Efficiency of the Spanish sector in the development of the high-speed railways

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Index

01

INTRODUCTION

1.1

Approach

High-speed rail is experiencing a clear revival in the world. The UIC (Union Internationale des Chemins de Fer) - the world's leading international railway organisation - stated at its World Congress on High Speed Rail in 2023 that "the development and implementation of high-speed lines is under study in all regions of the world, and that a very pronounced increase in the length of the network is already being observed in Asian countries". [1]

For its part, the *European Strategy for Sustainable and Intelligent Mobility*, published in 2020, gives high speed a key role in inter-urban and regional mobility in the medium term, as well as in achieving climate neutrality of mobility by 2050. It even forecasts (and proposes) that high-speed traffic will double by 2030 and triple by 2050 compared to the current level .[2]

The sector is in the same line. **The main network managers and railway operators, both public and private, both historical and new players, seem to really believe in this future role of high speed** and announce investments and expansion operations inside and outside their borders, Renfe (Spanish operator) among them[3]. According to a report by Allied Market Research[4], the global high-speed rail market was valued at USD 42.5 billion in 2021 and is expected to reach around USD 77.6 billion in 2031.

Ineco, as a leading railway engineering company, is experiencing this renewed interest first-hand, seeing how enquiries and activity are increasing in countries all over the world: Poland, Baltic countries, the United States, Colombia, Chile, India, the Philippines, Vietnam, etc.

This "revival" of high speed is not only growth, but it also implies a change of model that would go from adding independent projects in a reduced number of leading countries to integrate networks as the backbone of sustainable interurban mobility in more and more regions of the planet.

This optimistic view should, however, be subject to **a cautious analysis because there have already been previous episodes of enthusiasm in high-speed rail** with emblematic projects that have not materialised due to their high cost, such as the High Speed Train in Brazil (Rio de Janeiro - Sao Paulo - Campinas) or the Kuala Lumpur - Singapore International Connection, to name but a few in which Ineco has had some participation.

Moreover, **since almost its inception, high-speed** rail **has faced numerous Interrogations from academic, environmental and political spheres**.

Among the critical reports, the 2018 report by the European Court of Auditors[5], which analyses 14 European high-speed lines, including 7 Spanish ones, stands out for its impact. The report does not question the virtues of the mode itself, which it describes as "comfortable, safe, flexible and environmentally sustainable", but it does raise questions of design, governance and, above all, cost: "Profitability is at stake, (...) as the cost per minute saved is very high".

In Spain, high speed has enjoyed a greater social and political consensus. However, there have also been critical opinions such as those of the Fundación de Estudios de Economía Aplicada (Fedea[6]) or the Spanish Court of Auditors on the Railway Integration Companies of Adif Alta Velocidad. These reports identify that, despite the overall success of the Spanish experience, there have been and there are aspects for improvement.

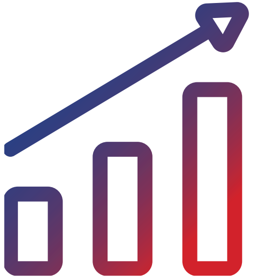
The current high-speed boom in the world seems to be much more based on the logic of mobility than in the past. The technological evolution itself, the improvement of its

performance, the economic development of Asia and other emerging countries, and a greater environmental awareness reinforce the case for high speed at the moment.

But for good predictions to become reality, critical issues need to be addressed, most notably the magnitude and slippage of construction and maintenance costs, i.e. the efficiency of high speed production in a life-cycle approach. This is probably the main challenge for the expansion of this mode of transport, as evidenced, for example, by the umpteenth rethink of the British High Speed (HS2) due to cost overruns[7].

This report analyses the efficiency of Spanish high-speed rail infrastructure production. Production is not the only parameter involved in high speed, of course: there are also issues such as operation, management, economic, territorial, social and environmental impacts... These are key aspects that have been addressed and require specific treatment. While taking them into account, this report focuses on production costs, which have perhaps been less analysed in the past, and which will determine, to a large extent, the fate of high speed in the world and the Spanish participation in this expansion.

Based on previous studies, data and Ineco's own experience and capacity for analysis in Spain and the world, it is concluded that **the Spanish sector can make great contributions to high speed and face the future with a realistic dose of optimism.**



1.2

The Spanish experience, looking towards the future

From this perspective, it is important to review the Spanish railway experience and, specifically, the high-speed railway with a certain prospective vision.

The Spanish railway has been occupying modest positions in the global and even European contexts. In its history, it had not played a leading role until the development of the Spanish high-speed railway a century and a half after its beginnings. Even in 1980, trains in Spain travelled at an average speed of 65km/h. **What has happened since then?**

First of all, **society and the authorities agreed to give a great boost to the railway and to create a political and institutional framework** which, with the necessary adaptations over time, is still in force today with a broad consensus and a long-term vocation.

Secondly, and linked to the first factor, **the national sector: Spanish professionals, institutions, companies and engineering firms were prepared and ready to take advantage of this initial impulse**, so that both the public and private sectors decided to stop importing technologies and develop their own strategies and products, positioning themselves nationally and internationally.

And thirdly, the development of an **institutional and technological model of its own** has been promoted, with particularities inherent to the demographic, orographic and technical configuration of Spain, fundamentally to the difference in gauge and, therefore, to the decision to use the now standard gauge to connect our network with the rest of the Trans-European Network.

In these 30 years, since the appearance of the Madrid-Seville high-speed line, **the Spanish railway sector, in all its fields, public and private - engineering, construction, supplies and logistics - has become a world reference**.

For this, on the one hand, an important joint commitment of the public sector, society and the Administration has converged, with a high investment and a clear prioritisation of the railway until today as a key element for sustainability and energy transition; and on the other hand, Spanish companies and engineering firms have contributed *know-how*, specialisation, technology, innovation and,

fundamentally, value in the whole chain or life cycle of the infrastructure.

This consensus is fundamentally based on the technological recognition and the high specialisation of all the members of the sector, supported from the first government team, which initiated this national commitment, to the current one, which has positioned the railway at the centre of the investment in transport infrastructures within the Recovery, Transformation and Resilience Plan.

The key element underpinning this idea is undoubtedly the contribution of value in a comprehensive and complete manner in all phases and areas of a railway line, from planning and financing to commissioning. **Spanish industry is therefore perfectly capable of developing a "turnkey" project or of tackling the most specific and concrete technical task**, all of this through a high level of professional qualification and with the most advanced technologies in all fields.

All of the above has allowed us to have today the second high-speed network in the world, still

with a high potential in terms of intermodality and capacity, being leaders, moreover, in the achievement of the basic railway requirements such as safety, service excellence, adaptation to the so desired interoperability, and, fundamentally, specialisation.

In short, to use a railway simile, in the last 30 years Spain has gone from caboose to locomotive. **Probably no other sector of the Spanish economy has undergone such a radical transformation**.

02

THE DEVELOPMENT COST OF SPANISH HIGH-SPEED RAIL

The high cost involved in the construction of high-speed rail is the main challenge for its expansion at a time when a renewed wave of development of this mode of transport is being seen in the world. In this sense, Spain has much to contribute.

As will be seen below, the country has developed the second high-speed network in the world with **one of the lowest construction costs per kilometre, the lowest among comparable countries**.

And it has done so by applying **very demanding design parameters** (maximum speed of 350 km/h, double track platforms and new construction), limited by a **complicated orography** (which implies large singular works) and an existing network of **different gauge**, and being, in many cases, **a pioneer** in the implementation of constructive (large tunnels) and technological (ERTMS) solutions. This initially entailed an initial disadvantage (cost of the pioneer) but, in the long run, it has allowed to take advantage of the learning curve and capitalise on the long experience in the efficient development of high speed.

Spain has also built relatively **quickly** and **well.** Construction times for Spanish lines are shorter than the European average. Cost overruns are also comparatively low and without major deviations on any line, contrary to what tends to happen in other countries. And quality, as will be seen, is also among the highest in the world.

Finally, it should be noted that this relatively cost-effective construction has been achieved **without detriment to its maintenance** during the operation phase, despite Spain's strategic choice of ballasted track. The maintenance cost of high-speed rail in Spain has been reduced to levels below the European average, which, together with a construction cost which is also lower, means that **the overall cost of the infrastructure throughout its life cycle can undoubtedly be considered low in comparative terms.**

An exploitation of the Transit Costs Project database[8], has been carried out, which is the most complete and homogeneous public database of high-speed railway construction costs. In addition, the main studies on the costs of high-speed rail published in recent years by different technical, administrative and academic bodies have been reviewed, which support the above. Although these sources use different methodologies and are not completely homogeneous - which makes direct comparison difficult - the same robust conclusions can be drawn when interpreted systematically.

2.1

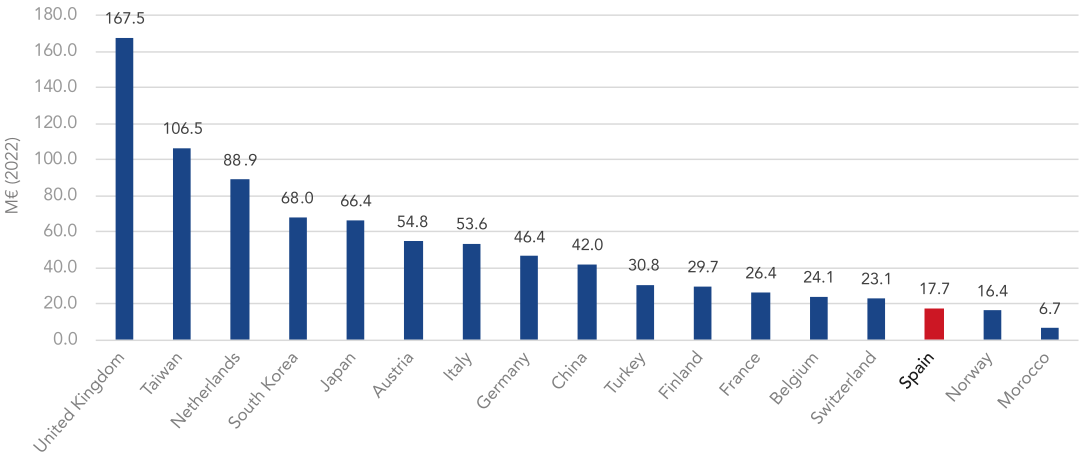
The overall cost of high speed

2.1.1 CONSTRUCTION COST

The values in the Transit Costs database have been transformed into 2022 euros to allow comparison between projects with different currencies and time horizons[9].

The analysis of this database shows that the average cost in Spain is among the lowest of the high-speed countries, with 17.7M€ (2022) (considering the weighted average per km), while the average cost in the rest of the countries would be 45.5, more than twice as high.

Cost per kilometer (weighted) by country



Own elaboration based on Transit Costs Project.

The only high-speed projects below Spain are the ones in Norway (from the 1990s and with a design speed of 210 km/h) and Morocco (probably due to the lower cost of labour and other costs), which are in no way comparable to the Spanish network as a whole. If only EU states are considered, **Spain would definitely have the lowest cost**. The only countries that are comparable with Spain are France and Belgium, which also use the same construction procedure of ballasted track.

The Transit Costs database includes as costs per kilometre of Spanish lines those published by AIReF (2020) in its report *Evaluación del gasto público 2019. Estudio Infraestructuras de Transporte*. However, it does not include the data for all the lines, so that **if we take the weighted average of the unit cost of all the lines included by AIReF, this would be €15.3 million** (2018 euros).[10]

On the other hand, **the European Court of Auditors (2018), in its special report on the European high-speed network**, lists the cost per kilometre of 10 European corridors with a (weighted) average of 23.8 million euros. Once again, **Spain is once again the country with the lowest ratio (15.0 M€), below France (17.1) and, especially, Germany (29.8) and Italy (34.3)**, which usually use slab track in high speed. **Moreover, of the 10 lines analysed, the four Spanish lines are the lowest cost.**[11]

There is further literature that attempts to establish benchmark costs for the construction of high-speed lines. For example, UNECE (2021) estimates the average construction cost to be between 15 and 30 million (2017 euros) for flat and hilly terrain, respectively[12]. The European Commission (2018) , in its report on the assessment of unit costs of railway projects, sets the average cost per kilometre of newly constructed lines at €14.1 M, with an interquantile range of €11.8-16.4 M[13]. For its part, the UIC (2015) estimates the cost of these new high-speed lines to be between €15 and €40 million[14]. The BBVA Foundation (2012) projects an average cost per kilometre of between 6 and 45 million (2005 euros), with an average value of around 17.5 M€[15]. PwC (2016), 35.8 M€ for Europe as a whole (2011 euros)[16], and the Cour des Comptes (2014), between 9.3 and 17.5 M€ for the French high speed (2003 euros), very similar to the Spanish[17]. **All these studies use very different methodologies and sources, but still point in the same direction: Spain has a lower unit cost than other countries**.

