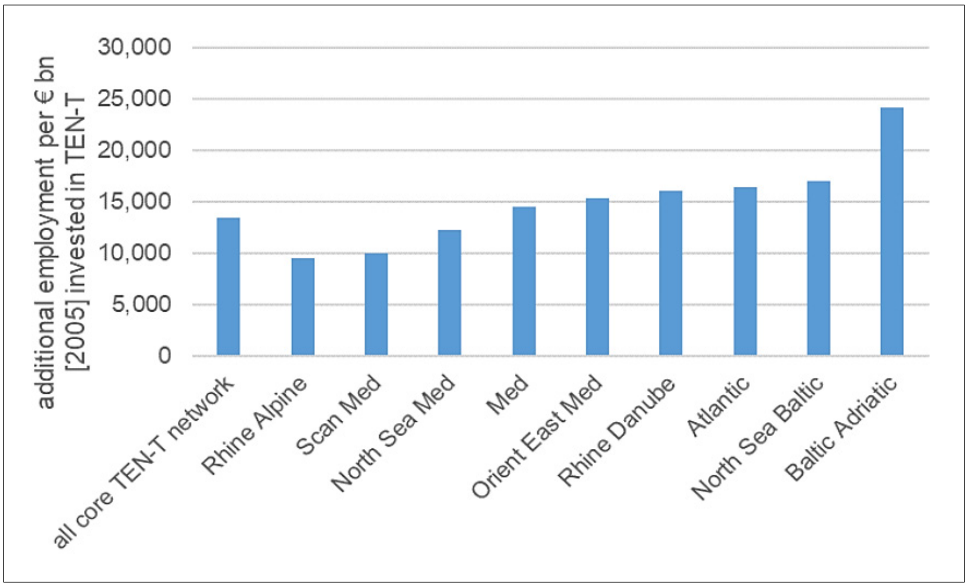


Red: multiplier and accelerator impacts; blue: impacts of time and cost savings.

Source: FhG-ISI et al. (2015).

The study of M-Five and TRT (2018) exhibits employment impacts differentiated by the CNCs, by countries, and by industrial sectors (ASTRA includes input–output tables for all the EU countries, Norway, and Switzerland; Figure 9 presents the results).

Figure 9: Employment Impacts by Corridors



Source: M-Five and TRT (2018).

The employment multipliers are relatively small for the corridors connecting highly industrialized regions (e.g., Rhine–Alpine and Scan–Med), while they are significantly higher in the industrially less developed corridor regions (North Sea–Baltic and Baltic–Adriatic). This indicates that it is not enough to consider only the agglomeration effects of HSR as they are in the focus of SCGEs and their simplified elasticity approaches, because the removal of bottlenecks (geographic, political, and social) can be highly beneficial for lagging regions.

5.3 Ongoing Developments for Integrated Assessment Methods (IAMs)

Assessment methods are fully integrated if they embody modules on economics, energy, the environment, transport, and technology development. The European Commission has supported several research and consulting projects—besides the SDM that section 5.2 presented—in this direction. The project TRANSTOOLS[24] started by combining detailed transportation modeling with assessment tools. This approach suffered from high complexity and gave rise to the development of a simpler aggregate model called HIGHTOOL,[25] which was open source and appropriate for estimating the aggregate outcomes of CNC plans. The development of TRIMODE[26] is presently taking place and aims at integrating differentiated transport modeling with macro-economic, energy, and environmental modeling (in this context, it uses the CGE E3MLAB; see section 5.1). Comparable to the models E3ME and ASTRA, these approaches integrate input–output tables with modest differentiation by sectors. They disaggregate the macro-economic figures by shift-and-share modeling at the regional level (NUTS 3).[27] This provides the interface for transportation modeling that also uses this geographical classification.

The most advanced development of input–output modeling and social accounting is EXIOBASE.[28] EXIOBASE is an extended multi-regional input–output model for which the European Commission and its Joint Research Center in Seville (Spain) has widely supported the development. Presently this open-source model is undergoing further development, and a consortium is applying it under the lead of the Norwegian University of Science and Technology. Table 5 gives an impression of the high degree of differentiation and the extensions by emissions and accounts for water, materials, land, and employment.

The model is appropriate particularly if detailed information on emissions is relevant to public decision making. The model provides highly detailed supply and use tables (for 200 products and 163 industries) for 44 countries plus 5 regions for the rest of the world. Therefore, it is possible to analyze the sources of emissions differentiated by regions on the production side (e.g., the PRC) and the consumption side (e.g., European countries). This reveals carbon leakages and counterproductive shifts of CO_2 production from industrialized countries to emerging economies, eventually resulting in a higher total CO_2 footprint on the consumption side. The model has proved to be applicable for instance in the context of the EU project LOGMAN,[29] which analyzed the impacts of global logistics and manufacturing on trade and transport volumes and their climate impacts.

