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An Ex Ante Analysis of the Planned Transportation Network in the Region of Extremadura (Spain) by Using Physical Parameters

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Abstract: Some relevant transport infrastructures are expected to be built in Extremadura, a Spanish region. Future investments could transform the regional transportation system and therefore could act as an important lever for economic and social change. The text describes the current situation and also the planned infrastructures, and an ex ante study is developed. The research has set the deficiencies of Extremadura in terms of transportation network, but current planning proves that the rail and airport infrastructures in Extremadura are set to involve a significant change of model. Moreover, the importance of taking into consideration the transport planning documents of neighboring countries in the transport analysis of bordering regions and the negative consequence of designing national and regional transport plans without considering the neighboring plans have been described.

Keywords: ex ante study; transport planning; transport policy; Atlantic corridor; regional HSR; regional airport; QGIS

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1. Introduction

It is a well-known fact that infrastructures are no guarantee for improving the economy, while they are a necessary condition for improving it [1–3] by enabling the mobility of goods and people [4,5] or reducing operational cost [6], among other factors [7,8]. Success or failure lies not only in taking complementary measures [9] but also in making the right decisions in the course of the initial stages of analysis [10]. This circumstance must be underlined, because Spain is probably the country with the largest oversupply of infrastructures, measured as the gap between transportation infrastructure capacity and demand [11]: Spain owns the third longest highway network after China and USA [12], and the second longest High Speed Rail (HSR) network [13], although it is the fourteenth world economy, according to the World Bank [14]. There is a high risk of infrastructures not meeting the objective of boosting the economy, and therefore, it is important for the details not to ruin the transport network potential [15]. Furthermore, recent studies reveal that HSR reinforces large cities but not necessarily the surrounding areas [16] or small and medium cities [17].

The basic conditioning factors in planning transportation infrastructures are their cost and the economic, social and environmental impacts of their execution and service startup, as well as their footprint and sustainability in the territory concerned [9]. Moreover, the irreversible nature of decisions made should not be overlooked [8,18]. For these reasons, an economically powerful, dynamic region can allow itself to make a mistake since it has the resources to correct erroneous decisions; however, less developed regions need to get it right when a window of opportunity opens up [19–21].

This text sets out to analyze the expected future scenario in transport infrastructure networks, evaluating if there are points that can be improved by means of a holistic approach and proposing possible modifications. Analysis is limited to motorways, HSR and airport, in a global manner. The scope is focused on the intermodality options, the territorial cohesion, the HSR line revolution, the rise of new interregional axis and the coherence between the planned infrastructures in two neighboring countries, Portugal and Spain.

2. Materials and Methods

2.1. Territorial Context

Extremadura [22,23] is a Spanish region which comprises a vast inland territory (41,634 km^2) sparsely populated: 1,073,000 inhabitants spread across 388 municipalities, with a population density of 27 inhabitants/km^2. It has the two largest provinces of Spain, Cáceres in the North and Badajoz in the South (Figure 1). Its annual GDP per inhabitant is 31.7% below the national average, the lowest of all Spanish regions, and it ranks below the 75% threshold of the European average. The urban structure of towns of over 10,000 inhabitants is described in Table 1, and the frequency distribution follows the typical configuration of regional systems in which the frequency of towns increases the lower the size class of the town [24].

The transport system comprises an airport (less than 10 flights a day) with mixed civil and military use, a highway network and an old single-track railway network not electrified. Some other big metropolis like Madrid, Seville, or Lisbon are not close enough to properly serve as regional transport centers. The lack of investments, a problem linked to the low population density, is accompanied by the absence of a regional model for the whole transportation system.

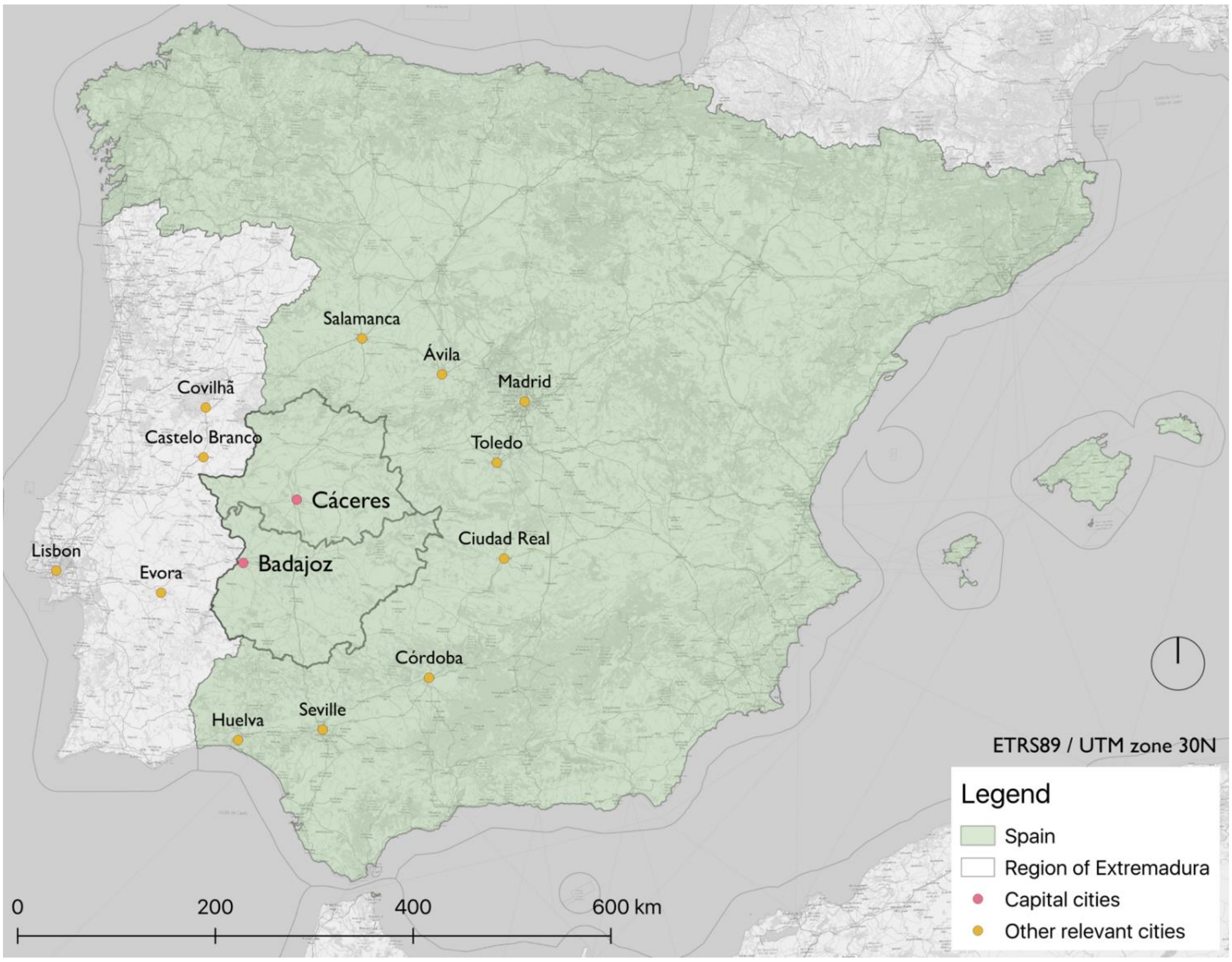


Figure 1. Region of Extremadura; capital cities and other relevant cities in both Spain and Portugal have been included. Source: prepared by the author.

Table 1. Urban system in Extremadura.

Town	Population (Thousands)	Size Class (Thousands)	Quantity per Class
Badajoz	150	>100	1
Cáceres Mérida	96 60	50–100	2
Plasencia Don Benito Almendralejo Villanueva de la Serena	40 37 34 26	25–50	4
Navalmoral de la Mata Zafra Montijo Villafranca de los Barros Coria Olivenza	17 17 15 13 12 12	12–25	6

Source: the authors.

In fact, Gurría and Nieto Masot [25] have written that the two essential factors to explain the location of the cities and their consequent development are the topography and the system of the elementary main roads. On the one hand, all the cities (except those of Cáceres and Trujillo) can be found in the sedimentary basins, which are historically the most productive especially because of their irrigation in the middle of the last century, on the right bank of the Tagus River basin and on the plains of the Guadiana River. This has been also quoted by Arenal-Clave [25,26], who indicate that "the organization and arrangement of the constituent elements of the urban system are totally related to the spatial organization of the agrarian productive base"; some other authors have also mentioned it [27]. On the other hand, most of the cities are located around two main historic routes: the current A-66 (a north–south freeway from Gijón to Seville whose origin is the Roman road Vía de la Plata) and the A-5 (the freeway which connects Madrid to Lisbon, whose modern origin can be found in the Charles III plan for the modernization of Spanish roads, 1761). In a nutshell, the areas with complex relief (mountainous areas of the central system, to the north; Montes de Toledo, to the east; and Sierra Morena, to the south; or the riparian areas linked to the Tagus River and its subsidiary river network) have been traditionally poorly communicated and shabbily harvested.

Research shows the enormous disruption of the region, with deficient rates of accessibility [28], caused by a deficient planning policy [29]. In the last years there have been some improvements [30], but regional disparities remain considerable. It has been said that, to make Extremadura's economy viable, it would need "land management focused on the planning of infrastructures" among other elements [31].

At the same time, ongoing improvement of infrastructures for tourism along with the attractions of heritage and the environment are managing to position the so-called Raya (the frontier between Spain and Portugal in Extremadura) as an international tourist destination [32]; moreover, strong touristic potential linked to inland water [33], spa [34], cultural resources in rural areas [35] or sustainable hunting [36] has been quoted; and Rodríguez, Sánchez and Ramajo described Extremadura as "an emerging inland destination" [37]. Its status as an objective I region has made a considerable contribution to this, besides the application of the INTERREG Operational Programs (1990–2006), the POCTEP (Operative Program of Cross Border Cooperation Spain—Portugal) (2007–2013), the INTERREG VA (2014–2020) [38] or the LEADER Approach (2007–2013) [39].

In other words, the current situation is that of a region with outstanding needs for investment in infrastructures in order to improve the regional economy, to improve the life of its inhabitants and to deal with the growing interest in tourism. The scheduled investment plans for the next few years are crucial for effective decision-making in planning infrastructures.