The summary of these sources is shown in the table below, together with the average cost per kilometre for Spain obtained from the Transit Costs database. The latter data is given in 2022 euros, while the rest of the sources are shown in real terms of other years, so the comparison is not direct. Similarly, not all sources include station or land acquisition costs, while others add costs not directly linked to construction, such as planning costs. Nevertheless, despite the difference in years, the Spanish average is generally in line with or below the references studied.

Unit costs collected from public sources, and comparison with the Spanish average

Source	Year monetary values	Area	Cost/km (M€)
AIReF (2020)	2018	Spain	15.3
European Court of Auditors (2018)	*	Europe	13.7-49.7
UNECE 2021	2017	Europe	15-30
European Commission (2018)	2018	Europe	*11.8-16.4 (1)*
PWC (2016)	2011	Europe	35.8 (2)
Cour des Comptes (France) (2014)	2003	France	9.3-17.5
UIC (2015)	2015	Europe	15-40
BBVA (2012)	2005	Europe	6-45 (3)
Order FOM/3317/2010 (2010)	2010	Spain	*4.6-19.3 (4)*
Transit Costs Project (5)	2022	World	45.5
Average Spain (Transit Costs)	2022	Spain	17.7

In italics are recommendations, not empirical data.
* The report reports data in nominal terms. (1) Interquantile range (does not include values above and below the third and first quartile of the distribution, respectively). Does not include land cost(2) Includes planning. (3) Does not include land cost. (4) Does not include the cost of land, but does include the cost of studies and projects. (5) Data updated to 2022 using the methodology described above.

2.1.2 MAINTENANCE AND LIFE CYCLE COST

The construction cost is not the only cost to be taken into account if efficiency is to be analysed from the integral perspective of the infrastructure's life cycle. In this sense, the **costs of maintenance and operation** during the entire operational phase form an important part of the overall cost of high-speed trains.

In Spain, the **average maintenance cost is in line with or below the European average**. In its management report for 2022[18], ADIF AV reports an annual maintenance cost for the high-speed network of 92.8 thousand euros/km which, together with an operating cost of 7.9, makes a total of 100.7 thousand euros/km of average operating cost. It is worth mentioning that this cost drops to 58.5 thousand Euro/km on the conventional network[19]. Therefore, the average weighted by the kilometres of each type of network would be 68.4 thousand Euro.

In order to compare this cost with other countries, it is necessary to refer to the annual PRIME (Platform of Rail Infrastructure Managers in Europe) report[20], the only source that allows a homogeneous comparison. This report, which analyses the ADIF network as a whole, shows that **Spain is below the European average in terms of infrastructure operating costs**[21] (the operation of services is not considered in this study).

If we take into account that Spain has a higher proportion of high-speed network (more expensive to maintain than the conventional network), it could be argued that its maintenance cost must necessarily also be lower than the European average, unless there is a very significant difference in the maintenance of the conventional network between Spain and the other countries, which does not seem to be the case. By way of example, Spain, with 25% and 6% of the network designed for more than 250 and 200-250 km/h, respectively, has an operating cost similar to the French network managed by SNCF, with only 9% of the network at more than 250 km/h, and to the German DB network, with an even lower percentage according to the PRIME report of 2021.

It should also be noted that this **maintenance cost has been** gradually **reduced over** time. In particular, over the last decade it can be seen to have been reduced in real terms, remaining at around the order of €100,000/current km per year since then, despite increasingly demanding standards and currency devaluation. This is due

to a number of reasons, including necessary efficiencies generated by experience and economies of scale as the network has expanded.

Nevertheless, **maintenance expenditure accounts for a small part of the overall cost**. The average expenditure in 2022 was 92.8 thousand €/km which, compared to a historical average construction cost, in discounted terms, of €17.7 $million_{2022}$ /km, represents approximately 0.5% per year of the investment cost. Even considering a useful life beyond 40 years, the maintenance cost would still be less than a quarter of the overall cost of a high-speed line. Thus, the magnitude of the maintenance cost, however high, would fall far short of cancelling out Spain's substantial construction cost advantage.

Finally, it is worth mentioning that the relatively low levels of maintenance costs compared to the European average have been achieved despite the generalised use in Spain of ballasted track, which is generally considered more expensive to maintain than ballastless track. Given the relatively low weight of maintenance compared to construction, it can be affirmed that the Spanish strategic choice for ballasted track has not increased the overall cost of high-speed railways, but rather has contributed to keeping it low.

As a conclusion regarding the operating costs of the infrastructure, one idea can be highlighted: Spain has an operating and maintenance cost per kilometre in line or below the European average, and, in any case, it has a relatively small value in relation to the initial investment. Therefore, the overall cost of the Spanish high-speed network is undeniably low.

2.2

Cost variability

The average aggregate cost could hide the **large variability** in projects of this type, whose unit cost depends on multiple parameters and requirements

The following table shows the costs per kilometre for each country analysed in the Transit Costs database, together with the dispersion (measured by the standard deviation between the average), the maxima and minima, as well as the percentage of lines designed for more than 300 km/h and the percentage of kilometres of all the lines analysed that represent tunnels and viaducts.

Characterisation of the high-speed lines analysed

Country	No. projects analysed	Average length of the projects analysed	Cost/km (M€ 2022)	Ratio deviation/ average (weighted)	Maximum	Minimum	% equal or plus than 300 km/h	% unique works
United Kingdom	2	320	167.5	13%	181.1	101,6	100%	16%
Taiwan	1	349	106.5	-	106.5	106,5	100%	90%
The Netherlands	1	100	88.9	-	88.9	88.9	100%	20%
South Korea	4	149	68.0	33%	97.6	48.6	100%	52%
Japan	4	131	66.4	31%	113.1	44.4	25%	94%
Austria	2	84	54.8	18%	77.2	48.4	0%	45%
Italy	6	127	53.6	39%	90.4	33.5	83%	29%
Germany	6	162	46.4	16%	61.8	37.2	50%	37%
China	18	321	42.0	18%	63.7	23.3	83%	41%
Turkey	10	282	30.8	37%	67.9	5.3	10%	8%
Finland	1	94	29.7	-	29.7	29.7	100%	11%
France	14	217	26.4	62%	113.5	5.8	93%	11%
Belgium	4	57	24.1	11%	30.6	21.4	75%	9%
Switzerland	1	45	23.1	-	23.1	23.1	0%	32%
Spain	10	251	17.7	35%	38.5	7.4	90%	17%
Norway	1	64	16.4	-	16.4	16.4	0%	27%
Morocco	1	186	6.7	-	6.7	6.7	100%	4%
Total	86	219	41.8	26%	181.1	5.3	70%	28%

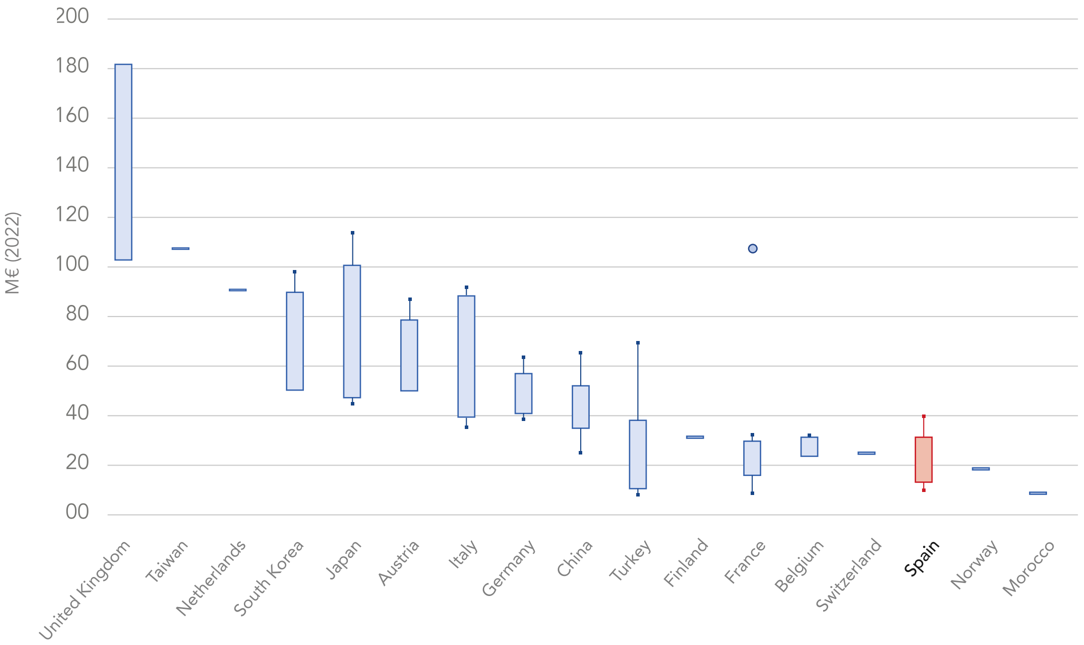
Own elaboration based on Transit Costs Project[22]

Spain shows a moderate variability in the average cost (35% deviation from the average) which, in any case, represents a deviation of around 6 million euros per project, half that of the database as a whole (11 million euros) due to the large number of different lines and the long period in which they have been built. The high-speed line with the lowest cost corresponds to the Venta de Baños-León section, with 7.4 M€ (2022), whereas the highest cost is the so-called 'Basque Y', with 38.5 M€[24].

The following graph shows the average costs broken down by high-speed line. It can be seen that France and Turkey are quite similar to Spain, both with one project significantly more expensive than the rest. Belgium would also have a very similar distribution to Spain, although with an average length much smaller than in Spain (57 km compared to 251 km).

On the other hand, Switzerland and Finland have an average cost similar to that of Spain, but have only one high-speed project or line in the database.

Cost per kilometer per project

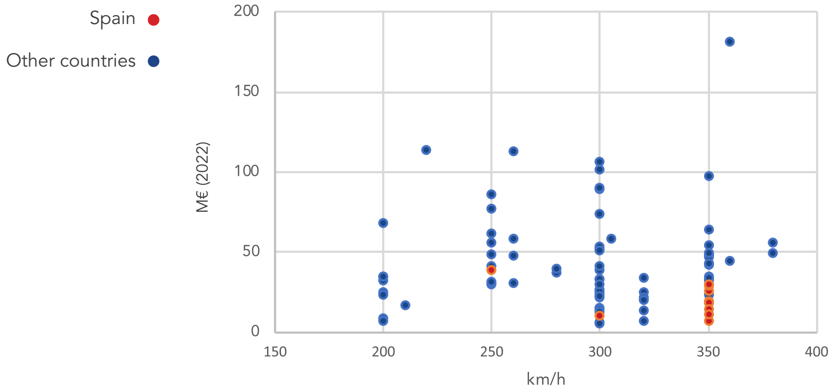


Own elaboration based on Transit Costs Project

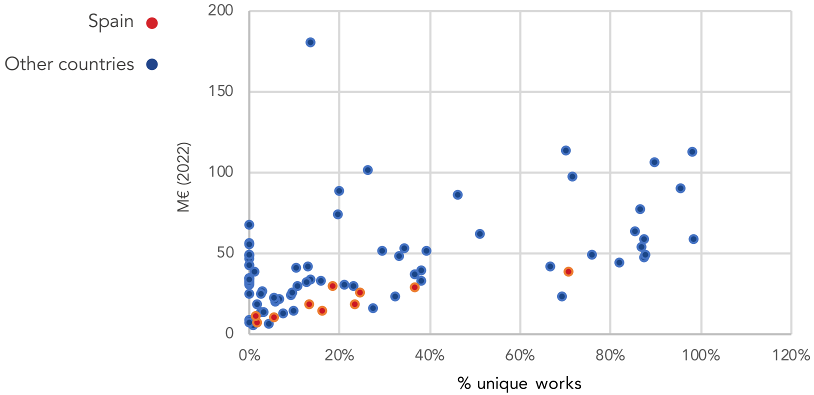
The cost of each line or project is largely determined, on the one hand, by the **design parameters** and track quality requirements, line speed; and, on the other hand, by the **orography** it crosses, in particular the investment required in singular works such as tunnels and viaducts. Both parameters are projected against the average cost in the following graphs.

Of the construction parameters, the one that has the greatest impact on construction cost is the **maximum design speed.** In this respect, Spain maintains a low average cost despite the fact that most of the projects analysed have a design speed of over 300 km/h[25], as can be seen in the left-hand panel of the graph above.