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[24] http://www.transportmodel.eu/.

[25] http://www.high-tool.eu/.

[26] http://www.trt.it/en/PROGETTI/trimode_project/.

[27] Shift and share: regional change is usually derived here from three components: the national growth effect, industry mix effect, and local share effect. NUTS: see Footnote 23.

[28] https://www.exiobase.eu/index.php/welcome-to-exiobase.

[29] https://cordis.europa.eu/project/rcn/92918/factsheet/en.

Table 5: EXIOBASE, Development Stages, Differentiation, and Extensions

	EXIOBASE 1	EXIOBASE 2	EXIOBASE 3
Base Year(s)	2000	2007	1995-2011
Products	129	200	200
Industries	129	163	163
Countries	43	43	44
RoW Regions	1	5	5
Emission Types	26	40	69
Water Accounts	94	344	388
Material Accounts	117	117	291
Land Accounts	14	15	15
Employment Accounts	6	6	14

Source: https://www.exiobase.eu/index.php/welcome-to-exiobase.

A further preferred field of application is the analysis of detailed impacts on employment. This is the focus of the impact analysis of new technologies on the labor market. Examples are developments of automated driving and the processing of vehicles by road and rail. In this context, the United Nations Economic Commission for Europe (UNECE) and the International Labor Organization (ILO) are using EXIOBASE for estimating the impacts of the transformation processes in vehicle manufacturing through electrification and automation (see International Labor Organization (ILO) 2018). As it is well known that input–output modeling is not appropriate for long-term forecasts or scenarios, it is possible to combine the model with dynamic macro-economic and energy modeling (see Egging et al. 2017). The volume of the model (it needs 14 GB of RAM for the time series from 1995 to 2011) leaves little chance to combine EXIOBASE interactively with other models like a transport model. Therefore, EXIOBASE, in the first instance, can be used to split up the impacts of changes with a high degree of differentiation that other models have quantified separately on an aggregate scale.

6. THE ISSUE OF OPTIMAL CONFIGURATION OF HSR NETWORKS

Conventional CBA concludes with a clear decision rule, at least from the theoretical point of view: the investment program should include all projects showing a positive present value or a benefit–cost ratio greater than one. The social rate of discount implicitly represents the opportunity costs, that is, the foregone benefits of alternative spending of investment funds. Because of the deviations between CBA theory and practice in many applications (e.g. caused by appraisal biases), much higher thresholds may be necessary to adjust the transport investment program to the feasible financial resources.

Contrasting CBA, an IAM is not a separate and independent final step of final assessment. It is necessary to integrate IAM into a wider system approach for planning and decision preparation, which consists of the following steps:

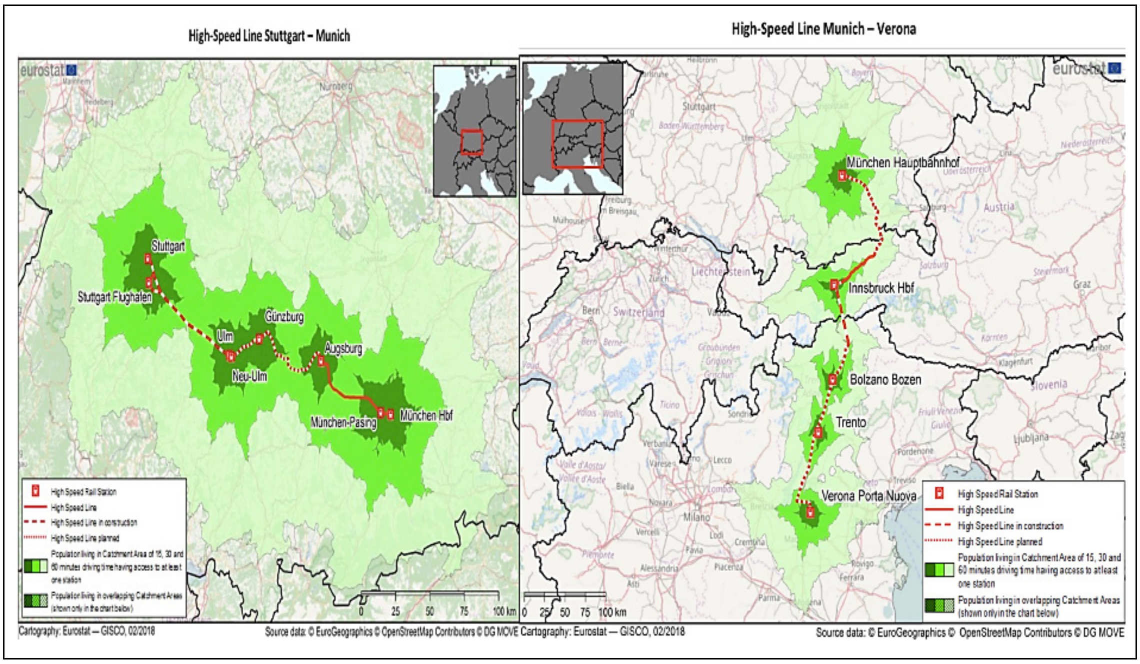
- Definition of the underlying goals and setting of targets;
- Analysis of target achievements and bottleneck removal;
- Development of alternative investment and action programs;
- Evaluation of programs and network design based on IAMs;
- Evaluation of projects and project design; and
- Life cycle analysis of maintenance and financial needs.