2.2. Method

The methodology focuses on an ex ante study, which compares the current situation and the eventual future scenario, in which all the planned infrastructures have been already built, and QGIS open software has been employed for the analysis of some indicators. This methodology has been widely employed for evaluating planned or constructed transportation networks [40–44]. The method is the following (Figure 2):

1. A group of parameters is defined to enable the quality of the road, railroad, and air networks.
2. The current situation and improvements expected are described.
3. A comparative analysis is made, and the points for possible improvement are evaluated.
4. Some conclusions are identified.

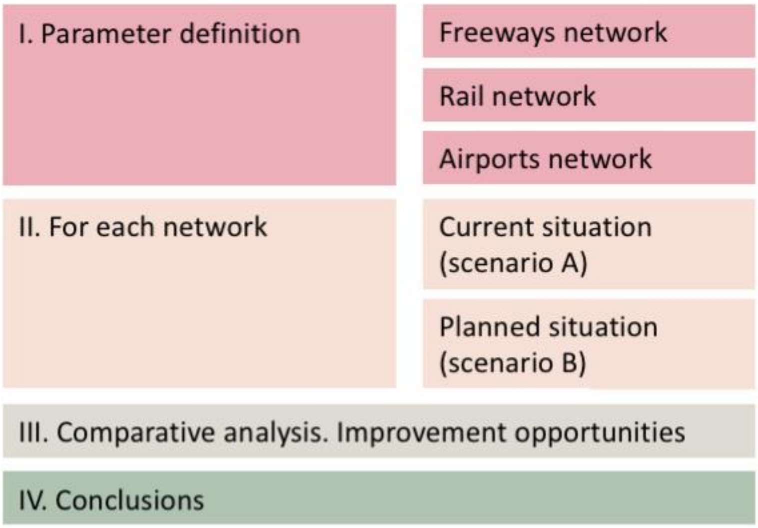


Figure 2. Method.

2.3. Parameters

There are many parameters for evaluating transport networks; in this case, eleven have been selected, linked to the three transport networks (Table 2).

Table 2. Parameters analyzed.

Network	Parameter
Freeways	Route factor Road density Nodes between freeways Average daily traffic
Rail	Rail catchment area Intermodality Competitiveness of the railroad compared to roads Existence of commuter trains/suburban railways Territorial cohesion by rail
Airport	Physical airport limitation Territorial cohesion by airports

Source: the authors.

2.3.1. Route Factor

The accessibility indicators enable different realities related to geography, the transport networks and their optimization with respect to different ideal situations. There are an enormous number of indicators [45], and the choice of one or another for evaluating a certain situation must consider the scale, the information available and the amount of disaggregated data [46,47].

This study intended to measure the quality of alignment (its approximation to a straight line), and therefore we took the route factor:

$$r_{ij} = \frac{d_{ij}}{d_{g\ ij}} \tag{1}$$

Being:

r_{ij}, route factor from nodes i and j.

d_{ij}, minimum distance through the freeway scheme between nodes i and j.

$d_{g\ ij}$, straight distance between nodes i and j.

From this, the integral route factor may be obtained, extending the above equation to a number n of nodes:

$$R_i = \frac{1}{n-1} \sum \frac{d_{ij}}{d_{g\ ij}} \tag{2}$$

Low accessibility corresponds to mountainous areas or zones with few infrastructures. This indicator was used in the Spanish National Plan for Highways 1984–1991 and has been used since then in various other studies.

2.3.2. Road Density

The road density is the relationship between the network dimension and the dimension of the territory they serve and enables territorial cohesion to be evaluated regarding others. In Spain, developed regions usually have the densest highway networks [48], and Extremadura held last place. This indicator has been used before in studies relating infrastructure development with economic growth [49] and in studies such as the African Institute Development Index [50], among others [51].

2.3.3. Nodes between Freeways

One of the points of conflict in routing freeways is adequate links between them. It is possible for a freeway to begin or end near a town without considering other freeways which start or end in the same city. These nodes could be considered imperfect, since the presence of a node requires traveling on city streets, geometrically less perfect or even having traffic lights, which would generate impedance affecting the entire network.

For a node to be properly resolved, it must comply with the following requirements:

- No access from adjacent properties
- No intersections with other transportation modes
- No traffic lights
- No stop signs
- Can be entered from any direction of traffic (not a semi-link)

The first two are conditions for freeways, the next two are linked to potential stops that generate traffic problems, and the last is related to versatility and accessibility.

2.3.4. Average Daily Traffic

The Average Daily Traffic (ADT) expresses the traffic load on a road. In general, an undivided highway works reasonably well with low ADT. As it nears a certain figure, it is reasonable for that highway to become a freeway.

Spain has traditionally considered 10,000 vehicles/day as the threshold after which a highway should be transformed [52]; this number slightly varies in other places: the Florida Department of State sets a minimum of 8700 vehicles/day for rural areas [53].

However, today, other factors are considered, such as traffic safety, continuity of itinerary or accessibility zoning. The continuity of the itinerary takes on special relevance in a small community with a low number of motor vehicles. Similarly, accessibility zoning, is thought relevant in mostly rural areas and in those areas where there is illegal urban development supported by highways [54]. Now, divided highways with an ADT under 10,000 vehicles/day are common.

We therefore consider it of interest to analyze the ADT on those highways which are not freeways.

2.3.5. Rail Catchment Area

The catchment area is a common parameter for analyzing adequate placement of transportation networks which require a concrete access point, whether station, port or airport. It may be defined as the part of the territory whose inhabitants are potentially interested in accessing this transportation mode. To evaluate the planned access area of a railroad station, catchment areas are considered suitable for research on whole transportation lines [55].

2.3.6. Intermodality

Intermodality is another relevant parameter for transportation modes with access nodes [56–58]; therefore, the lack of intermodality changes the attraction of the stations. Concerning HSR, intermodality is one of the requirements to be successful [9,59]. The situation of railroad stations is therefore related to intercity bus stations in the main cities, and also the airport has been included.

2.3.7. Competitiveness of the Railroad Compared to Roads

Travel time between home and activities usually becomes the main parameter for choosing the transport model [60]; for that, travel time can be used to make comparisons between different modes of transportation [61]. The relevance of time savings has also been found to be a key factor in transport improvement schemes [62]. Therefore, it was decided to compare the travel times between the HSR and private vehicle without taking costs into account.

2.3.8. Existence of Commuter Trains/Suburban Railways

A relevant indicator related to the articulation of regional transportation is the existence of commuter trains, whose demand in Spain has increased considerably in the last decades [63], proving the importance of these systems in territorial development.

2.3.9. Territorial Cohesion by Rail

As mentioned at the beginning, transportation infrastructures can unite the various administrative regions that make up a country. Presence/absence is a relevant indicator for determining the regions in a country with underdeveloped transport systems [64,65]. The territorial cohesion related to a mode of transportation can also be measured in another way: by evaluating the distance from a territory to the nearest transportation node. To do this, territories located 50 or 100 km from the transportation system have been determined. Therefore, both indicators were used to measure territorial cohesion by rail.

2.3.10. Physical Airport Limitations

There are several parameters for determining and limiting the operability of an airport, as well as eventual infrastructure enlargement or improvement. We have taken four limiting parameters into consideration:

- Mixed civilian/military use. Joint-use airports usually have operating problems, especially in those linked to the tourist industry [66].
- Air-space restrictions. Airports located in dangerous, prohibited and restricted airspace have limitations on their development.

- Infrastructure boundaries. Boundaries on highways or railroad tracks limit possible enlargement of the airport.
- Fog.

In view of all the above, an analysis considering these four parameters has been made.

2.3.11. Territorial Cohesion by Airports

As in terms of railroad infrastructures, it makes sense to analyze the presence/absence of airport infrastructures in Spanish provinces. We must remember that transport infrastructures are public amenities that are not only governed by commercial criterion. European policies on transport establish the two-fold intention, in all their documents, of moving ahead in liberalizing transport and, at the same time, taking into consideration structuring criterion and social cohesion.

2.4. Current Situation and Future Scenario

Current planning in Spain, at the state level, is defined by the *Infrastructures, Transport and Housing Plan* 2012–2024 (PITVI), drafted by the Ministry of Development. The Portuguese *Strategic Plan for Transport and Infrastructures* 2014–2020 (PETI 3+) has been also consulted.

Moreover, there is an infrastructure plan for Extremadura drafted by the regional government: the *Regional Strategic infrastructure plan 2016–2030* (PEPIEx). This plan has been considered as a reference document.

Therefore, the ex ante study compares the current situation, prior to the aforesaid plans, and the future scenario, resulting from the actions included in the three plans when completed, in 2030.

3. Results

3.1. Freeways

The current network, up to 720 km, will be enlarged considerably in the future (Figure 3, Table 3). Moreover, other roads planned outside of Extremadura will improve communication with cities located 150–200 km from the region.

In this study, it has been considered that future freeways will follow the same route as the present roads which are going to be substituted or replaced, although in some cases they will probably differ.

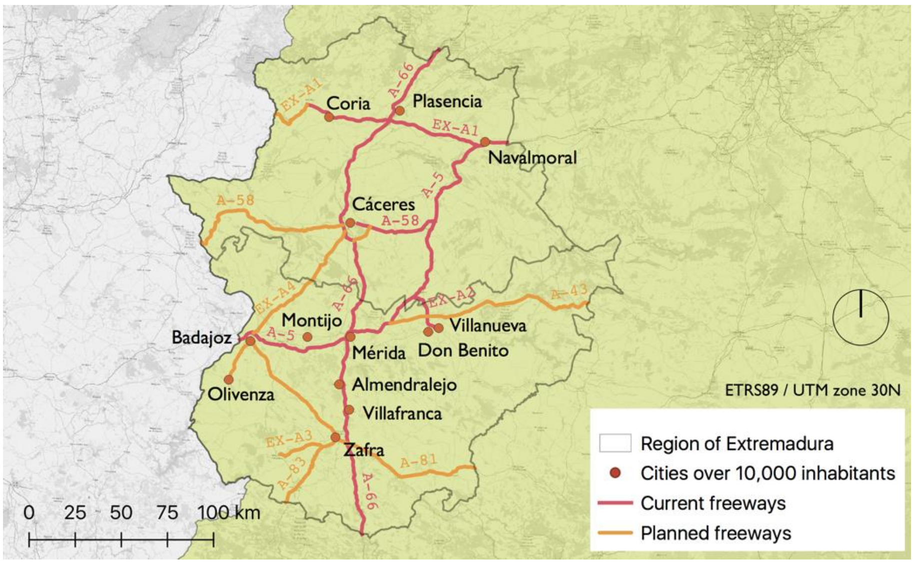


Figure 3. Current and future freeways network in Extremadura. Source: prepared by the author based on the official documents above mentioned.