Cost/km vs. maximum design speed

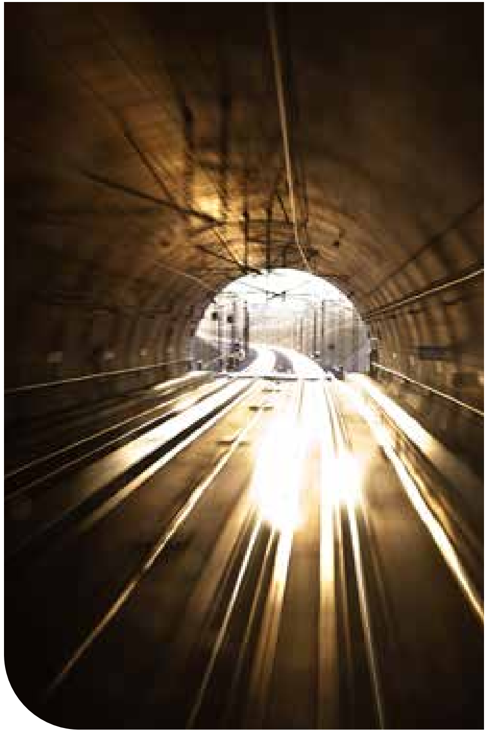


Cost/km vs. unique works



Furthermore, Spain has a significant **percentage of singular works** (tunnels and viaducts) and their cost is among the lowest of those analysed for each level of complexity (understanding complexity as the presence of tunnels and viaducts), as can be seen in the right-hand panel of the previous graph. Spain would be in the average level of complexity if we remove the clearly more mountainous countries (Austria and Switzerland), as well as the Asian countries, without forgetting that the extension of the network analysed is much greater[26].

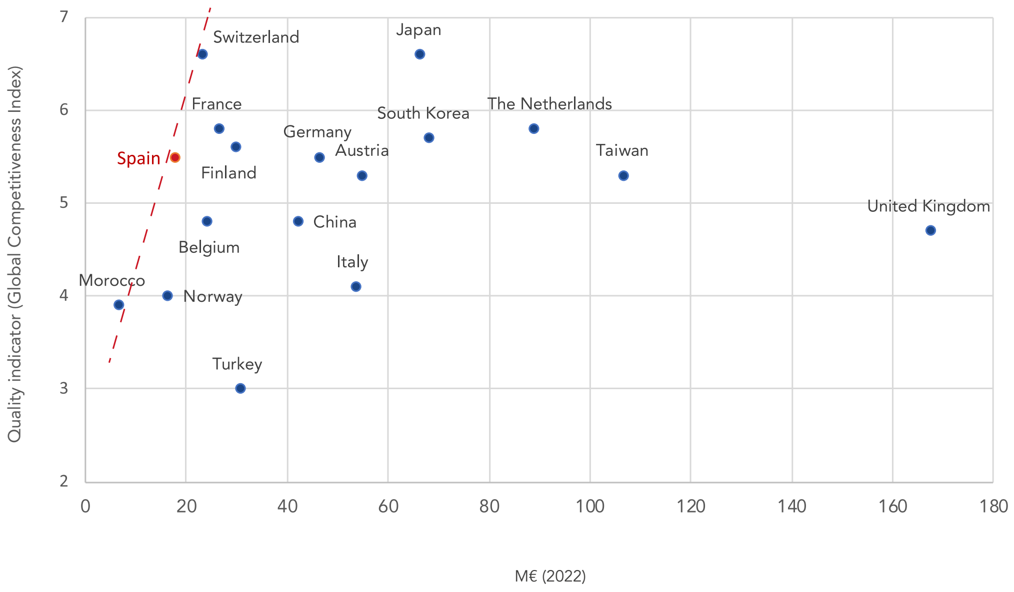
Likewise, the development of high-speed rail in Spain has been almost entirely carried out through the construction of new double-track platforms, whereas in other countries it has been based on existing platforms. However, as mentioned above, the database does not allow differentiating this characteristic.



Finally, in terms **of quality**, Spanish high-speed rail also stands out. The following graph represents the rail infrastructure quality index, published by the World Economic Forum as part of its Global Competitiveness Index[27], against the unit cost extracted from the Transit Costs Project database.

It can be seen that no country has a better quality-cost ratio than Spain, except perhaps Morocco and Switzerland, and that those countries that achieve higher scores in the quality index do so at the cost of more than proportional increases in their cost/km. It can be interpreted, therefore, that **Spain would be located at the technological frontier of possibilities for the quality-cost/km ratio and, within this frontier, at a balanced point.**

Quality index - cost/km (weighted)



In dashed line, the cost-quality maximising frontier.
Own elaboration based on data from WEF, Transit Costs Project.

2.3

Cost overruns and construction times

In terms of the construction process alone, Spain also comes off well.

There have been no excessive cost overruns in the construction of Spanish high-speed lines, despite the fact that the scale of these infrastructures means that unforeseen expenses crop up quite frequently. Moreover, Spain embarked on high-speed lines without major previous references, a fact that usually leads to **cost overruns,** sometimes up to several orders of magnitude, as is the case in other countries.

In this regard, **the European Court of Auditors (2018) estimated, for the projects analysed, an average cost overrun of 78% at the railway line level, while in Spain this value was around 33%[28].**

Moreover, in terms of construction times, Spain is also, on average, below the main European countries. Again, the European Court of Auditors (2018) estimates **the average number of years of construction work on the lines analysed in Spain at 15.5 years, while the European average is 18 years.**

2.4

Fiscal effort

A final aspect to be addressed in the analysis of Spanish efficiency in high-speed rail production is the **macroeconomic fiscal perspective** or fiscal effort.

According to OECD data[29], between 2000 and 2021 Spain invested €96 billion in nominal terms in all rail infrastructure (conventional and high-speed).

In the same period and in the same terms, Italy invested €120 billion, Germany €133 billion, France €149 billion and the United Kingdom €175 billion.

Average annual investment in rail infrastructure as a percentage of GDP.

Nominal Euros

	2000-2012		2013 - 2020	
Country	Average annual investment	% of GDP	Average annual investment	% of GDP
Europe*	39,884,042,638 €	0.32%	49,420,257,101 €	0.33%
Spain	5,759,769,231 €	0.59%	2,375,444,625 €	0.21%
Germany	4,931,461,538 €	0.21%	7,341,195,706 €	0.23%
France	4,516,881,146 €	0.24%	9,867,808,086 €	0.44%
Italy	6,481,692,308 €	0.43%	4,468,125,000 €	0.27%
United Kingdom	6,800,079,497 €	0.35%	12,416,085,805 €	0.51%

* Europe (European Union, United Kingdom, Norway and Switzerland).
Own elaboration based on data from OECD (railway infrastructure investment) and EUROSTAT (GDP).

Measured in terms of fiscal effort relative to GDP, Spain made a greater effort than the European average up to 2012. Specifically, 0.59% compared to the European average of 0.32%. From that year until the last year with homogeneous records (2021), Spain's fiscal effort in rail infrastructure investment fell to below the European average (0.21% compared to 0.33%).

The investment effort in rail infrastructure in Spain up to 2012 may be due, among other reasons, to the need to modernise and expand the rail network. According to AIReF (2020), **by 2017 Spain had converged with the main European countries in terms of rail capital endowment in relation to GDP.** Up to that year the major commissioning of the current network had taken place: Madrid-Barcelona-French border, Madrid-Valladolid, Cordoba-Malaga and Madrid-Levante. Furthermore, a large part of the investment in this period was earmarked for the commissioning that took place later or will take place soon: the Atlantic Axis, the lines to Galicia and Asturias (including the Pajares bypass), the Mediterranean Corridor, and the line running between Plasencia and Badajoz, among others.

Therefore, the analysis of Spanish efficiency in the production of high-speed infrastructure takes a macroeconomic view at the country level and not only line by line. Spain has increased the length of its high speed network by more than 8 times since 1992 and is already the first European country per kilometre of high speed, representing approximately one third of the European high speed network and almost a quarter of the entire network in execution or planned according to UIC data[30]. This **substantial modernisation in a short period of time has been achieved with an annual investment lower in absolute terms than in other European countries, and with a fiscal effort, per GDP, only slightly higher, so it can be considered a clear reflection of the efficiency of the sector.**

03

REASONS FOR THE PROVEN EFFICIENCY OF HIGH-SPEED DEVELOPMENT

In the previous point we have justified and documented how **Spain has managed to develop the most extensive high-speed network in the EU with the lowest average construction cost .** And how it has done so without penalising the cost of maintenance, which is in line with the rest of European countries.

Thus, there is enough evidence to affirm that **the global cost of Spanish high-speed lines, considering the complete life cycle of the infrastructure, is undeniably low.**

Likewise, the development of high-speed rail in Spain has been carried out with **very high design and quality parameters, at the forefront of the sector, in relatively quick times and without major budget deviations**, despite initially adverse physical and economic conditions. All this suggests that the country is clearly efficient in the construction of high-speed lines.

The transcendence and magnitude of this result makes it necessary to understand its origin in depth. Therefore, this section will delve into the possible causes that have led to this efficiency in the development of high speed, which, in any case, is a complex economic, social, technological and political phenomenon developed over more than three decades. The causes are multiple and their incidence varied[31].

This report first reviews the factors related to classical economic analysis and then analyses the cultural and socio-political factors, the institutional and technological context and dynamics, as well as the economic and financial framework surrounding high speed[32].

The methodology is based on the analysis of data and the review of specialised literature, completed with the description of paradigmatic cases of success and the dialogue with several protagonists of the last thirty years of Spanish high-speed railways.

Thus, the chapter starts with **the causes of lower costs from the point of view of classical economic analysis (point 3.1).** The following sections present political, social, cultural and technological factors whose impact on costs is less obvious or direct, but more important and far-reaching, and therefore cannot be ignored in any case.

This analysis begins by addressing **the social and political consensus that has characterised the development of high speed in Spain (point 3.2)** which, in addition to facilitating processes and reducing production costs, allows a major boost to be given by the public sector regardless of political cycles or territorial spheres. This generates a **public institutional and economic framework which acts as an essential axis for the success of the implementation of high speed in the country (point 3.3)**. This public impulse relies on a mature civil society and business sector ready to articulate and take advantage of a great modernising transformation in Spain: **a prepared human capital and a business sector with an appetite for growth and innovation (point 3.4)**. Finally, it analyses how this context of public impetus and maturity of the business sector allowed **the incorporation and development of its own technology, as well as the use of experience as a key element for the competence and success of the national railway sector (point 3.5).**

3.1

Direct economic factors

A first element of analysis of Spanish efficiency is that of the economic factors of direct impact: the cost of some inputs used in the development of high speed and the economies that may exist linked to size or scale.

Unit cost advantages of some inputs

One of the factors affecting the cost of building a railway line is the unit cost of each of the inputs necessary for its development. In general, the costs of some of these inputs are lower in Spain than in other high-speed railway construction countries. There are two main differential aspects: on the one hand, **labour costs** and, on the other hand, the **cost of land**. In both cases the cost for Spain is lower than in other countries on average.

With regard to labour costs (understood as wages plus taxes minus subsidies), based on data published in Eurostat, it can be seen that **Spain has an average hourly cost lower than that of the European Union (-23%), as well as with respect to the main European Union countries, such as Germany, France and Italy**. Specifically, in 2022, the labour cost in Spain will be 23.5 €/hour, compared to 30.5 €/hour in the European Union, as shown in the table below.

Labour costs in Spain compared with other countries and the European Union.

Nominal Euros

	2021		2022	
Country	Coste per hour	% of EU	Coste per hour	% of EU
European Union	29.0 €	-	30.5 €	-
Spain	22.9 €	- 21.0%	23.5 €	- 23.0%
Germany	37.4 €	29.0%	39.5 €	29.5%
France	39.3 €	35.5%	40.8 €	33.8%
Italy	28.8 €	-0.7%	29.4 €	-3.6%

Source: Eurostat and own elaboration

In accordance with the report prepared by AIReF (2020)[33], the labour costs of high-speed railways account for a percentage of the total costs that differs depending on whether it is the construction of new track or its operation and maintenance. **In construction costs, labour costs account for around 10% of the total, while in operation and maintenance costs they are higher and can reach 50%.**

With regard to the cost of the land on which the infrastructure or its services run, it is more difficult to measure this aspect in homogeneous terms with other countries. In any case, Eurostat data also show that **Spain has an average cost per hectare that is somewhat lower than the European Union average (-18.4%)**.

Cost of land in Spain compared to the European Union.