In general, the underlying goals are specified and broken down starting from the Brundtland definition of sustainability: economic, environmental, and social (Brundtland Commission 1987). Dependent on the societal preferences and the stage of economic development, it is possible to interpret this goal system as comprehensive social welfare or social happiness (see Hayashi et al. in this volume) and to model it as a vector maximum approach (see Musso and Rothengatter 2013). If the process of decision making follows the logic above, it will be necessary to define quantitative target levels for goal achievements and constraints. In countries with decentralized decision making for infrastructure networks, this is a most difficult issue and often results in very general and not quantitatively based target descriptions. However, setting targets in a too general or even fuzzy way can be the starting point for planning failures, which end up with negative records for inefficiencies (see the megaproject criticism of Flyvbjerg 2014).

Clear quantitative target settings prepare the base for developing integrated concepts for target achievement and removal of identified bottlenecks on this way. For the transport sector, these concepts include infrastructure, vehicle technology, regulation, and pricing policy. HSR in this context can provide the backbone for long-distance passenger transport, including efficient border crossings to remove bottlenecks for interregional or international connectivity. In this case, it is important to combine HSR with the development of regional and urban networks to improve accessibility and avoid problems with regional equity. Figure 10 gives examples of the different sizes of catchment areas for HSR stations. The left-hand example illustrates the corridor between Stuttgart and Munich and shows good accessibility of HSR stations, which also allows for the exclusion of some stations from high-frequency services to increase the average speed between the main agglomerations. The right-hand example, depicting the corridor between Munich (Germany) and Verona (Italy), indicates that the catchment areas of the stations between these agglomerations could increase by improving the regional transit services. These examples underline that it is necessary to develop the secondary networks simultaneously to feed the HSR services in a better way and to improve the location quality of regions. This would contribute to avoiding negative backwash effects for areas without a direct HSR service.

When designing HSR—beyond its function as a backbone network —as an instrument for improving the environment and regional development, as section 3 presented for the Spanish HSR policy, it is necessary to check whether such a policy is superior to the backbone concept combined with improvements of secondary regional transit systems.

Figure 10: Examples of Catchment Areas for HSR Stations



Source: European Court of Auditors (2018).

A rational algorithm for political decision making would suggest developing alternative configurations for HSR networks with different densities. This means that evaluating alternative concepts makes the opportunity cost calculus explicit. IAMs can evaluate the present outcomes for all the underlying goals and the degrees of target achievement. These outcomes will show whether a dense regional HSR network may be superior to an HSR backbone concept with respect to regional equity and environmental sustainability (e.g., CO_2 savings for climate protection). They will also confront the policy makers with the associated budget needed for equity and the environment in the life cycle of investments. Life cycle assessment makes it transparent that public finance may be needed not only to implement an investment project but also to provide the necessary maintenance for decades, which may limit the political appetite for constructing dense HSR networks on the one hand. On the other hand, positive information on long-term WEI can motivate regions and stakeholder groups that expect benefits from the HSR investments to participate in the finance of investment and future maintenance, for example according to the value capturing suggestions of Yoshino and Stillman (2018).

Having identified the best network configuration the setting up of an appropriate master plan follows. The optimal design for individual projects can be determined with the support of CBA and risk analysis, followed by optimal scheduling methods which consider the synergies between HSR links when developing the network in a staged process.

The present state of HSR implementation in the EU, which the European Court of Auditors (2018) characterized as more a patchwork than a network, shows that there is high potential for improving planning and decision processes by quantifying WEIs and applying IAMs to achieve an efficient EU HSR network configuration in 2030 and beyond.

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