Table 3. New freeways.

Document	Freeways
PITVI	A43, Puertollano-Mérida A-58, Valencia de Alcántara-Cáceres A-81, Badajoz-Espiel-Granada A-83, Zafra-Huelva Ring in Cáceres
PEPIEx	EX-A4, Cáceres-Badajoz EX-A3, Zafra-Jerez Badajoz-Olivenza

Source: the authors.

3.1.1. Route Factor

Accessibility of municipalities in Extremadura to the largest cities was calculated. The cities selected were those with a population of over 10,000: 13 municipalities which make up 49% of the total population of Extremadura. The analysis evaluates the improvement in quality of alignment by distances. Route factor of the various cities with respect to the rest of the cities in the group were compared, and other cities outside the region were also included: Madrid, Lisbon and all the capital cities of the neighboring provinces in Spain and also in Portugal (all of them are included in Figure 1).

There will be substantial improvements in the cities located to the south (province of Badajoz), and slight improvements in the municipalities located to the north (province of Caceres) (Table 4). Altogether, the most unfavorable numbers went from 1.77 (Don Benito) to 1.71 (Coria). The global Route Factor will raise an improvement of 5.7%.

Table 4. Route factor study.

	Badajoz	Cáceres	Mérida	Plasencia	Don Benito	Almendralejo	Villanueva de la Serena	Navalmoral de la Mata	Zafra	Montijo	Villafranca de los Barros	Coria	Global
Ri present state	1.66	1.60	1.51	1.47	1.77	1.56	1.73	1.53	1.58	1.66	1.58	1.76	1.62
Ri future scenario	1.49	1.51	1.43	1.42	1.65	1.48	1.61	1.47	1.43	1.59	1.50	1.71	1.52
Improvement (%)	10.4%	5.4%	5.3%	3.0%	6.7%	5.1%	7.0%	4.2%	9.2%	4.4%	5.2%	2.7%	5.7%

Source: the authors.

3.1.2. Road Density

The current road density is 17 km per 1000 km^2. Along with Aragon and Castilla-La Mancha, it is the autonomous region with the lowest density of freeways in Spain (Figure 4). In the future scenario, the density improves notably, as there will be 74% more freeways (Table 5).

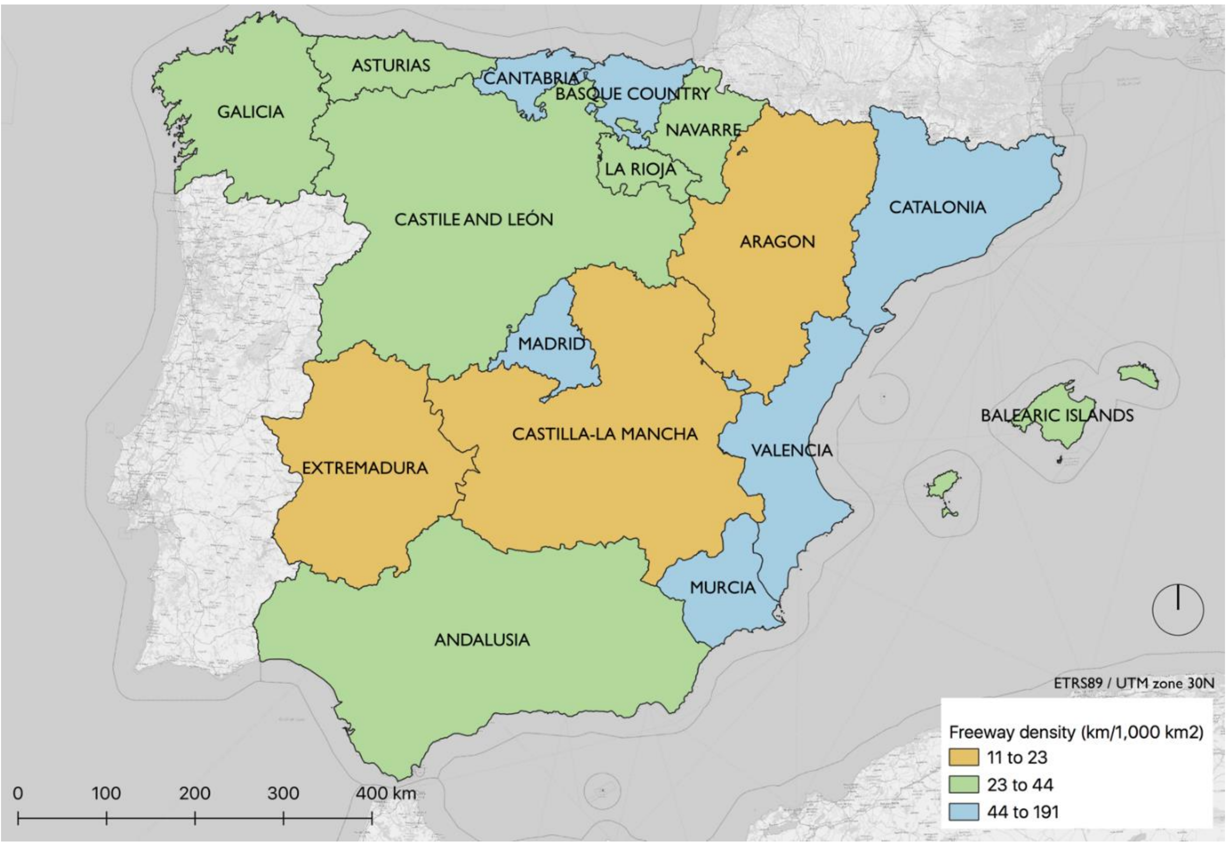


Figure 4. Freeway density in 2016. Source: Eurostat.

Table 5. Comparison of freeways density.

	Present State	Future Scenario	Improvement
Km freeways	720	1253	74%
Density (km per 1.000 km^2)	17.3	30.1	

Source: the authors.

3.2. Nodes between Freeways

At the present time, there are a total of six nodes between freeways. All of them but one are direct links; therefore, traffic can move from one to another safely (Table 6). In the future situation, nothing about the group of new nodes (Table 7) can be known, although probably most of them will be performed properly, and the existing wrong one is not expected to be resolved.

Table 6. Nodes between freeways. Present state.

Node	Absence of Access from Adjacent Properties	Absence of Intersections with Other Modes of Transportation	Absence of Traffic Lights	Absence of STOP Signs	Can be Entered from Any Direction of Traffic	Total
Mérida (A-5 and A-66)	Yes	Yes	Yes	Yes	Yes	Yes
Cáceres (A-58 and A-66)	No	No	No	No	-	No
Plasencia (EX-A1 and A-66)	Yes	Yes	Yes	Yes	Yes	Yes
Navalmoral (A-5 and EX-A1)	Yes	Yes	Yes	Yes	Yes	Yes
Trujillo (A-58 and A-5)	Yes	Yes	Yes	Yes	Yes	Yes
Miajadas (A-5 and EX-A2)	No	Yes	Yes	Yes	No	No

Source: the authors.

Table 7. Nodes between freeways. Future scenario.

Node	Absence of Access from Adjacent Properties	Absence of Intersections with Other Modes of Transportation	Absence of Traffic Lights	Absence of STOP Signs	Can be Entered from Any Direction of Traffic	Total
Mérida (A-5 and A-66)	Yes	Yes	Yes	Yes	Yes	Yes
Cáceres (A-58 and A-66)	Yes	Yes	Yes	Yes	Yes	Yes
Plasencia (EX-A1 and A-66)	Yes	Yes	Yes	Yes	Yes	Yes
Navalmoral (A-5 and EX-A1)	Yes	Yes	Yes	Yes	Yes	Yes
Trujillo (A-58 and A-5)	Yes	Yes	Yes	Yes	Yes	Yes
Miajadas (A-5 and EX-A2)	No	Yes	Yes	Yes	No	No

Table 7. *Conts.*

Node	Absence of Access from Adjacent Properties	Absence of Intersections with Other Modes of Transportation	Absence of Traffic Lights	Absence of STOP Signs	Can be Entered from Any Direction of Traffic	Total
Cáceres (A-66 and EX-A4)	Not already defined					
Cáceres (A-66 and A-58 west)						
Don Benito (A43 and EX-A2)						
Torrefresneda (A-43 and A-5)						
Badajoz (A-5 and EX-A4)						
Badajoz (A-5 and A-81)						
Badajoz (A-81 and Olivenza)						
Zafra (A-66 and A-81)						
Zafra (A-81 and A-83)						
Zafra (A-83 and EX-A3)						

Source: the authors.

Average Daily Traffic

A search was made of the ADT recorded on the highway stations, and the sections with over 6000 vehicles/day are shown in Table 8. In the future, there will be only one highway with an ADT over 10,000 vehicles/day, a really good improvement.

Table 8. ADT over 6000 in one-lane roads. Data: Ministry of Transports, 2016, and Regional Government, 2017. In italics, roads to be converted into freeways according to the planning documents.

Road	Station	Municipality	ADT	% Heavy	Description
EX-206	BA-1683	Villanueva De La Serena	17,787	2.5	Villanueva to Don Benito
EX-100	*BA-0021*	*Badajoz*	*17,285*	*7.1*	*Future EX-A4*
N-432	*BA-328/2*		*16,738*	*4*	*Future A-81*
N-432	*BA-374/2*		*13,576*	*9*	*Future A-81*
N-521	*CC-322/2*		*13,033*	*4*	*Future A-58*
EX-101	BA-0763	Zafra	9987	8.6	Access to Zafra from A-66
EX-304	CC-7073	Ronda Sur Plasencia	8383	3.5	Ronda Sur in Plasencia
N-521	*CC-17/1*		*8080*	*5*	*Future A-58*
EX-107	*BA-4313*	*Badajoz*	*7818*	*5.0*	*Future dual EX-107*
EX-206	BA-0160	Don Benito	7649	4.5	Don Benito to Medellín
EX-119	CC-0211	Navalmoral De La Mata	7371	4.8	Navalmoral to Talayuela
EX-328	BA-4183	Puebla De La Calzada	7010	8.2	Access to Montijo from A-5
N-432	*BA-6/1*		*6998*	*12*	*Future A-81*
N-430	*E-209*		*6843*	*16*	*Future A-43*
EX-107	*BA-0170*	*Olivenza*	*6761*	*3.2*	*Future dual EX-107*
EX-351	BA-0250	Villanueva De La Serena	6673	3.8	Villanueva to Rena
EX-107	*BA-7193*	*Corazón de Jesus*	*6438*	*4.1*	*Future dual EX-107*
EX-206	CC-1443	La Alberca	6387	2.5	Cáceres to Torreorgaz
EX-110	BA-4123	Gévora	6338	4,0	Badajoz to Bótoa
EX-108	CC-1053	Coria	6125	13,2	Access to Coria from EX-A1

Source: the authors.