Nominal Euros

	2021		2022	
Country	Cost/hectare	% of EU	Cost/hectare	% of EU
European Union*	14.555,1 €	-	15.864,3 €	-
Spain	12.901,0 €	-11,4%	12.938,0 €	-18,4%

* Average based on published data from 23 Member States

The weight of costs associated with land acquisition, as estimated by the BBVA Foundation report (2012), usually represents between 5% and 10% of the total cost of the investment (however, this percentage includes planning costs for technical and economic feasibility studies).

The low population density in which a significant part of the high-speed rail network in Spain is developed is probably one of the main factors behind the lower cost of land in Spain. More than half of the kilometres of the high-speed lines in service run through the four central communities with the lowest population density (Aragón, Castilla y León, Castilla - La Mancha and Extremadura), which means lower land costs, lower costs for the replacement of affected services and less local opposition. The basically radial route followed until recently in the high-speed line has allowed these advantages compared to if it had started by connecting the most densely populated coastal areas[34]. The Spanish expropriation legislation, which reduces the blocking capacity of property owners, also influences land costs.

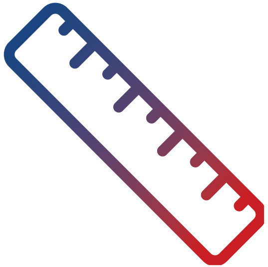
Spain does not have cost advantages in the rest of the major input items - such as energy or materials - given that these are goods that can be traded on international markets and whose prices reflect the world situation with minor fluctuations. There might even be some disadvantages for Spanish companies in some areas, such as energy and the logistical costs of positioning materials on construction sites.

In conclusion, **Spain has some advantage in labour and land costs compared to the EU average, but their weight in overall costs is small and therefore could explain, at most, a minor part of the cost advantage of Spanish high speed**.

Advantages of scale

Transport infrastructures are characterised by large economies of scale when considered as part of the complete transport value chain as a set of infrastructure costs plus the costs of transport operations or services. Economies of scale are understood as those that occur when unit costs are decreasing with respect to the level of production. In railway construction, this would translate into lower average unit costs of construction and maintenance as the volume of activity grows and spreads throughout the territory.

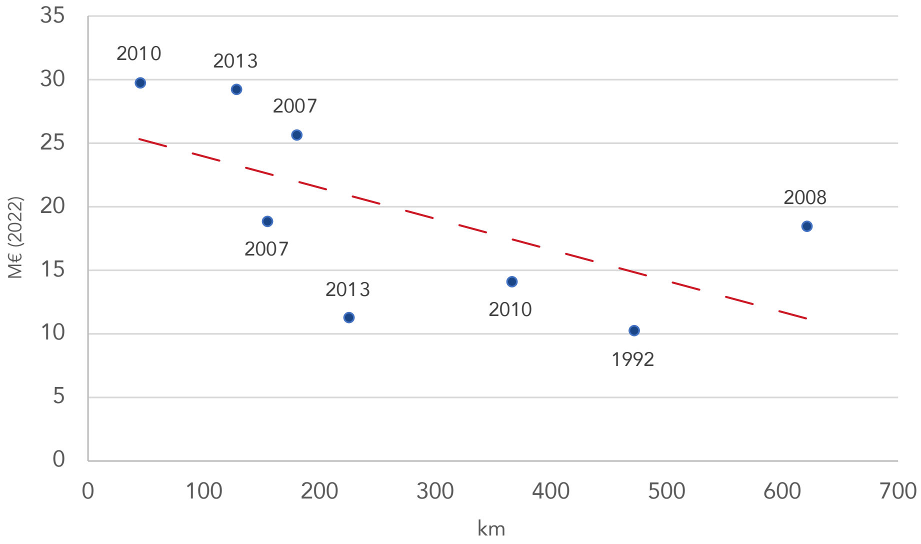
Traditionally, the economic literature has focused on the infrastructure and operation as a whole to study these economies of scale, scope or network. And, although construction itself is not a typical case, there are, and in the Spanish case perhaps more intensely so, certain processes that benefit from scale.



Thus, high-speed construction in Spain may have developed certain economies of scale given the magnitude of simultaneous works, especially in the period 2000-2010. These may have arisen from the efficiency generated by coordinating several projects at the same time, which also allows for the dilution of certain overheads. Likewise, by having a high volume of investment and activity in Spain, it has been possible to process contracts in sections, maintaining contracts of a size that allows the advantages of scale to be exploited, maintaining competitive pressure in the industry as a whole to reduce their unit cost.

In fact, it can be seen that there may be some evidence on this point. The following graph compares the unit cost of a high-speed line with its length. It can be seen that construction has been cheaper the longer the line was built. Moreover, it is worth noting that, except for the Madrid-Seville line, the rest of the cheapest actions were carried out simultaneously during the decade 2000-2010.

Cost / km versus line length



Own elaboration based on Transit Costs Project.

3.2

Social and political consensus

The growth of the infrastructure network in Spain in a relatively short period of time and, specifically, **the spectacular growth of the high-speed network, is facilitated by the broad social and political consensus generated around its development.**

This spirit has meant that changes of government have not affected the progress of actions which have not faced great resistance from other administrations or the citizens.

Spain entered the 1980s from a relative social, political and economic isolation that was combined with its peripheral situation with respect to European countries with greater economic and social development. The relative economic backwardness (with a GDP per capita in 1980 of 73% of the EU-15 average) was coupled with the delay in the development of the transport infrastructure network. The stock of public capital, in general, and in particular the infrastructure stock, was below the European average[35]. In 1980 Spain had only 1,933 km of motorways and dual carriageways, 79% of which were toll roads, while other countries already had the bulk of their network in place.

In this context, a desire was **generated in Spanish society for political and social openness and for economic development and integration, for which the construction of transport infrastructures was a symbol and a very appropriate means to achieve them.**

With Spain's incorporation into the European project in 1986 and the arrival of its funds and, subsequently, with the tax revenues of the expansionary economic cycle, the modernisation of the network was made possible. Investment in infrastructure remained somewhat higher than the European average until 2011 and beyond. This made it possible to close the gap in infrastructure provision with respect to Europe and put Spain in the well-known position of leadership that it currently holds[36].

During this period, milestones in the development of the network in Spain had great repercussions, among which the high-speed connection between Madrid and Seville in 1992, with a very innovative scheme, stands out.

This first line was a great success in terms of management, passenger numbers and media impact, so that, far from cooling the initial enthusiasm for transport infrastructures as happened elsewhere, it reinforced it, creating a benchmark for all the territories of Spain and laying the foundations for the subsequent growth of the Spanish High Speed.

The Madrid-Seville line was approached with a very clear and immovable service horizon, which put tension on all the agents involved in its achievement, sharpening the approach to solutions and processes, and avoiding rethinking or delayed uncertainties. **Its commercial and technical success made it clear that the new infrastructures had to be designed in accordance with high-speed parameters**.

A not insignificant aspect of this positive social and political context for infrastructures is that the **phenomenon labelled "NIMBYsmo" did not take root in Spain as elsewhere**[37]. This phenomenon translates into public opinion or local press opposition to the construction of infrastructures in their particular environment and is a key obstacle to the development of projects on time and at cost.

As indicated below in the section on HS2, in the UK, the design phase, including environmental studies, is developed with a view to strong scrutiny afterwards, so that even small technical decisions are documented in a very detailed and exhaustive manner. This significantly raises the costs already in this preliminary phase. Subsequently, both the representatives of the affected constituencies (in the UK small local authorities under the single representative system) and the local communities impose more costly technical solutions or high compensation packages on the project, which increase the cost.

In Spain, local requirements that raise the cost of actions have been increasing in recent years, although they are taking place in a context of generalised support for actions, which to a certain extent reduces the "bargaining power" of the local perspective.

The lower level of opposition from local communities to the actions in Spain is also favoured by the low population density of many of the areas through which the high speed train runs[38]. This lower density, as seen in the previous point, not only reduces local opposition, but also reduces the cost of the land and services affected.

This social and political consensus has also favoured in Spain the maintenance of a simplified expropriation legislation that allows for the acceleration of procedures with the declaration of the public utility of an intervention, and the streamlining of the administrative processes and public consultations involved. This is not to say that Spanish legislation does not provide guarantees and possibilities of appeal to expropriated owners, but its procedure is based on general legislation as opposed, for example, to the British case, or the prevailing Anglo-Saxon case, in which the effects on property require primary legislation for each project.

All the aspects reviewed in this section ultimately have a positive reflection on the production cost of the infrastructure.

This traditional scenario in Spain is evolving and legislation, processes and opinions are adapting to a more sophisticated and sensitive society. However, in Spain there is no "local" resistance to investment in the territories, but there are increasing demands and costs associated, for example, with widespread subterramientos and compensatory measures, a phenomenon sometimes labelled *YIMBYism*, which also presents risks.

In any case, it can be concluded that the Spanish high-speed railway continues to arouse a broad consensus based on the attributes that made it attractive to citizens since its launching in 1992: safe mobility with a much lower accident rate than the rest of land transport, innovative by applying the latest technological mobility systems and sustainable with the use of renewable energy.

3.3

The driving role of the public sector

High-speed rail in Spain has had, since its beginnings, a strong public commitment in a stable and continuous manner throughout the different political cycles and economic contexts.

The political support and leadership of the current Ministry of Transport, Mobility and Urban Agenda, the involvement of the infrastructure manager in the design and construction phases, and European and Spanish public funding have made the network possible.

3.3.1 MINISTRY LEADERSHIP

High-speed rail has been a priority of the Ministry since its inception in its different political stages and financial and economic contexts.

The Ministry is responsible for planning functions at all levels. In particular, the current Directorate General for Planning and Evaluation of the Railway Network is responsible for **railway planning in** accordance with the principles established by the strategic infrastructure plans, which are summarised in the so-called Indicative Railway Strategy. This department is also responsible for the elaboration and monitoring of feasibility and informative studies, the initial stage in the development of high-speed lines.

Adequate planning is a necessary, although not sufficient, condition for the success of an infrastructure programme. In this sense, political consensus in Spain provides **continuity and stability** in its objectives and implementation strategies, which is key to overcoming the historical deficiencies in terms of infrastructure compared to Europe.

On the other hand, the development of **high-speed rail has been adapted to the different financial and budgetary scenarios of the last 30 years, and despite the difficulties faced, the country's choice of high-speed rail has never been discarded.**

3.3.2 INVOLVEMENT OF THE PUBLIC ADMINISTRATOR (ADIF)

The Administrator of the Spanish General Interest Railway Network, Adif, or, more strictly speaking, the group formed by the state-owned commercial companies Adif and Adif Alta Velocidad, **has played a fundamental - and differential - role in the development of the current high-speed network**.

Its technical capacity, resources, functions, involvement and culture have led it to be a major player in the Spanish high-speed experience and to play **a different role from the one usually held by other network managers and other promoters or project leaders of high-speed railway initiatives.**

The first high-speed line between Madrid and Seville was built without the separation of infrastructure management and service operation. With the creation of the Gestor de Infraestructuras Ferroviarias (GIF), which later became Adif, the construction, maintenance and operation of the infrastructure was separated from the operation of services.

Adif is currently responsible for the design, construction, supervision and maintenance of the rail network, as well as for rail traffic management and the operation of infrastructure and stations. The **management model carried out in Spain by Adif is that of outsourcing the design and construction phases, but with very direct involvement**.

Adif technical training

Unlike other high-speed project promoters and even other network managers who standardise the complete delegation of technical management, even breaking down, diluting, stratifying and distributing responsibilities through complex procedures and contracts with third parties, Adif has, until now, relied on highly capable and qualified teams to assume direct responsibility for strategic, relevant and complex technical decisions. Made up of **a large number of engineers with experience and training in the different railway specialties or subsystems** (platform, track, energy, signalling, etc.), the team makes possible a strong involvement in the different phases of the actions, so that, once a contract is awarded, its technicians **establish a proactive dialogue with the engineers and specialists of the awarded companies. A dialogue that goes beyond the solution of day-to-day incidents in the works and looks for improvements or opportunities** in the execution, even if they were not initially contemplated.

This "face-to-face" dialogue between Adif and companies is widespread and is seen as normal and positive by Spanish companies. Its benefits are especially significant in highly complex singular actions such as tunnels and viaducts.

Due to its **design standards** and the **orographic complexity** of the country, the Spanish network has important **singular actions**. An example of this are the **tunnels**. The Guadarrama tunnel (28 km) or the Pajares tunnel (25 km) were executed through several contracts and direct involvement of Adif in the coordination and overcoming of incidents, as well as in the development of *in situ* innovations, so that the execution itself had relatively minor deviations for what are usually such outstanding actions.