3.3. Railways

The current railway network is made up of a series of itineraries communicating 11 of the 13 largest cities in Extremadura (the two smallest, Coria and Olivenza, are excluded from this group). There are also connection points with other regions and with Portugal (Figure 5).

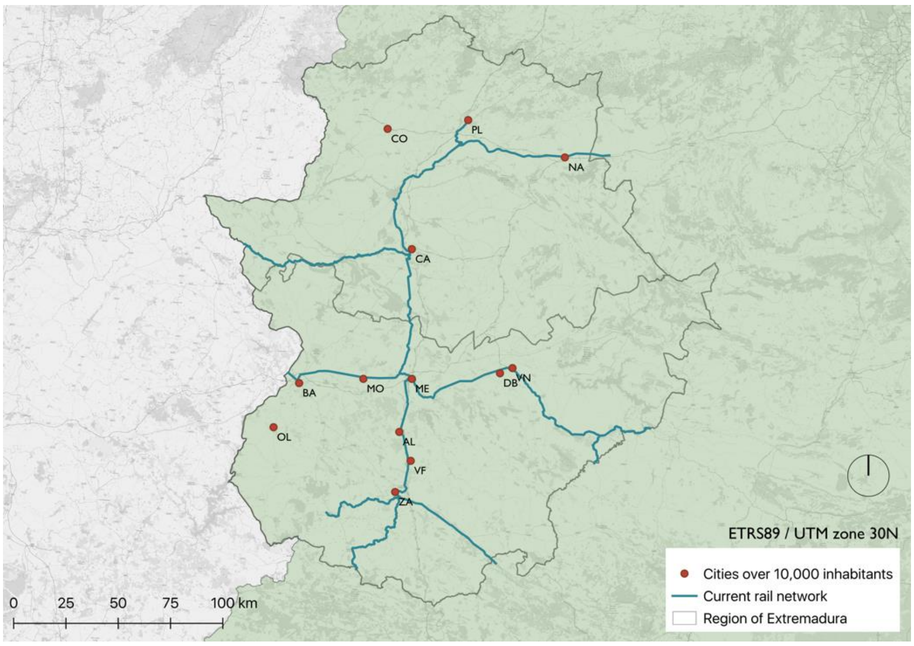


Figure 5. Current rail network in Extremadura Source: prepared by the author.

The network tracks—all of them with Iberian gauge—are obsolete (some crossings still date from the 19th century), and delays and cancellations are common (953 in 2018) [67]. There is not one kilometer of HSR in service, no electrified lines or double tracks, and the connections are very poor (Table 9, Figure 6).

Table 9. Direct links between the three main towns and the three big metropolises by train (before March 2020).

To/From	Badajoz	Cáceres	Mérida
Madrid	2	5	4
Lisbon	1 (270 min)	0	0
Seville	0	0	1

Source: the authors.

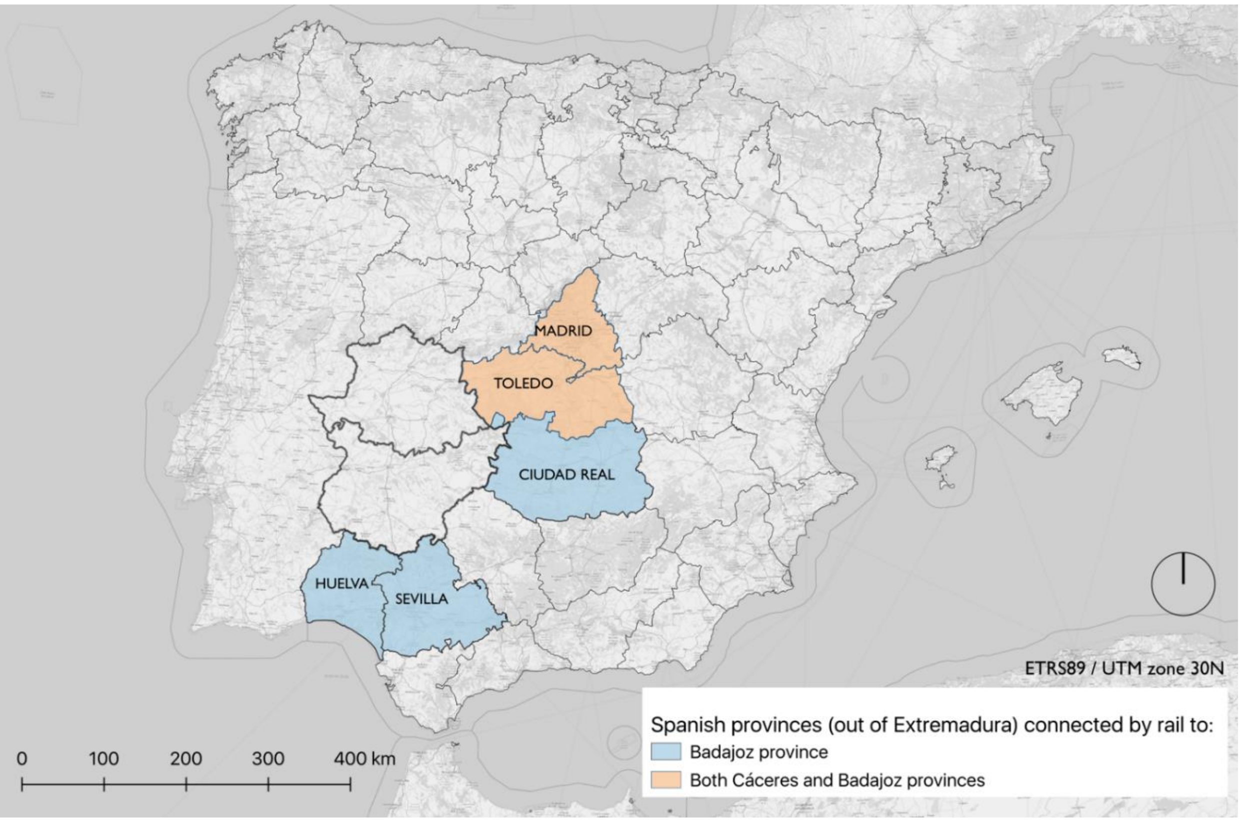


Figure 6. Map with direct links through the Spanish rail line. Source: prepared by the author based on the official timetables.

This historic delay has been repeated in the new generation of HSR corridors in Spain, since out of the five radial corridors initially scheduled, the only one that has not come into service to date, not even partially, is this one: Madrid-Badajoz-Portugal. Furthermore, this corridor is part of the Atlantic corridor defined in the Trans-European Transport Network, TENtec.

As far as the future HSR rail network is concerned (Figure 7), the latest actions mentioned by the PITVI refer to the construction of a new HSR line between Talayuela and the Portuguese border, and the Pantoja-Oropesa stretch, which makes it possible to close the track to Madrid; an improvement of the current line may be scheduled by modifying the width of the track. Furthermore, following the structuring approach of the Spanish network, a study of the León-Plasencia corridor is proposed. The PITVI includes also the restocking of the conventional track between Mérida and Puertollano.

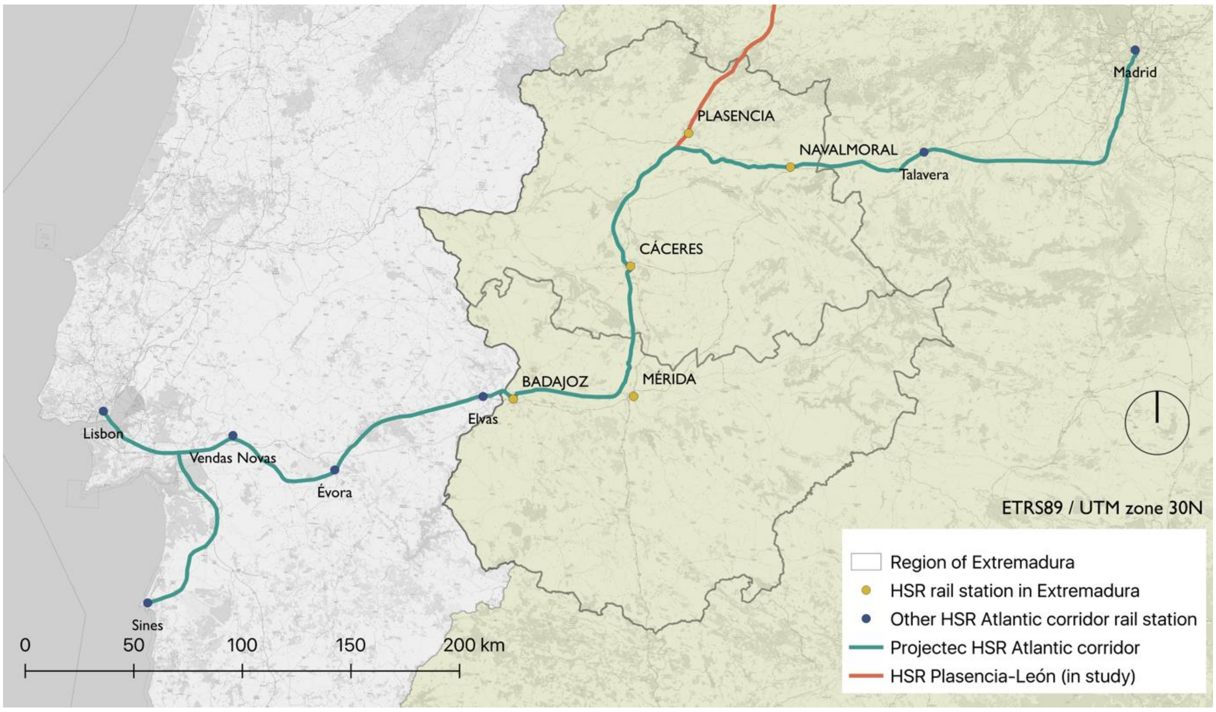


Figure 7. Future Atlantic corridor in central and west Spain. Source: prepared by the author based on the official documents above mentioned.

Today, works have already commenced on different stretches of the HSR line, at different points in the network. Moreover, the stations have been already defined: central rail stations in Badajoz, Cáceres and Navalmoral, a cul-de-sac rail station in Mérida and an ultraperipheric rail station in Plasencia.

As regards Portugal, the PETI 3+ includes the so-called international southbound corridor that reached Badajoz with Lisbon and the Sines port. It is foreseeable to significantly improve the line, including the construction of a new line between Evora and Elvas, covering 79 km. The speed for the passenger line project is 250 km/h [68], unlike the 350 km/h projected for the new lines in Spain. The stations planned for on this stretch are: Caia (border), Elvas, Evoramonte and Evora. Nothing is indicated, however, about the line that still exists between Abrantes and the Spanish border in Valencia de Alcántara, which for decades has been the shortest itinerary between Madrid and Lisbon.

3.3.1. Railway Catchment Area

The poor service conditions of conventional railroad lines dissuade a portion of potential users from traveling on them. In our opinion, this causes the generic distance catchment area method to be unreliable.

The situation of HSR is different, and future users may be foreseen based on other studies done on lines already in service. Thus, in Spain, preferential and priority catchment areas of about 30 km around each HSR station are usually employed [56,69].

The current HSR confirms that the entire community is outside the influence of the network. However, the future scenario includes five stations (four Spanish, one Portuguese) with catchment areas that include part of the Extremadura territory (Figure 8).

A study was done to determine the total population living within the areas described, by using the 2018 National Statistics Institute census: the affected population is 610,325 in an area of 12,593 km^2. That is, about 30% of the area is included, and service is provided to 57% of the total population (Figure 9).

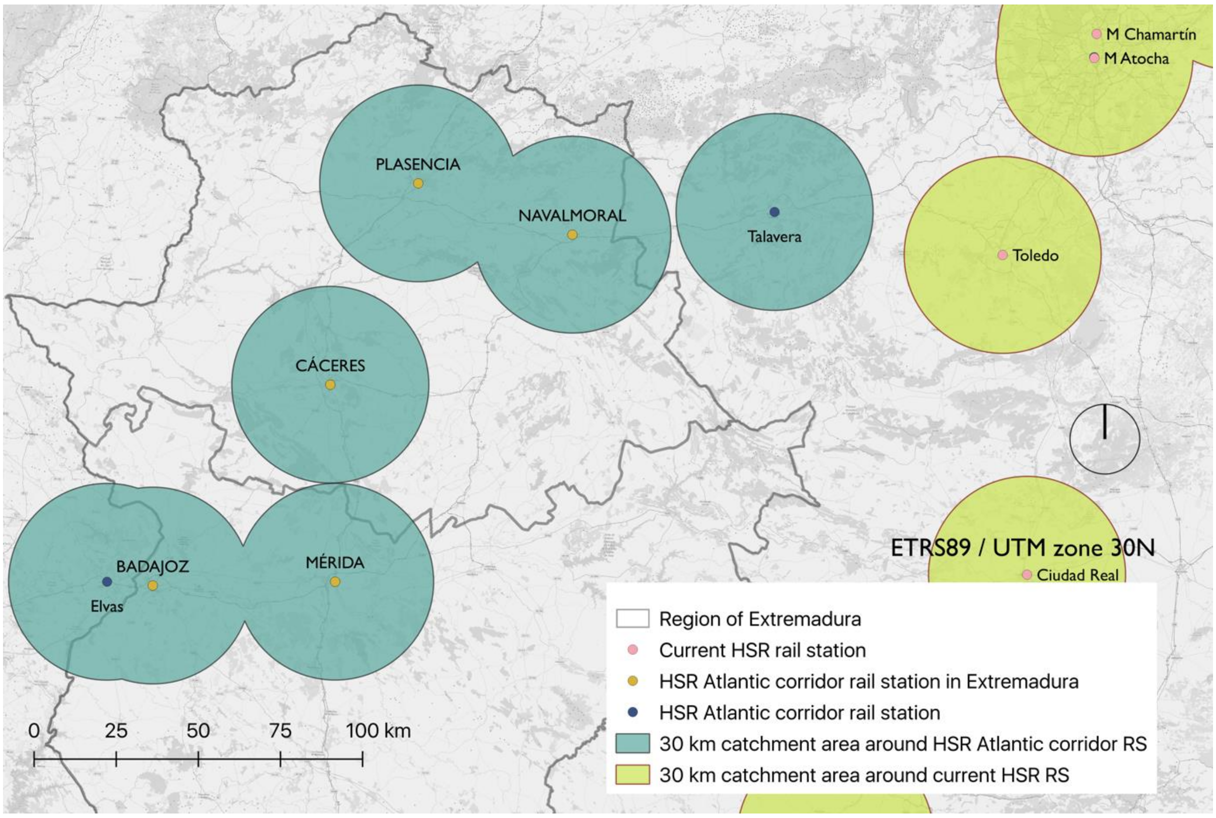


Figure 8. Catchment areas, 30 km around current and future HSR stations. Source: prepared by the author based on the official documents above mentioned.

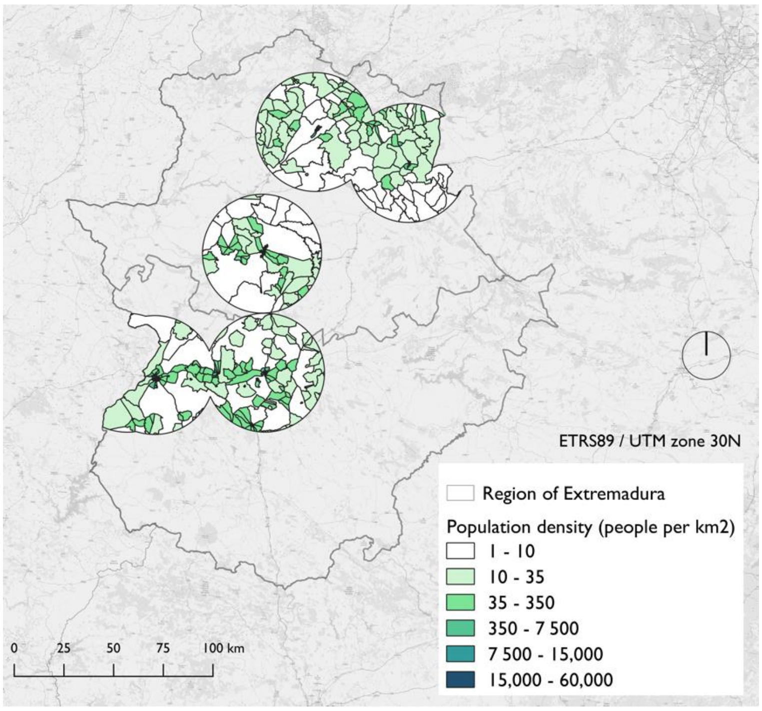


Figure 9. Population living in the defined catchment areas (30 km around the future HSR stations net). Source: prepared by the author based on the official cadaster.

3.3.2. Intermodality

There is a lack of intermodal nodes in Extremadura. The train and bus stations are never integrated into the same space, except in Navalmoral (Table 10), nor does the airport in Badajoz have a train station, even though the line runs near the same. In addition, concerning the future, there is not any future intermodal node projected for the HSR network, being Navalmoral the exception.

Table 10. Intermodality; cities in italics will have an HSR station, with no expected changes. Distance on foot has been defined according to www.google.com/maps (accessed on 28 December 2019).

Node	Intermodality with Bus Station	Distance on Foot
Badajoz Rail Station	*No*	*3.2 km*
Cáceres Rail Station	*No*	*0.4 km*
Mérida RS	*No*	*1.6 km*
Plasencia RS	*No*	*2.2 km*
Don Benito RS	No	0.6 km
Villanueva RS	No	0.1 km
Almendralejo RS	No	1.4 km
Navalmoral RS	*Yes*	-
Zafra RS	No	0.5 km
Montijo RS	No	1.5 km
Villafranca RS	No	0.7 km
Node	**Intermodality with RS or bus station**	**Distance to the closest one**
Airport	No	14 km

Source: the authors.

3.3.3. Competitiveness of Railway Compared to Highway

To evaluate this parameter, the study was limited to cities which will have an HSR station, as well as Madrid and Lisbon. The study of the current situation used data for distances and travel times by train and highway (Table 11), taking the real distance by rail and the real fastest service. For travel in private vehicles, distances and travel times were those between train stations (data: www.google.com/maps, at times without traffic jams, accesed on 21 January 2020). For simplicity, we do not consider other factors, such service interval or extra time for rail services to account for the time passengers spend waiting at the station. This penalty time is considered in research which requires much more precision [62,70]; in this case, it is possible to use the table B4.1 in the *Passenger Demand Forecasting Handbook* [71].

Table 11. Current times train and private car.

	Rail			Road		
Stretch	**Distance**	**Real Traveling Time (minutes)**	**Operating Speed (km/h)**	**Distance (between Rail Stations)**	**Real Traveling Time (minutes)**	**Improvement Time (Rail Over Road) as a Percentage**
Badajoz-Mérida	59	43	82	68	46	6.5%
Mérida-Cáceres	71	58	73	68	48	−20.8%
Cáceres-Plasencia	91	68	73	81	51	−33.3%
Plasencia-Navalmoral	68	53	77	58	38	−39.5%
Navalmoral-Madrid	200	121	99	188	108	−13.0%
Badajoz-Lisbon	-	296	-	229	131	−125.9%

Source: the authors.

The poor competitiveness of the present railroad network has been confirmed. The absence of competition is another of the reasons why it does not make sense to analyze the current system's catchment areas.