The Spanish network also h**as some unique viaducts**. The Ulla Viaduct (Galicia), with a 117 m pillar and a 105 m high central arch, the Deza Viaduct (Galicia), built using a very precise and complex system by progressively lowering both arches, or the Contreras Viaduct (AV Levante), one of the largest concrete arch bridges (261 m span), are a reflection of several of the differential aspects of the 'Adif model' of Spanish high-speed development.

These complex and outstanding infrastructure worksare normally implemented through different contracts and even different sections Their execution also responds to the engineering capacity of the construction companies and Adif itself, as each incident or setback does not usually entail litigation and stoppages.

Other technical challenges on the Spanish network also reflect the team involvement of several actors, such as automatic gauge changes for passenger trains with sliding track running on both gauges (UIC/Iberian), operated at 30 km/h.

Milestones in the development of innovations and performance on the network are largely the result of this framework of collaboration and involvement of Adif, such as the speed of turnouts (350 km/h turnouts on direct track, and 220 km/h to deviated); the laying of track on ballast at a rate of more than 3.3,000 m single track/day; high-speed overhead contact line certification (350 km/h + 10%) according to European Technical Specifications for Interoperability (TSI); nationally designed 2x25 kV AC substations for high speed; or maintenance technology including laboratory and auscultation trains.

All these elements, developed in the high-speed network, were not designed cold before their execution, but their design was perfected as the network was executed, without major litigation, cost overruns or stoppages.

Adif's technical capacity has an impact on the different phases of the actions, not only during the execution of contracts. Thus, in the **design phases** based on the informative studies prepared by the Ministry, traditionally with tighter deadlines in Spain than in other countries, and subsequently in the drafting of basic and construction projects, Adif provides expert views and dialogue with the engineering companies.

During the **procurement phase** itself, the drafting of tender documents and the evaluation of bids benefit from this technical capacity, which will ultimately lead to cost reductions. Also on the financing side, costing and operation benefit from this technical capacity.

In short, Adif's technical profile allows it to adopt a highly qualified project or works management role in each action.

On the other hand, **Adif's involvement in the thousands of contracts that make up the Spanish high-speed network for more than 30 years has allowed it to raise profits from the strict perimeter of each contract or work**

to the management of the creation of the network as a whole.

Thus, standards have been developed that apply to various contracts relating to sleepers, types of catenary and a multitude of components and systems, reducing their cost. Procedures have also been developed for the coordination of the execution, safety and commissioning of the different systems of a section, even if they are executed by different companies; a proprietary network management system - DaVinci System - or world leadership in the implementation of ERTMS level II, among other synergies exploited.

This strength of Adif implies an advantage that goes beyond the strictly technical aspect: it **allows it to have a better negotiating position at the level of each contract and in the development of the entire network vis-à-vis construction and engineering companies**. In economic terms, the asymmetry of information between the public and private sectors is reduced, which is in the public interest.

Ultimately, Adif's technical capacity is based on the country's human and technological capital as a whole and on a public commitment to provide the administrator with the resources and functions to be configured with this outstanding profile. It is worth mentioning, in this line, that Ineco, as the Administration's own means and a company owned by Adif and Adif Alta Velocidad, has been key in this matter.

Public engineering companies are not a differential aspect of Spain, as they also exist in other European countries. But the fact that Adif has been able to count on the flexibility and agility of a company such as Ineco and that its staff has participated in the culture of involvement in Adif's works has reinforced the technical relevance of the public sector which, combined with the skills of private construction companies and engineering firms, has led to a versatile and efficient model in the development of high-speed rail.

Flexible contract management model

Another frequently cited factor in the Spanish case is the different weight of the different phases in the development of the infrastructure and, consequently, the different weight of the companies involved in these phases.

Generally, in Spain the **design phase** (basically comprising the informative studies and the project and its sub-processes of environmental assessment and public consultation) **is quicker and shorter than in Anglo-Saxon countries** and less detailed.

This, which, a priori, could be presented as an institutional weakness, has proven not to be so. The construction companies and the contract management (Adif) have the technical capacity to deal with unforeseen events and to make up for aspects not addressed in the design phase with the experience and knowledge of the public authorities and the companies in later phases.

In short, **if there is a high technical capacity in the execution phase of the work (which requires technically qualified construction**

companies, technical assistance and equally qualified works management by the network manager), it may be more advantageous to articulate detailed solutions to unforeseen events in the execution phase compatible with the necessary rigorous approach to the previous phases, even if these do not address all possible unforeseen events.

This distribution of technical expertise throughout all phases of the infrastructure life cycle, instead of concentrating it all in the design phase, can also represent an institutional advantage by balancing the bargaining power between the actors and breaking with a certain technological monopoly of the engineering firms that occurs in Anglo-Saxon countries.

The European Union, probably sensitive to this situation, legislated in this direction (through Directive 2004/18/EC and then by Directive 2014/24/EC)[39] a new procurement method for "particularly complex projects", through the so-called "competitive dialogue".

This rebalancing of phases that has been taking place in Spain also seems to be in line with the latest trends in optimal contractual design for infrastructure investments under the umbrella of the term **early contractor involvement**. This principle requires flexibility and involvement of the contractor in detecting possible improvements or changes in order to prevent setbacks or readjustments from resulting in cost overruns or stoppages. It is therefore suitable for long and complex projects such as high-speed rail projects.

One of the elements that has driven this flexible management of high-speed contracts in Spain is the relatively **low judicialisation** derived from contractual modifications or addenda, in comparison with other models such as the Anglo-Saxon one, which require more resources, time and energy to resolve these obstacles through the courts. However, recent years seem to point to an increase in judicialisation also in Spain, which remains, in any case, below that prevailing in Anglo-Saxon countries.

Another new element that may affect flexible contract management is the standardisation of management and planning techniques for BIM (*Building Information Modelling*) methodologies, which could reinforce the Anglo-Saxon model to the detriment of the Spanish flexible model.

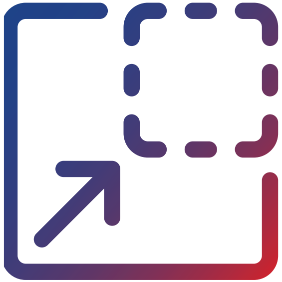
The future is likely to be somewhere in the middle or somewhere in between. Although the application of BIM procedures and the judicialisation of conflicts reduce the space for flexible ad hoc solutions, works will always require the capacity to react "at any given moment", so some intermediate option along the lines of *early contractor involvement*, and taking advantage of BIM methodologies for the efficient management of assets, detecting collisions and overlaps between actions in advance, could integrate this path for the future.

Contracts with adjusted amounts: contract processing

In Spain, the development and tendering strategy developed by Adif has consisted in the execution of the network through contracts of relatively small amounts (compared to the total investment volume). An aspect linked to the previous point of flexible contract management.

This is known as the **"staging" of works contracts**[40], **which consists of segmenting the railway line into several contracts by sections, the length of which depends on the specialities and orography so that their size allows the advantages of scale to be exploited, but does not lead to excessive concentration**. Thus, for the platform, the sections can be from about 10 to 15 km in simple terrain to only 2 km or less in complicated terrain. For other specialities, the sections are larger: for example, in track and equipment or electrification. In general, the dimension of the sections takes into account the minimum efficient dimension implied by the technology.

Articulation through multiple contracts allows firstly to reduce the systemic risk of some incidences (such as a company going bankrupt or the spread of delays); it increases



the short-term competitive pressure in each tender (more possible bidders), and also generates a more competitive ecosystem of companies or industry sector in the long term (less tendency to control and hoard know-how, technologies and expertise).

The implementation of this contract model requires the infrastructure manager to have the administrative capacity to manage many contracts at the same time and reinforced technical coordination so that the participation of different companies does not lead to conflicts or inefficiencies. Adif's capacity to provide itself with resources for administrative management by assigning them prominence and relevance is critical for this to happen.

An example of this coordination is the strategy of direct purchases by Adif, which is sometimes applied. In these cases, it is not the contractor who buys certain materials or inputs, but Adif does so directly, reducing double marginalisation, obtaining better prices due to its position in the market and being able to coordinate logistical operations, priorities and supplies.

Direct purchasing is not widely applied as it also reduces the positive effects of market play and may reduce incentives and advantages of some suppliers. But a balanced use has proven to have positive effects on the product quality-cost-benefit ratio.

Learning and standardisation of processes in Spanish high-speed railways

Linked to this strategy of relatively small contracts is the so-called standardisation of processes in the development of the Spanish high-speed network. **With frequent tendering processes, the administrator itself can capitalise on previous experiences and transfer them to specific aspects of the tender specifications. Contractors are also more likely to transfer the lessons learnt to their tenders.**

Adif has always maintained a position of respect for technological neutrality, but at the same time has ensured that the specifications at all times are compatible with the standards required for the coherence and efficiency of the network and with the state of the art. And that technological progress in the different specialities is not exclusively favoured by a single or a small number of suppliers.

In this way, the knowledge and experience that Adif (supported in many cases by Ineco[41]) generates is integrated into the general acquis by being incorporated into the specifications themselves and made accessible to the industry as a whole.

The knowledge generated in the 30 years of high-speed rail thus does not remain exclusively in a few companies. Adif retains an important part of this knowledge and shares it with construction and engineering companies.

Smaller contracts are also to a large extent simpler and their incidents more manageable. Contracts in the same category are similar and therefore more standardisable in many respects (reference costs, deadlines, evaluation criteria).

3.3.3 EUROPEAN FUNDING

It would be neither fair nor rigorous to refer to the development of the Spanish high-speed railway without mentioning European funding.

The importance of European funding (incorporated into the cost) is not limited exclusively to the magnitude of the funds granted, which reduce the Spanish taxpayer's fiscal effort (although in this study all costs are taken into account regardless of their origin), but this funding entails specific requirements and procedures (planning, evaluation, management and monitoring) that could have some relevance and generate greater efficiency in the use of resources.

European funds have played a major role in investment in transport infrastructure. According to data provided by the Directorate General for European Funds[42], 76% of the aid received by Spain through the Cohesion Fund and the Regional Development Fund (ERDF) between 2000 and 2020 was devoted to building transport facilities.

Specifically, the EU has invested 57,641 million euros between 2000 and 2020 for the construction of transport infrastructure in Spain. The importance of this aid has been decreasing with each financial framework, being 36% in the 2000-2006 period, 16% in 2007-2013 and 6% in the 2014-2020 framework.

Infrastructure investment in Spain.
Nominal Euros

Financial framework	Total investment	European aid	%
2000-2006	98,075,381,136 €	35,105,802,347 €	36%
2007-2013	122,517,481,427 €	20,131,883,604 €	16%
2014-2020	38,317,922,743 €	2,403,786,899 €	6%

Source: Airef (2020)

With regard to investment in high-speed rail, in the periods 2000-2006 and 2007-2013 the aid received from the Cohesion Fund, the European Regional Development Fund (ERDF) and the TEN-T aid amounted to 11,146 million euros[43].

Of the approximately 57.2 billion euros invested by Adif in Spanish high-speed rail, 20.8% was financed by European grants and 21.8% by EIB loans. The percentage of high-speed investment financed by European funds has been decreasing over time, although with the approval of the Recovery, Transformation and Resilience Plan, this financing will increase again until the end of the plan's horizon in 2026.

It should be noted that Spain has generally performed comparatively well in the use of these funds (with some criticisms), as evidenced in reports by the Commission and other independent bodies.

In general terms, Spain has materialised a high percentage of its European Structural Funds expenditure commitments. Understanding the absorption rate as total payments divided by total commitments, Spain has executed around 92%[44] of its spending commitments in the 2000-2006 and 2007-2013 European programmes, a figure similar in percentage to France and Germany (with smaller absolute amounts of funds), and higher than Italy, which also had a high volume of funding like Spain.