In the study of the future situation, new data were taken on distances and travel times (Table 12). For data on HSR distances, the same distances as the trains were used, even though the HSR lines in Spain usually shorten the distances with respect to the traditional Iberian gauge lines (Table 13). The distances between stations must be considered for the commercial speed of the line. For Badajoz-Merida, a speed of 175 km/h was assumed, equal to Puente Genil-Antequera, a 35 km stretch, while for the other Spanish itineraries, a speed of 212 km/h was supposed, equal to Córdoba-Puente Genil, a 74 km stretch. Concerning Badajoz-Lisbon, a 219 km stretch with four intermediate stops and a maximum speed of 250 km/h, data were taken from a similar Turkish HSR stretch (designed for the same maximum speed: the train covers Eskisehir-Bozüyük, a 50 km stretch in 15 min, which means a 200 km/h average speed). As observed, the improvements expected made the HSR faster, and therefore more competitive, than the highway.

Table 12. Comparison of expected time by rail and real traveling time by road.

	Rail		Road		
Stretch	**Distance**	**Expected Time (minutes)**	**Distance (between Rail Stations)**	**Real Traveling Time (minutes)**	**Improvement Time (Rail Over Road) as a Percentage**
Badajoz-Mérida	59	20	68	46	56%
Mérida-Cáceres	71	24	68	48	49%
Cáceres-Plasencia	91	31	81	51	39%
Plasencia-Navalmoral	68	23	58	38	39%
Navalmoral-Madrid	200	57	188	108	47%
Badajoz-Lisbon	219	66	229	131	50%

Source: the authors.

Table 13. Length of some Spanish lines (traditional and HSR).

Corridor	Traditional Rail Line	HSR Line
Madrid-Barcelona	677.6	620.9
Madrid-Sevilla	571.1	470.8
Madrid-Valencia	401.4	397.6

Source: the authors.

3.3.4. Commuter Trains/Suburban Railways

As noted in the introduction, research over the past few years shows that Extremadura is a highly unstructured region, where the accessibility rates of the main towns are extremely deficient. Communications in public transport are very scarce, especially by rail, proof of which is the fact that there has never been a suburban train network in the region. Undoubtedly, the previously mentioned lack of a double-track railway hinders the efficient exploitation of the network.

The PITVI does not consider the possibility of developing a regional rail system in Extremadura. Beyond the big metropolis such as Madrid or Barcelona, there are also Spanish regions that have consolidated the image of metropolitan areas thanks to the geographic proximity of their towns and cities, as in the case of Galicia or Cantabria, although their main cities (Coruña or Santander) are not big metropoles.

3.3.5. Territorial Cohesion by Rail

The map of presence/absence of the HSR in the territory shows that at the present time there are 27 provinces in the peninsula with HSR stations (Figure 10). The PITVI improves this situation notably and takes the HSR to all the Spanish peninsular provinces.

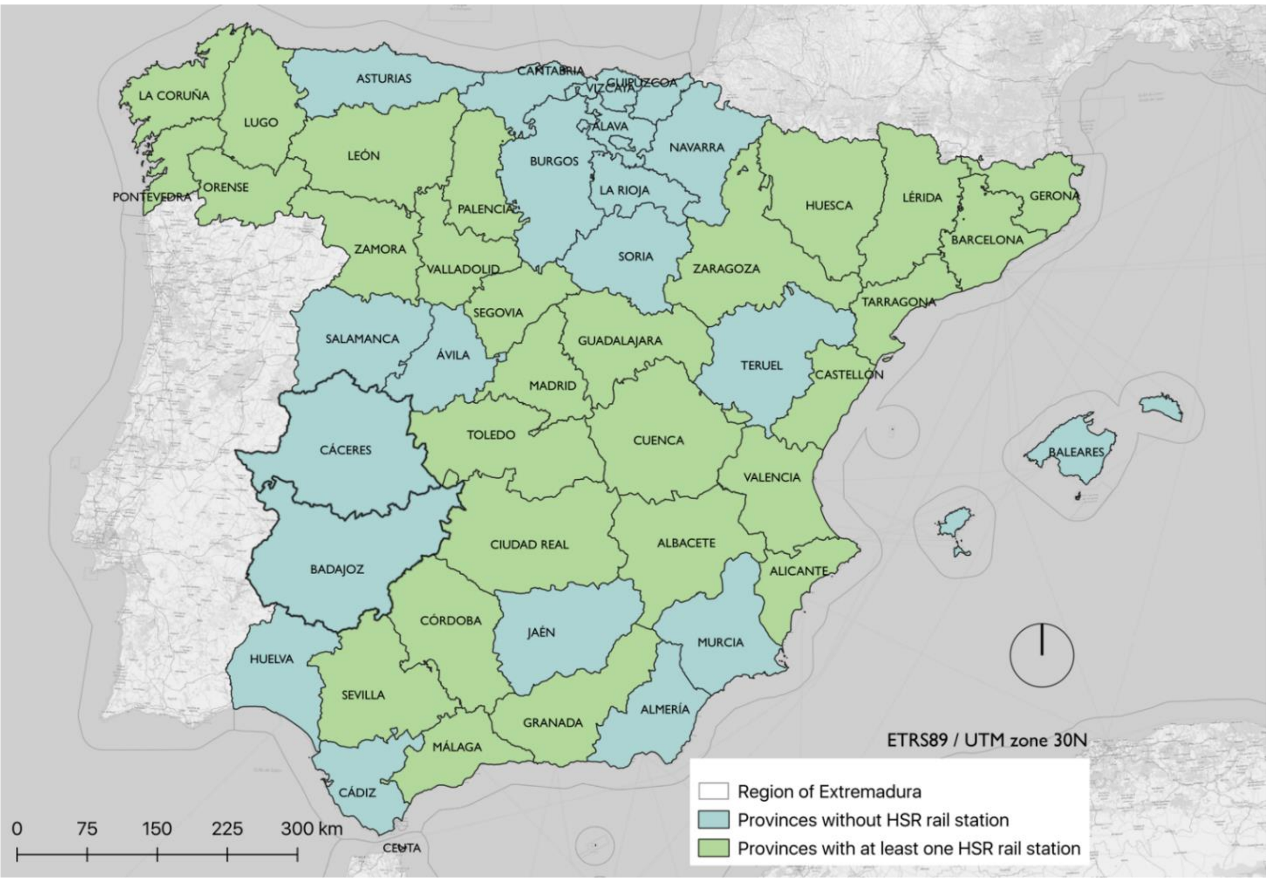
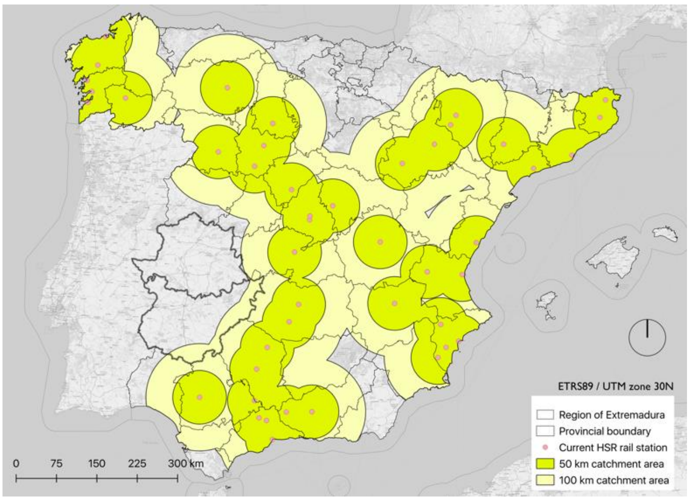


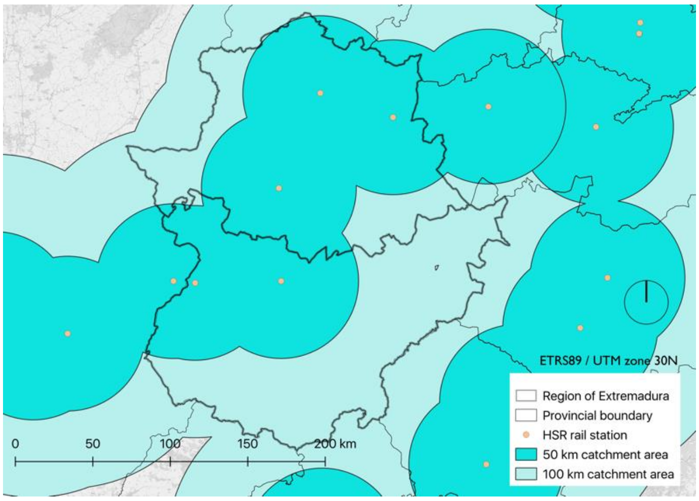
Figure 10. Presence/absence of HSR rail stations (January 2021) Source: prepared by the author based on the official documents above mentioned.

Another map was drawn of the territory located 50 km and up to 100 km away from existing HSR stations (Figure 11). An analysis would show that Caceres is the peninsular regional capital farthest from the entire HSR system (over 150 km). The future scenario shows an interesting change: almost the entire region would be at least 100 km from any HSR system station (except a small area near Talarrubias).



(**a**)

Figure 11. *Conts.*



(**b**)

Figure 11. Catchment areas (50 km and 100 km) from HSR stations. (**a**) Present state and (**b**) future scenario in Extremadura. Source: prepared by the author based on the official documents above mentioned.

3.4. Airport

In Extremadura, there is a mixed-use airport, i.e., civil and military. In terms of the PITVI, no actions are contemplated for Extremadura in this mode of transport.

3.4.1. Physical Airport Limitations

Regarding physical limitations, the current situation of the airport was analyzed with respect to the four parameters defined above: exclusive or shared use of the airport, existence of air-space restrictions, infrastructure boundaries, and fog. A summary is presented in Table 14.

Table 14. Parameters defined.

Parameter	Badajoz Airport
Mixed civilian/military use	Yes
Air-space restrictions	Yes. It is in LER86A and LER86C restricted spaces
Infrastructure boundaries	No
Fog	Yes

Source: the authors.

The airport is joint civil military, a circumstance which causes civil traffic dependency with respect to military traffic and the need for every civil operation to have military authorization, and places practical limitations on air traffic and airport design [72]. With regard to restrictions, the airport is included in two restricted zones: LER86A and LER86C. Insofar as infrastructure boundaries, the current runway, which is 2852 m long, is near the A-5 Freeway (200 m) and the BA-023 highway (220 m). However, a large number of aircraft can operate with a runway that long, meaning this factor is not important. Furthermore, there are open spaces in the surrounding area (Figure 12). Finally, concerning the fog, the Territorial Plan for Civil Defense in the Autonomous Region of Extremadura [73] and the General Directorate for Traffic's map of winter risks [74] describe the zone where the airport is located as problematic in that respect.

It may be observed that the existing airport is conditioned by three of those four parameters.

Figure 12. Open spaces in the surrounding area. Source: Iberpix, Instituto Geográfico Nacional.

3.4.2. Territorial Cohesion

The presence/absence map of airports currently in service in peninsular Spain shows that there are 34 out of 47 provinces with commercial airports in service. The PITVI does not change this situation, as the actions included in it consist of improving facilities already built (Figure 13).

Another map was drawn to show the territory located 50 km and up to 100 km away from an airport. It may be seen how most of the Peninsula is located 100 km at most from this type of space (Figure 12).

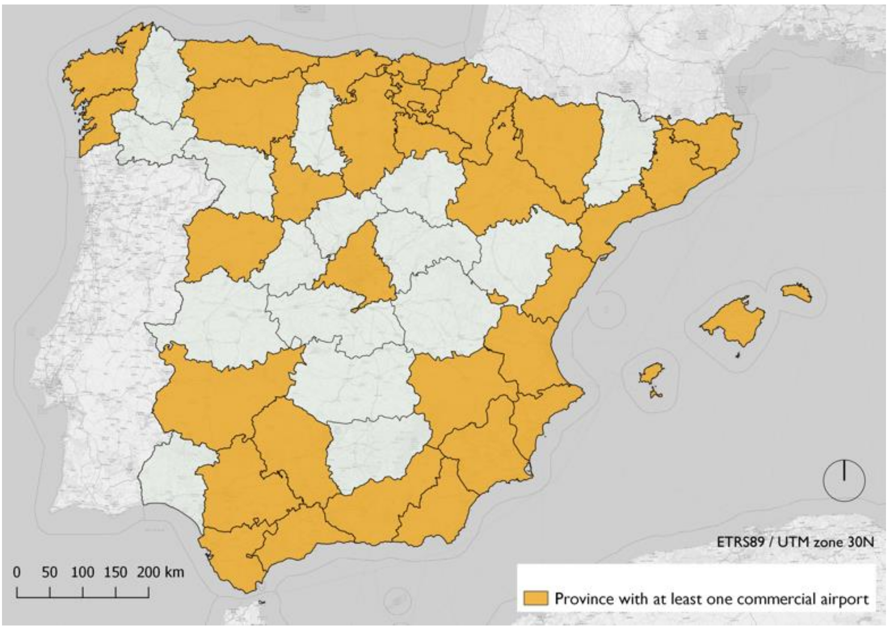


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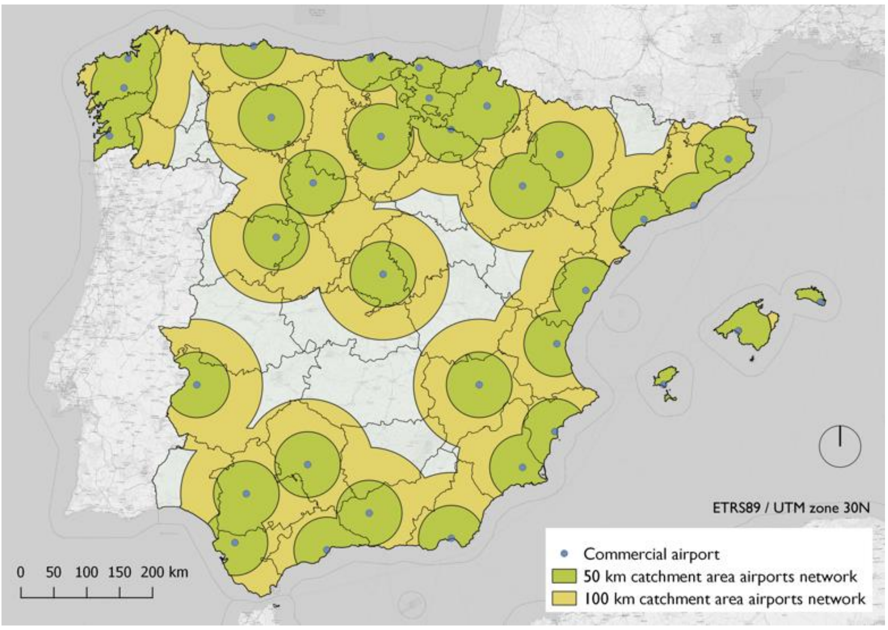
Figure 13. *Conts.*



(**b**)

Figure 13. (**a**) Presence/absence of airports in Spanish provinces (January 2021). (**b**) Airports catchment areas (50 and 100 km) (January 2021). Source: prepared by the author based on the official documents above mentioned.

4. Discussion

4.1. Future Situation of Freeways and the Portuguese Question

The highway network in Extremadura can be defined as adequate, mostly concerning the big towns. Moreover, even the future scenario will enhance the network.

All the towns with more than 12,000 inhabitants are already linked to the general highway network, except Olivenza; the future network will include this one. In addition, the analysis of parameters such as the route factor, the ADT or density show the that the future configuration of the network is on target.

Concerning the ADT, it has been proved that the 10,000 vehicles/day criteria for upgrading roads into freeways has been overcome: in the future, in Extremadura, there will be few not upgraded itineraries with more than 6000 vehicles/day. The global route factor raises an improvement of 5.7%, with Badajoz the city being the most significant growth: 10.4%, while Coria, Plasencia and Navalmoral have the lowest increment (2.7%, 3.0% and 4.2%). These three towns are the northern ones. Elsewhere, the freeway density rises from 16.96 to 30.09 km/km^2, although in the southern Badajoz province the increment is notably stronger (from 13.09 to 31.19 km/km^2) than in northern Cáceres province (from 19.73 to 28.89 km/km^2).

These data corroborate the variation of the existing network, based on the existence of the two historical axes, bedrock of the A-66 and A-5 freeways completed in 2008 and complemented by A-58 in 2010. The future scenario includes three new freeways axis in the south (A-43, A-81 and A-83) which will have continuity in the bordering provinces of Badajoz. Thus, the city of Badajoz will have direct freeway links to its neighboring capitals. That means the historical mobility problems in this province, especially in the east–west connection to Ciudad Real and also Valencia, will be overcome.

However, there is another important problem insofar as the connections with Portugal are concerned. Three connections by freeway to the border are planned by the Spanish authorities, but only one of them will have continuity in the neighboring country (the current one, Lisbon-Caia border itinerary). Adding to this that in Portugal there is no north–south freeway axis near the border, travel on that axis will be very limited (Figure 14).

Finally, another matter remains pending: the proper definition of nodes, which are not explicitly laid out in the planning documents.

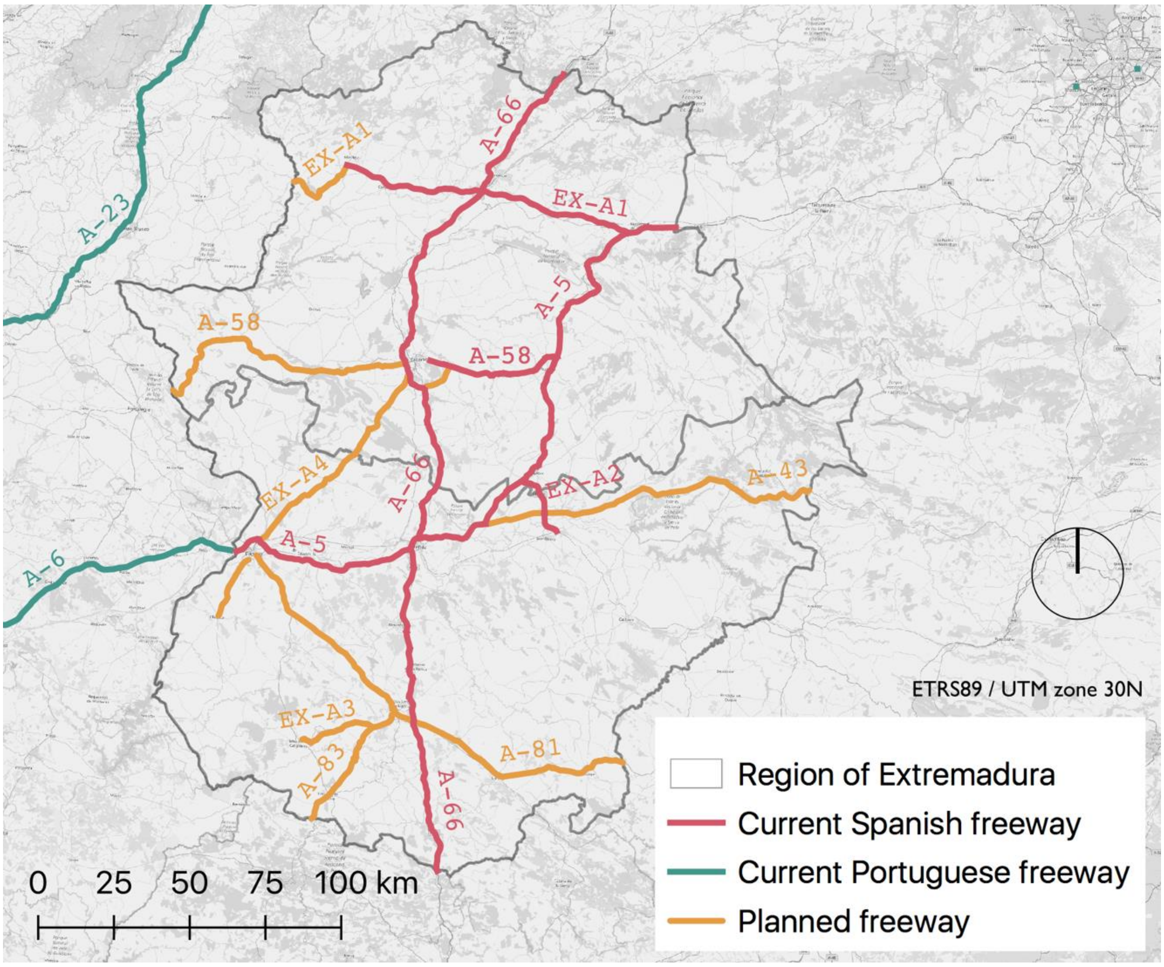


Figure 14. Future freeways in Extremadura and current freeways in Portugal and Spain. Source: prepared by the author based on the official documents above mentioned.