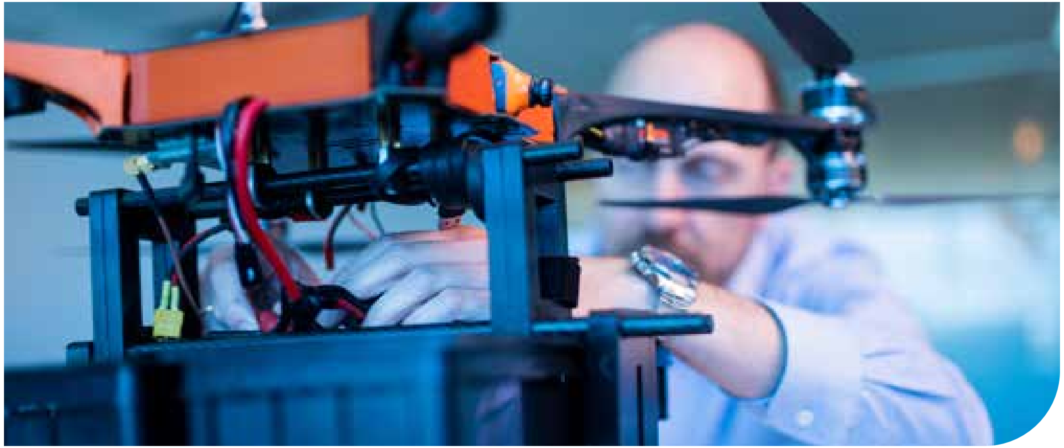
To a large extent, Spain's relatively good use of European funds may reflect the strong political consensus in Spain on the importance of advancing high-speed rail and European integration since the 1980s.

3.4

Business sector capacity

The impetus given by the public sector lies in a society that is more modern and open to change.

On the one hand, citizens, especially the new generations, were more highly qualified and technically prepared and, on the other hand, the business sector had developed a greater predisposition and capacity to incorporate and develop technologies and to open up to the outside world. These key factors for the success of the Spanish high-speed experience are developed here.



3.4.1 SPANISH ENGINEERING

Spain currently has many engineers in its various branches with good theoretical training and professional skills, as well as a large number of companies specialising in the provision of engineering services, and industrial and construction companies with high technical qualifications.

According to the Observatorio de la Ingeniera de España (Spanish Engineering Observatory)[45], in 2022, there were some 750,000 engineers in Spain, a rate of 15.7 engineers per 1,000 inhabitants, somewhat above the European average. This value exceeds the density of engineers in other European countries such as France and Italy, although it is somewhat below that of countries with a high industrial weight such as Germany. It should also be noted that according to this study, 40% of graduates in 2022 will be under 35 years of age and 73% under 45 years of age. Therefore, although in recent years, as in the rest of the Western world, there has been a downward trend in enrolments in engineering schools and in the number of graduates[46] - which is important to counteract because more are needed - Spain has a young population trained in technical disciplines and, in general, in STEM disciplines that will enable it to face the medium-term challenges in a wide range of technical activities, including civil engineering.

Most of **engineering graduates are active in the exercise of their profession in some activity linked to their training** and, for the most part (60%), they work **in large companies with more than 250 employees, which are the most productive**. There is also a large sector of smaller engineering companies (with fewer than 50 employees) specialising in some activity or local area or which are recent companies (start-ups) in a very dynamic context[47].

Academic education in the engineering degree in Spain is essentially based on the numerous higher technical schools of engineering in the universities which, in many cases, trace their origins back to earlier institutions, so that the training has a long tradition and prestige that is recognised internationally as shown by some international rankings and, above all, by the number of graduates who work in engineering companies all over the world or who work in Spanish companies but on projects in other countries.

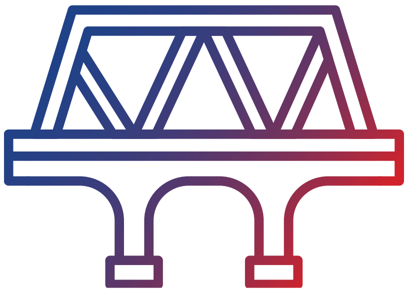
Thus, **university engineering degrees in Spain are well positioned in international rankings**. For example, the Academic Ranking of World Universities (ARWU), better known as the "Shanghai Ranking[48]", places the Universidad Politécnica de Madrid (UPM) as the sixth best university in the area of Civil Engineering. The QS World University Rankings by Subject 2023 (QS World University Rankings by Subject 2023)[49] also places two Spanish universities (UPM and Universidad Politécnica de Cataluña) among the top 100 in the areas of engineering and technology.

This quality of training produces professionals who are of particular benefit to the transport system. By way of example, it is worth noting that the route designed by Ineco for the preliminary project of the Madrid - Barcelona high-speed line in 1975 is practically the same as the one built decades later[50].

In addition, in the field of railway training, specific training courses have been created to provide comprehensive knowledge of the sector. The industry, engineering companies and the rest of the actors in the sector require qualified personnel due to both the high technological content and the strong momentum of transformation and digitisation that is taking place. There is a wide variety of high-level courses, such as the Master's Degree in Railway Systems[51] offered by the University of Comillas or the Master's Degree in Railway Systems Engineering[52], offered by UC3M and Alstom.

This training also allows Spanish engineers to enter the **market with a very good acceptance by the international business world**.

One area where this international welcome is most evident is in civil engineering, which has around 60,000 graduates, a significant number of whom work in international companies or on international projects. According to the Spanish Civil Engineering Association, "3,000 of the 26,000 civil engineers registered in Spain work on major projects around the world, both in Spanish companies and in those of other countries. This does not happen in any other profession, nor in any other country, and has been the case for more than three decades".



3.4.2 SPANISH CONSTRUCTION AND ENGINEERING COMPANIES

The relationship between the development of high-speed rail - and, in general, between the development of transport infrastructure in recent decades - and the growth and maturity of a private sector of companies in engineering as well as in construction and specialised industry, has been one of synergy and clear mutual reinforcement.

The high levels of public investment in transport infrastructure, and specifically in high-speed rail, have allowed many existing and new companies to acquire experience and know-how, to capitalise financially, and to grow inside and outside Spain. The result is a powerful railway industrial fabric, technologically advanced and with a long-term vision. **Unitedlly, this more competitive and modern industrial fabric has resulted in the efficiency of the construction and maintenance of the network** addressed in this study.

Construction companies

Over the last three decades, Spanish large-scale infrastructure construction companies with high technical, financial and organisational skills have expanded their business with great success, often winning international tenders for major projects.

The internationalisation process of Spanish companies has been going on for a long time, from their historical presence in geographies such as Latin America and North Africa to their more recent consolidation in highly competitive markets such as the Middle East, India, Australia, the United States and Canada. Currently, more than 80% of the portfolio of large Spanish construction companies is located abroad, in some 100 countries.[53]

The international media are echoing Spain's success abroad. **In terms of construction companies, according to the latest report on the 100 largest construction companies in the world by Deloitte[54], Spain has 7 companies in the ranking - 4 among the 50 largest - with a combined turnover of 75,096 million dollars** (ACS, Acciona, FCC, Ferrovial, Sacyr, OHLA and Grupo San José) and sixth place in terms of countries, behind China, Japan, the USA, France and South Korea.

Ranking of Spanish construction companies

Ranking 2022	Company	Revenue (USD million)	% 2022/2021
12	ACS	35,412	7.5%
33	ACCIONA	12,863	34.2%
43	FCC	8,118	3.0%
46	FERROVIAL	7,954	-0.8%
53	SACYR	6,165	11.5%
79	OHL	3,434	4.4%
98	SAN JOSE BUSINESS GROUP	1,150	4.8%

Source: Global Powers of Construction 2022 prepared by Deloitte

Another frequently cited ranking is that of Public Works Financing[55], according to which three of the five largest concession groups in the world in the field of transport infrastructure are Spanish (Abertis, Sacyr and ACS) in terms of number of projects.

Engineering

On a comparative level, the weight of Spanish engineering companies is different from that of the Anglo-Saxon model. **While in the Spanish case, the technological and engineering weight of a project falls both on pure engineering companies and on the Public Administration and construction companies, in the Anglo-Saxon model, private sector engineering companies assume this function almost exclusively**. Thus, in the Spanish model, it is more common to find technical experts in both the Administration and the civil works construction sector.

This does not imply a subordinate or degraded role for Spanish engineering. On the contrary, the Spanish engineering sector plays a fundamental role in technological innovation and international success. There are approximately 1,500 engineering companies in Spain, of which around 100 are large or medium-sized (employing most of the technicians working in the sector), many of these larger companies, and some of the smaller ones are highly internationalised.

Thus, **the prestigious American magazine Engineering News Record (ENR) has placed eight Spanish firms in the top 225 of its ranking of engineering companies by level of revenue generated outside the domestic market**[56], including Ineco, along with the other major companies in the sector.

Furthermore, the Spanish engineering sector has a great capacity for innovation. Proof of this advanced technological development is the participation of Spanish companies in numerous projects developed under the European umbrella Shift2Rail, working to improve the quality of the railway of the future.

As a result, many of the most important transport engineering projects of recent times have at least some Spanish participation, especially in high-speed projects, some of which are highlighted in the box below.

Ineco - High-speed rail corridor running through the coastal and desert areas of Saudi Arabia between Makkah and Medina.

The contract consists of providing engineering and consultancy services for the project, which is expected to carry 166,000 passengers a day at peak periods, with the most modern technology and the lowest possible environmental impact. The line will have 35 trains with a capacity for more than 450 passengers each.

Ineco - Mayan Train that will connect the main regions of the Yucatan Peninsula: Campeche, Chiapas, Tabasco, Quintana Roo and Yucatan.

The contract consists of performing the shadow operator duties for the Mexican Tren Maya, with approximately 1 550 km of track. The Shadow Operator will be in charge of reviewing the basic engineering of the entire project, defining the operation requirements and technical specifications of the rolling stock and railway systems, verifying that the maintenance requirements are consistent with the operations plan approach.

Idom - Electrification of the high-speed Rail Baltica line

The contract consists of the successful introduction and implementation of the energy subsystem for the entire Rail Baltica network, with some 870 km of track and 11 service sections.

Ayesa - Management and supervision of the entire high-speed rail corridor for the people of Delhi (India)

The contract covers from the tendering and design phase, through inspection and statutory approvals, to commissioning and initial operation.

Typsa - Tunnel construction on HS2 London-Birmingham high-speed line

The contract consists of the preparation of the basic design as well as the construction of lots S1 (Euston Tunnels and approaches) and S2 (Northolt Tunnels). In total, the construction of 24.4 km included in London to allow a maximum design speed of 320 km/hour.

Sener - Specialised engineering and construction management support HS2 London-Birmingham

The contract consists of specialist engineering and construction management support and assistance in the preparation of the procurement of the major civil works packages for the London to Birmingham section of the route. The proposed London to Birmingham line will be approximately 140 miles (225 km) in length.

Spanish railway and high-speed rail industry

Beyond construction and engineering companies, high-speed rail supports a wide and diverse industrial and economic fabric. According to Adif, in Spain there are more than 600 companies involved in the development of the railway network, of which some 220 companies are exclusively or predominantly focused on the railway sector. It is noteworthy that 75% of these companies are state-owned, a fact favoured by Adif's management and contracting strategy, which prevents an excessive concentration of technology and activity and opens the benefits of Spanish high-speed development to a wider range of companies.

This sector is made up of consultancies and engineering companies of great prestige and international scope of activity; construction companies, among which are all the large Spanish civil works construction companies and a significant number of smaller, more specialised or territorial companies. In addition, there is a broad spectrum of specialised companies such as components, maintenance, equipment, track, etc.[57]

The Spanish sector has accumulated a great deal of experience in the design, construction and management of large high-speed railway projects and in the management of railway services and integration systems, which is why **the sector, often in collaboration with Ineco or with the administrator Adif itself, has been able to grow and expand throughout the world.**

An increasing number of Spanish companies, either individually or in consortia, are participating in emblematic international projects. Spain exports civil engineering, consultancy, high-speed infrastructure signalling, communications technology, traffic management, etc.

Spanish companies are now clearly in the leading group in terms of knowledge, experience and technology. This leading position is the result of years of hard work and a commitment to specialisation, investment in R&D and service excellence. Moreover, all the major international groups have cutting-edge centres of excellence in Spain that are world leaders, enabling them to innovate, manufacture and export from Spain all over the world.

3.5

Incorporation and development of proprietary technology and learning experience

The development of high-speed rail in Spain has been important throughout the country, leading to a continuous technological and efficiency evolution in the entire railway sector. This development has contributed to the creation of the **Spain Brand**, where high speed is one of the spearheads.

It is important to highlight that, in the development of the Spanish High- Speed network, unlike other countries, the **concept of equity and territorial development has prevailed over the** problems of congestion or connection of production centres, without ruling out other purposes linked to mobility, productivity, technology, economic growth and European integration.

3.5.1 THE BEGINNINGS OF HIGH-SPEED RAIL IN SPAIN: MADRID-SEVILLE

The first time high-speed rail was considered in Spain was between 1972 and 1975, and it was precisely with the support of Ineco. The public engineering company carried out a feasibility study for the establishment of a new international gauge railway line between Madrid-Barcelona and Port-Bou, the layout design of which was maintained, to a large extent, later in the preparation of the preliminary project of the line in 1975 and in its construction.

Subsequently, the Government evolved towards a much more ambitious objective and extended

to the whole territory the construction of a new and modern railway network to be integrated with the future European high-speed network in Spanish technology and innovation will play a decisive role.

In 1986 the idea of a high-speed line was conceived with the NAFA (New Railway Access to Andalusia) between the Ministry, Renfe and Ineco, which would end up being the first high-speed line in Spain, Madrid-Seville (1992). This first high-speed line was approached with a very clear and immovable milestone, the inauguration of the Universal Exhibition 'Sevilla 92', and the planned timetable was met when the line was put into commercial service on April 21st, one day after the inauguration of the Exhibition. As a result, the challenge of constructing an innovative infrastructure in record time was achieved, constituting Spain's greatest railway engineering work to date.

Spain was the fourth country in the world to bet on high-speed rail (after Japan with the Tokyo-Osaka line in 1964, France with the Paris-Lyon line in 1981 and Germany with the Hanover-

Würzburg line in 1991). And it did it in record time. **This colossal project, a new 471 km line, in European gauge and designed for speeds of 250 km/h**, but suitable up to 300 km/h, was completed in about 5 years and has been used by more than 100 million passengers to date.

This **first line of the Madrid-Seville HS line** began to be designed in 1,668 mm gauge, but during its development it was changed to the then so-called international gauge (1,435 mm), different from those implemented in the rest of the national network, for which at this early stage there was no other choice but to resort to imported models and technologies.

For the construction of this first line, it was necessary to overcome the complex orography that connected the Meseta with Andalusia, trying to avoid the collapse of the Despeñaperros Natural Park, with gradients of more than 500 m in height. **The development of this line was a work of a magnitude far greater than any previously carried out in transport engineering in Spain**, influencing the creation of the Spain Brand.

The difficulty in the construction of this line was enormous, from the absence of regulations for the definition of parameters and elements to the execution in the so-called international gauge, different to that implemented in the rest of the network. These difficulties meant many complications, but also **opportunities in the development of its own technology and regulations**.

In this way, something extraordinary was achieved: the **construction of one of the few lines in the world to open on schedule (21 April 1992)**.

3.5.2 DEVELOPMENT OF PROPRIETARY TECHNOLOGY THROUGH NETWORK EXTENSION

This eagerness to overcome challenges and the success of the Madrid-Seville line laid the foundations for the subsequent development of an extensive, comprehensive high-speed network of its own and, above all, connected with the rest of the European network.

The challenge of expanding and building a new network in the late 1990s creates two major opportunities:

- To take advantage of a **significant volume of investment** in the short term.
- To develop **own technology**, which generates lasting wealth not only through the wealth created by the transport system itself, but also through strategic leadership and the capacity to treasure exportable knowledge..

Thus began a paradigm shift based on the capacity of Spanish engineering to assume historical leadership, independent of other proven **models** such as the French and German ones.

In 1998, several fundamental documents for the definition of high-speed rail in Spain, based on experiences in other countries, such as the **Project Drafting Manual**, which mainly defined the functions of the Project Management and the content of the projects, followed by the 1999 **Manual of Instructions and General Recommendations** and the **Technological Definition** of high-speed track, both produced by Ineco-Tifsa, which served as a starting point for the subsequent creation and successive adaptation until today of an extensive set of railway reference regulations.

The new network that arose after the Madrid-Seville line came into service was conceived, unlike other administrations, with new double-track platforms suitable for speeds of around 350 km/h (maximum speed of 403.7 km/h[58] and 385 km/h in tunnels). This is how the planning and project for the Madrid-Barcelona line began, with the need to make its operation compatible with the rest of the Iberian gauge network. This required an initial technological development of its own, such as the **evolution of elements for the compatibility of the two gauges**.

Automatic gauge changers were created, allowing trains with sliding track (the Spanish rolling stock industry adapted to this need and designed the Talgo and CAF sliding track axles for passengers) to change gauge while running in a short period of time and without the need to stop. The gauge changeover industry has evolved considerably in Spain from the first ones installed on the Madrid-Barcelona line to the present day, where almost 100 gauge changeover operations are carried out every day. In other cases, **three-rail tracks are designed to allow both gauges to run on the same track**, which, although not high-speed, allow the high performance network to be extended with a lower investment.

Eliminating critical roads becomes an ongoing challenge, starting with the supply of materials, in an environment where production and logistics suffer from the 1992-1996 hiatus in civil engineering activity and where the difference in widths adds difficulties unknown to other administrations.

Logistics

The logistics of the construction of the new high-speed lines completely changed the traditional approach, where the materials for the superstructure were mostly transported by rail, the track gauge was the same, and they were also included in the works contracts.

Adif assumed responsibility for the result from the outset. As a sign of this involvement and leadership, in order to optimise both the deadlines and the quality of the materials, **Adif directly manages their production, quality and transport with the support of Ineco. This leadership is due to the need to control one of the main critical paths of the project, with advantages that outweigh the risk of possible claims in the event of failure of the supply chain by the contractors of the works**. Exquisite planning is required, seeking to combine locations and modes of transport.

Most of the materials are transported directly by road to the assembly bases, stockpiles or the track itself, except for the rails and switches and crossings, which are transported by rail to the assembly bases with access to the national network on Iberian gauge and to the new network on international gauge. Most of these bases have become maintenance bases, in such a way that the economic dynamism generated by construction in the surrounding area is converted into lasting wealth during operation.

Industrial development and performance

All these needs have a direct impact on the productive fabric, **increasing the production of some factories or the appearance of new ones, specialising personnel in both design and construction, increasing the fleet of machinery, transport, etc. in such a way that it has been possible to achieve the supply performance necessary for the execution of several high-speed lines in parallel.**

The **execution** of the lines also implements our own methods adapted to the casuistry of our lines. **Track construction methods have been developed and patented that achieve a 5-fold increase in track assembly performance compared to those used on the Madrid-Seville line.** This increase in performance is mainly due to the use of a rail unloading gantry on the definitive sleepers instead of using auxiliary track, a method developed by TECSA, going from assembling some 4,000 m per week to some 4,000 m per day. **The assembly of** high-speed **track equipment** has also been **improved**, from being assembled with heavy cranes to small gantries, which optimise means, resources, quality, safety and, therefore, execution costs.

Safety

The integral chain of the project, production, logistics, transfer of materials, construction and commissioning, in which different companies and techniques work in parallel, puts the focus on a relevant and important aspect: **safety**. A unique, impartial and expert management of rail traffic during the works is necessary, guaranteeing the arrival of materials to the site in time and form, organising track occupation, regulating on-site traffic with the most productive scenario at all times.

A specific system is thus created, specific regulations are developed, training requirements are implemented for the personnel involved, etc. All of this is led by expert teams from Adif and Ineco.

Tunnels

In the construction of tunnels, the most advanced methodologies available at the time were used; the use of TBM machines increased very rapidly: in urban works in general, and in railway tunnels with lengths of more than 5-6 km.

Thanks to the use of tunnel boring machines and the experience in their use, tunnel construction performance has been extraordinary, reaching finished tunnel productions of more than 1,000 m per month (tunnels of La Cabrera[59] located on the Madrid-Valencia high-speed railway line) and Sorbas[60] located on the Madrid-Almeria high-speed railway line).

Electrification

With the introduction of high-speed trains, electrification switched to the **2 x 25 kV system at 50 Hz**. The conductors have a smaller cross-section, the structures are lighter and therefore more economical, **and the distance between substations has increased significantly, making it possible to make better use of the public high-voltage network**.

Following the Madrid-Seville LAV, Spanish technology companies acquired know-how for the development of a Spanish-branded contact airline, the **EAC-350,** which has evolved into the **C-350**[61], of entirely national design.

ERTMS system

Spain is a pioneer in the implementation of the **ERTMS** system. In 2006, the system was put into service on the Madrid-Lleida line, the second line with ERTMS in Europe. This was a milestone in the modernisation and digitisation of the network and the fleet, which has enabled Spanish high-speed lines to be at the forefront and a European benchmark for digital railways.

After that first line, the progress in the deployment of the ERTMS system has not stopped in Spain. More than 2,700 km have now been equipped, making Spain the European country with the most ERTMS kilometres.

Spain has served as a testing ground for the system for the whole of Europe, demonstrating the interoperability of ERTMS by contracting the equipment to different technologists, promoting competition, independence and allowing trains from different manufacturers to run. The rapid expansion of ERTMS shows Spain's commitment to interoperability and European rail integration, without which rail in Europe has little future. It is an example that it would be desirable for other European countries to follow.

The lessons learned during this process have led to improvements in the system and reduced lead times until the subsequent lines are commissioned.

During this period, **one of the longest interoperable routes in Europe, the one between Barcelona and Malaga**, is being built. On this section, the rolling stock, equipped with ERTMS, runs on an infrastructure equipped by four different manufacturers.

Management and operation

Network management is another area in which Spain stands out for its technical expertise and innovative advances that guarantee greater security and efficiency. **A clear example is the DaVinci System[62], one of the most advanced in the world. Owned by Adif and developed by Indra, it is the reference tool for the control of Spanish high-speed railway traffic**. It is adaptable to conventional networks and has already been implemented in several countries. This development has been able to integrate in a single applilcation all the systems that make up the elements of a traffic regulation centre.

During this time, innovations were also generated in the field of railway operation, for example, for the Madrid - Lleida high-speed line, a new system for detecting falling objects was developed, which is currently installed on Spanish lines.[63]

In conclusion, in this decade of great innovation - the 2000s -, **almost 2,000 km** of lines were built, and high-speed trains reached cities such as Barcelona, Toledo, Valladolid and Malaga and connected with Huesca by means of a 3-wire track.

3.5.3 TECHNOLOGICAL DEVELOPMENT IN THE LAST DECADE

Between **2010 and 2020**, the high-speed railway will reach cities such as Valencia, Alicante, León, Zamora and Figueres and will connect the high-speed with Castellón by means of a 3-wire track, completing **more than 1,500 km**.

In this phase, the Spanish company and industry continue parallel to the growth of the Network which, although at a slower pace than in previous years, is aligned with progress in improving efficiency, construction performance and the machinery used, as well as increasing innovation and development.

Progress is being made in the **track fastenings** used, with improved performance and durability, in **rail welding**, in **track equipment**, using more sustainable and efficient materials, all with in-house technology and resulting in improved subsequent maintenance. **Gauge changer technology** is being **perfected**, allowing increasingly faster and safer passage through a Spanish patented dual gauge changer Tria-Adif[64]. This technology has aroused interest in

other geographical areas with similar problems, such as Eastern European countries, including recently Ukraine.

ERTMS level II is implemented, in the development of which Spain has become a pioneer, with numerous advantages, especially in terms of capacity, a key element in terms of liberalisation.

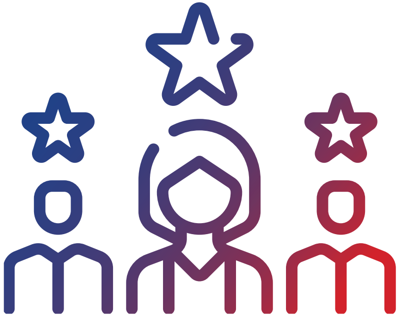
In **addition, Spain Brand is beginning to export its model to new countries, especially the Mecca - Medina High Speed Line, a line of more than 450 km and 300 km/h** where a mainly Spanish consortium has designed and built the superstructure, systems and rolling stock, all in a completely new environment, in a period of approximately **6 years**.

Experience in electrification has given way to the evolution of the C-350 in other types of light contact line but adapted to conventional lines, such as the CA-200. This type of alternating current electrification for conventional lines has been exported to other countries such as Israel.

All these improvements have been implemented in the design and construction of the following lines that have allowed high-speed access to cities such as León, Burgos, Cádiz and soon to Asturias, Murcia and Extremadura.

In conclusion to this chronological narrative of the generation of innovations and the acquisition of experience in Spanish high speed rail, it is worth mentioning that the recent history of railways in Spain summarised in this document shows how, **starting from the "caboose", Spanish engineering and "ingenuity" have been able to build, in record time, one of the best high speed networks in the world. A group of people and organisations faced, with self-confidence, the challenges and obstacles that arise from overcoming each previous obstacle. An episode of involvement and commitment was generated in the Spanish high-speed network, which made it possible for companies, administrations and individuals to align their different interests towards a common goal.**

Beyond the successes achieved, culture, knowledge, trust, ambition and responsibility are attributes that are embedded in the sector and that allow it to adapt to different future circumstances, to continue sharing and exporting technology and, above all, to move forward as individuals and as a society.



The HS2 programme, designed to create a Y-shaped high-speed rail network, increasing rail capacity and connecting, in its initial approach, the main cities in England (London to Birmingham, Manchester, Sheffield and Leeds), is at an advanced stage of construction in its so-called Phase 1 between London and Birmingham, but has accumulated significant delays in its Phase 2 (Birmingham to Manchester, Sheffield and Leeds), of which only one sub-phase (2A, between Birmingham and Crewe) has been completed through Parliament, but there are significant delays in Phase 2 (Birmingham to Manchester, Sheffield and Leeds), of which only one sub-phase (2A, between Birmingham and Crewe) has completed its parliamentary process and is about to start its preliminary works (Enabling Works and Environmental Works). The other sub-phase (2B) is in the parliamentary process for the Manchester access branch, and in the phase of complete redefinition of its eastern branch.

The large cost and schedule slippage suffered by the project has led to successive reductions in its scope, starting with the cutting of the eastern branch in 2020 on the occasion of the publication of the *Oakervee Reporty*, the Integrated Rail Plan, then delaying the programme for access to London between Old Oak Common and Euston, and finally suspending the whole of Phase 2, announced by the Prime Minister at the Conservative Party Convention.

Part of the reasons why the costs of HS2 are much higher than in other countries such as Spain are well known and affect other non-rail construction projects in the UK: high engineering and construction labour costs, and high population density accompanied by dispersed urbanisation (which significantly raises the costs of expropriation and diversion of services).

There are, however, other singularities that have conditioned the viability of HS2.

Differences in the strategic definition phase

The HS2 programme has important differences in its strategic conception compared to the Spanish programme.

The most important is that HS2 was born as an action to significantly increase rail capacity and connectivity on axes that were already operating at full capacity (and with speeds of around 200 km/h in many cases), with its high-speed rail nature being a secondary factor, compared to the desire to provide territorial structuring through significant reductions in journey times on which the development of the Spanish programme is based. Several strategic studies determined that a new high-speed line ("Greenfield Project") was advantageous compared to other actions to improve the existing network, also with relevant costs and implications and lower performance, a discussion which also took place in Spain at the conclusion of the Madrid - Seville high-speed line and which also opted for a new high-speed line, although for different reasons.

In the case of the United Kingdom, the possibility of a return to capacity enhancement measures on the classic network has always been present (HS2 Strategic Alternatives. Final Report. DfT. October 2013, and subsequent versions).

This has always been a threat to the project, which is not backed by the political consensus that the high-speed rail programme in Spain has enjoyed in the last decades.

Complexity of the planning phase

The uniqueness of the legal context and governance in the construction of major transport infrastructure in the UK, particularly in England and Wales, makes the development of the entire conceptual and planning phase a complex process, rooted in the Anglo-Saxon legal framework that severely limits the powers of government over the rights of individuals and private property, such that a greenfield project, which requires significant expropriation and interference, can only be implemented by empowering the development body through primary legislation, i.e. through a parliamentary process that, even with cross-party political consensus, can only be implemented by giving powers to the development body through primary legislation, which requires significant expropriations and affections, can only be executed by empowering the promoting body through primary legislation, that is, through a parliamentary process which, even with political consensus between parties, is influenced by the character of each parliamentarian as the sole representative of his or her constituency, which sometimes conditions his or her position as much or more than party discipline.

Thus, the conceptual and preliminary design of the project, including its environmental impact studies, are developed in consideration of future scrutiny, sometimes very tough, by the Select Committee, which means that even small technical decisions have to be taken and documented in a very detailed and exhaustive manner, subject to very rigid procedures, which significantly increases the costs already in the planning and preliminary design phase.

In addition, the above-mentioned single representative per constituency character of the members of parliament gives a strong leverage to local communities, which often adds extra elements to the project in the form of more costly technical solutions or compensation packages.

All this imposes engineering costs and durations several orders of magnitude higher than in the Spanish case in this phase, which for HS2 has been multiplied by the fact that up to four parliamentary processes have been launched or planned (Hybrid Bills for

Phase 1, Phase 2a, Phase 2b-West and the not yet initiated Phase 2b-East).

Ineco has been supporting HS2 in these processes since 2012, both in Phase 1 and Phase 2, adapting the methodologies of Spanish railway engineering, based on agility backed by expert knowledge, to the rigour of the formal processes destined for the parliamentary process.

Rigidity and completeness of the design phase

British engineering is characterised by a high level of detail in the pre-construction phase, with great rigour in the *Technical Assurance processes*, which go beyond the classic concept of quality assurance, and focus more on the development of documentary evidence that supports compliance with the usual concepts in its legal and contractual context, such as *standard of care*, *standard skill and expertise*, etc. These processes are usually imposed more by legal departments and even insurance contracts than by the need for quality in design, and in the case of HS2 they have come to impose that more than two thirds of the time and resources of the design programmes are consumed by these processes rather than the effort dedicated to design and value engineering.

This means that changes in the design, even in non-primary aspects of the design, entail investments of time and resources that are much higher than in the Spanish case, and also discourage the involvement of construction companies in the refinement of the design due to the impact on the programme and the added responsibilities, in contrast to the Spanish case, where they have brought significant efficiencies. HS2 was aware of this in the tendering of the Phase 1 civil works contracts, and developed formulas to stimulate this involvement (Early Contractor Engagement), which however have not produced the expected results given the rigidity of the limits imposed by the powers and limits of the Hybrid Bill.

In spite of this, Ineco has managed to contribute significant improvements in sections where it has intervened, based on the agile and intuitive approach supported by the usual expert knowledge in Spanish engineering, such as the award-winning proposal for the Delta Junction in Phase 1, consisting of the optimisation of the layout and structures of the railway junction access to Birmingham.

Exceptional requirements for excellence; the programme as a vector for country policies

Beyond its main mission as a rail capacity enhancer, the bodies promoting HS2 decided to turn it into a vector of excellence and deployment of multiple country policies.

HS2 thus set itself standards in health and safety far above the already exacting requirements of the British construction industry, and is indeed a world exemplary project in this respect (only one fatality recorded in four years of work on the entire Phase 1). This affects not only equipment and safety measures, but also procedures, personnel, etc., with a corresponding impact on costs.

HS2 has also set itself the goal of sponsoring programmes aimed at increasing the professional qualification of workers at the national level, particularly graduates and apprentices.

It has also set as a goal in its work to achieve Biodiversity Net Positive status, i.e. to develop compensatory measures that ensure that the project not only has no negative effect on biodiversity but that the balance is positive, and has set 2030 as the date by which Net Zero (zero net emissions) must be achieved in all work on the line.

The project has thus seen added requirements above the industry standard, which puts it at a disadvantage when compared to conventional grid performances.

Resources

One aspect that has had a particular impact on HS2's costs has been the distorting effect on the market of its high demand for qualified resources. The lack of experience in high speed rail has attracted expert companies from other countries, such as Ineco in the engineering field, and several large Spanish construction companies, but has distorted the market in all areas, from labour costs to the costs of other inputs, including the insurance market.

Here, too, the Spanish experience and the approach adapted to the market reality of Adif (and to a large extent, also of its precursor, GIF), have proved more efficient. At the beginning of the programme's take-off, using the expert knowledge of companies such as Ineco, as coordinator and author of several critical projects, and dividing the design - and later construction - packages into sizes adapted to the reality of the market at each moment, has allowed the level of railway qualification in the sector to grow gradually, to achieve one of the most experienced engineering and construction markets in the world.

On the other hand, HS2 has not opted for its own designs, accessible to all contractors, of key elements with a great influence on cost, such as the case of sleepers or type of catenary, which contrasts with Adif's strategy, which has standardised a multitude of components and systems, reducing their cost .

Requirements

Finally, a success factor of the Spanish experience, which has not been reflected in the HS2 approach, is the early definition of requirements and technical specifications.

The effort initiated by GIF and culminated by Adif, also with the collaboration of Ineco, in the detailed definition of all types of technical specifications (from NAV track standards to platform NAP) from a very early stage of the programme, has allowed for multiple efficiencies, as resources have been concentrated on the design rather than on the discussion of requirements and specifications which, in the case of HS2, have entailed an additional effort.

04

CONCLUSIONS

In recent years, the railway as sustainable transport has gained relevance in the world and, within this, high-speed trains over medium distances.

There is a resurgence of this modality and Spain can play a very important role, even a leading role in its development.

This report confirms, first of all, a result that already appeared in several previous references reviewed: **Spain is very efficient in the production of high-speed infrastructure. It is, in fact, the most efficient country in the production of this infrastructure among the comparable cases**.

This result is supported, as is done in this study, by the Transit Costs Project database of the Marron Institute of New York University, which is perhaps the most complete and homogeneous to date and therefore the best for drawing these conclusions.

This study also extends the traditional construction perspective to cover the entire life cycle of the infrastructure and includes operation and maintenance costs. Although the information on this subject is less complete, the analysis carried out allows us to conclude that **Spain's efficiency advantage is maintained and could even be reinforced with this life-cycle perspective**.

Secondly, the report delves into the causes, combining a theoretical approach with empirical

analysis and successful experiences narrated by many of its main players. **A coherent and comprehensive reasoning is put forward, covering technical, cost and economies of scale advantages, as well as technological, institutional, cultural and/or political factors.**

All these causes allow us to speak, in a certain sense, of a **Spanish model of high-speed development** based on a broad **social and political consensus**; an adequate **institutional framework** with a Ministry of Transport, Mobility and Urban Agenda that gives railways a high priority, a powerful, young, technically solvent and committed **network administrator (Adif),** supported by a **public engineering** company **with great human talent and international excellence (Ineco)**.

The design of a **development strategy based on multiple contracts of adjusted size and based on standards approved by the administrator** that allows balancing the advantages of scale with the preservation of a competitive and multiple ecosystem of companies; **a flexible and balanced contract management** without excessively tilting the weight of the actions in the design phase, so that preliminary studies do not take too long and problems and unforeseen events can be solved in an agile manner; **a competitive and dynamic private sector,** made up of a large number of consultancy and engineering firms, specialised construction companies and manufacturers, all of them highly qualified and capable of articulating, patenting and exporting **technological innovations** and, above all, in the generation of a **Spanish high-speed culture** that is embodied in a commitment to the project and a pride in participation that reduces conflicts and speeds up solutions.

It is not that Spanish railways do not have aspects to improve, such as planning, overcoming an excessively radial structure, increasing the number of users, increasing freight on the network, or completing liberalisation, among other aspects that are being addressed. But **the development model of the Spanish high-speed network has been - and is being - a clear success story**.

An achievement that successive governments, the Ministry of Transport, public entities such as Adif and Ineco, construction companies, engineering firms, the industrial sector, the training system at all levels, the technicians and people involved, and Spanish society as a whole can congratulate themselves on.

However, the purpose of this report is not one of homage, but of prospective analysis. In this sense, two **key questions are whether the model that has worked in the past can be maintained in the future and, on the other hand, whether the Spanish model can be generalised, replicated or exported to other places**.

The Spanish model is already evolving and needs to evolve in order to enhance its advantages of flexibility and agility in a more complex and competitive international environment. This means integrating the traditional involvement of agents and contract management inherent to the Spanish model with the demands of transparency, technological development, legal security, accountability and rigour concomitant with a large, internationalised activity that operates in scenarios with different cultures.

The Spanish high speed sector, at all levels, is clearly capable of succeeding in the expansion of high speed in the world. It is important to disseminate the Spanish high-speed experience and Its capacities.

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21 The breakdown of these costs is not equivalent to that made by Adif and therefore the comparison is not direct. However, if the “Other operating expenses” item in the report is discarded, the operating cost would be slightly below 70 thousand euros/km, in line with the weighted average of 68.4 calculated above.

22 This table shows the data from Transit’s database of analysed projects, not from each country’s network, which in Spain is currently around 4 000 km.

24 It is worth mentioning that both sections are unique. The Venta de Baños-León section is built on single track (although on a double platform), whereas the Basque Y is a line under construction and with a particularly complicated orography, with 71% of its route consisting of tunnels or viaducts. If we exclude these projects, the lowest cost would correspond to the Madrid-Seville line, with 10.2 $M€_{2022}$, and the highest to the Barcelona-Figueres section, with 29.2 $M€_{2022}$ and its continuation Figueres-Perpignan, shared with France, with 29.8 $M€_{2022}$.

25 The cost of a line increases proportionally, even exponentially, with the design speed, and very high-speed infrastructure (> 300 km/h) is particularly expensive (European Court of Auditors, 2018).

26 In other countries, the exhibition could tend to include special projects with a large percentage of unique works.

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