4.2. Future HSR Network, Intermodality and Mobility

Concerning the rail, the situation will be clearly different, mainly because of the new HSR. The planned railway strengthens the preeminence of the Madrid-Lisbon axis. In contrast to the freeway network, where a clear north–south axis can be found, in the HSR network only a "in study" northern link is described and not even a southern link to Seville is cited; moreover, a possible connection to Portugal in the north is not evaluated, despite that in the recent past this was the base of the Lisbon-Madrid itinerary (in fact, this would the shortest rail route between the two Iberian capitals). Thus, a planned HSR network will reinforce the main axes but will not change the current lack of links to the north and the south.

The major matter pending is the location of stations with respect to cities, with two possibilities: peripherical or central. Both cases have been established in Spain, also in some other countries such as France, and research has proved that location determines in a radical mode the future urban development [75,76].

The main argument justifying a peripheral station is associated to the reduction in travel time of the main itinerary. Penetrating the cities makes the route longer. Furthermore, city stations require the use of more substantial construction, making them more expensive. Nevertheless, these costs in the average city should not be significant compared to the cost of the whole line. By comparison, the main advantage of city stations is the capacity for capturing more travelers, since in addition to long-distance services, regional services could also be introduced [77].

In terms of travel time reduction, the new HSR lines are usually implemented in areas with a notable prior presence of aircraft with which it competes [78], and, in fact, this appears to be the case in Spain [79]. Nevertheless, the HSR in Extremadura is uncommon in the country: this line will not compete, with guarantees, with the aircraft in the Lisbon-Madrid connection since the projected speed scheduled in the Portuguese stretch, 250 km/h, makes it all the more difficult to cover the Madrid-Lisbon stretch with no intermediate stops in less than 180 min (Table 15), as this is the competitive threshold when air travel takes about 80 min [80]. Certainly, when the Atlantic rail axis is completed, there will be a relevant percentage of travelers moving by HSR between Madrid and Lisbon, but the conception of the line leads one to think that this is an ideal infrastructure for structuring the intermediate territory through the succession of existing stops, more than for capturing flows of travelers needing to travel between Lisbon and Madrid at a higher speed than that offered by aircraft.

Table 15. Framework for HSR and aircraft journey time comparison. Data: (Givoni, 2005) and current flight time Madrid-Lisbon. Distance Madrid-Border 491 km, expected commercial speed 248.4 km/h; distance Border-Lisbon 217 km, expected commercial speed 212 km/h.

Aircraft Journey (In Minutes)		**HSR Journey (In Minutes)**	
Rail journey city center-airport	20	Time to embark	20
Time to embark	60	HSR journey [1]	180
Flight Madrid-Lisbon	80		
Rail journey city center-airport	20		
Total journey	180	Total journey	200

Source: the authors.

However, the arrival of the HSR with central stations can involve a change of mode: the significant cutting down of expected travel times between regional cities (Table 12) and the presence of a double track bring the possibility of using the new line for regional services. HSR central stations allow to introduce a regional rail transport system. An example of HSR line exploited as a regional rail network is the regional metropolitan line between Stockholm and Eskilstuna (Sweden), 115 km with four intermediate stations. Since the line is an HSR one, the number of travelers was multiplied by seven, and the percentage of the metropolitan journeys between Stockholm and the other stations has increased from 6% to 30% [81].

Furthermore, the current absence of an efficient public transport network and the lack of intermodality lead to mobility in Extremadura tending toward using a private vehicle, thus causing a lack of demand for public transport. Town planning is also orientated toward the private vehicle, producing the presence of the town-cluster model [82], closer to the urban features of the Mediterranean countries where urban sprawl leads to the failure of the public transport system [83]. For that, future stations should be converted into transport nodes, and town planning should be aiming at creating new town centers in the districts around the stations, which is something that does not occur today. In this sense, municipal urban planning should turn toward the new transportation infrastructures, maybe in line with TOD models [84], ABC plans from the Netherlands or the five fingers Copenhagen model which advocated "the right business in the right place" motto [85–87]. It is well known that central rail stations are even positive for the health of city dwellers, as they impulse the pedestrian mobility [88], or for developing integrated labor markets [89]. In Spain, by contrast, there are some examples of erroneous urban political decisions, which have caused the construction of ghost cities in the periphery of well-consolidated cities [90].

Likewise, the significant improvement in the freeway system could contribute to schematize bus as a feeder of the HSR network; this model is currently being developed in the region of Galicia, whose seven HSR stations will be also bus terminals [91]. Nevertheless, a wrong model in terms of usefulness and connectivity of the nodes could even impact negatively in the future number of services offered by railway operators for regional, interregional and international connections. Thus, it could happen that the absence of demand creates a lack of intermediate stops in the Lisbon-Madrid services; in that sense, it would be necessary to develop awareness campaigns after the line will come in service.

4.3. The Airport

Concerning the air transport network, the current airport is inadequate for the region. A research on the Spanish airport system [92] revealed scale deficits in Badajoz airport, partly due to their mixed use. For this reason, the airport cannot be considered as more than a provisional installation, pending construction of a new infrastructure.

In terms of volume of population, Extremadura could not need an airport, and that it would be sufficient to connect the region better to Madrid, Seville and Lisbon. However, in terms of territorial structuring, construction of the airport is considered to be vital. In the introduction, mention was made of the increasing relevance of international tourism linked to heritage and the environment in the regional economy. Airport infrastructure is the first and last point of tourists' contact in their holiday destination and constitutes the mobility axes of tourists [93].

Moreover, the aeronautical market has changed in recent years with the appearance of low-cost carriers (LCC), which enables direct flights between small cities and large cities at competitive prices for a small number of potential users; the existence of significant scope for exploiting better connections in the intra-European markets for LCC has been proved [94]. It has been proved how the substantial increase in LLCs after the integration of Europe has provided an extensive boost in demand to/from foreign countries for regional airports in the whole continent [95–97]. In addition, in the British Isles, with a strong airport density, the development of an LCC network has proved that no matter whether a regional airport operates as an origin or destination gateway, notable improvements in the accessibility linked to these nodes can play a significant role in economic and/or tourism development [98]. Badajoz airport is not used by LLC nor does it have connections with other European countries: another proof of its bad operativity.

The main question is to define where it should be built an eventual new airport, outside of the restricted air areas and of the fog areas, and close to both freeways and HSR networks. Some studies have evaluated the possibility of planning it near Cáceres: since 1975, several attempts have been made to build an airport in the vicinity of this city, being the last of these dates back to 2008 [99].

Some data can reinforce the idea of a possible new airport in Caceres, in terms of territorial accessibility. If the Badajoz and Salamanca airports—both with restrictions for civil use due to their military titularity—are not borne in mind, Extremadura is the only region with no commercial airport, being Cáceres the sole Spanish province that does not border on another province with an airport (Figure 12). Moreover, a study showed Cáceres in the group of the worst NUT-2 regions by air connectivity [100].

In any case, the airport should be located on a point of the new HSR line, in order to project an HSR station in the airport. Article 10 of Decision No. 1692/96/EC highlights the fact that attention should be paid to the connection of regional airports to the network: in this case, an eventual airport should be well connected to the Atlantic axis. The intermodality HSR–airport has been largely discussed. López Pita and Robusté [101] have illustrated the need for the European transport system to consider both rail and air travel from the viewpoint of complementariness. Janic [102] has also described the significant mitigation of environmental impacts and energy consumption of the air passenger transport that could be achieved by increasing the complementarity of operations of both HSR and air transport models. Givoni and Banister [103] have argued about the benefits of the aircraft and HSR integration and cooperation, and they have emphasized the importance of rail stations into airports. It has been described that air–rail cooperation could be viewed as a special type of "code sharing" which is common in the airline industry, similar to the hub-and-spoke operations offered by two airlines [104,105].

Finally, it has been widely established that regional airports are economically sustainable if there is a significant use of the infrastructure, or else they would be a problem rather than a resource for its region [106,107]. Although the existence of advances in new models of sustainable management of small airports [108], which should be applicated in such airport, its viability could depend on this link to the HSR system. In this case, Cáceres could be considered as a peripherical airport for Madrid. RENFE, a rail operator, considered that the Barcelona airport hinterland includes Madrid (150 min using the HSR) [109]; according to this distance, the eventual Cáceres airport hinterland would include both the Madrid and Lisbon areas (Table 16). OUIGO French system [110] can be considered as a pioneer project for linking city centers and ultra peripherical airports through HSR low cost services; IZY low cost rail [111] and the AVLO [112] would continue this trend.

Table 16. Distances in minutes from the Cáceres airport to the two capitals in the peninsula, with no intermediate stops. Spanish expected commercial speed 248.4 km/h; Portuguese expected commercial speed 212 km/h.

City	Population (Eurostat 2014)	Distances to Cáceres (km)	Distances (Min)
Madrid	6.5 M	359	87
Lisbon	2.8 M	349 (217 in Portugal, 132 in Spain)	93

Source: the authors.

5. Conclusions

This study analyzed the present and the future of the transportation network—freeways, high speed rail and airports—of Extremadura, a Spanish region. According to the planning documents in force at state and regional level, some transportation infrastructures are expected to be built in the next years which could transform the regional transportation system and therefore could act as an important lever for economic and social change.

To do this, an ex ante study was carried out. Some parameters were defined for evaluating the current situation and also the eventual scenario after the construction of all the planned infrastructures. Open software QGIS was used for determining different catchment areas and also for plotting figures which represented transport networks or presence/absence data.

The research has set the deficiencies of Extremadura in terms of transportation network, but current planning proves that the rail and airport infrastructures in Extremadura are set to involve a significant change of model. The planned freeway network will signify a substantial improvement, apparently adequate for the needs of the region. In addition, the new axis could generate a new territorial system, outstanding the traditional preponderance of the two historical two axis, exemplified today by the A-66 and the A-5 freeways.

Moreover, the rail network will be strongly modified because of the new HSR line, which will connect the mail cities to Madrid and Lisbon; this new line involves the construction of the very first double and electrified track in the region. Finally, it has been established that Badajoz airport has strong limitations which determine its use as a touristic gate for the region.

Concerning freeways, a substantial improvement of the connections between the province of Badajoz and its bordering territories will be carry out. This can be reasonable, as most of biggest town are located there; by contrast, in terms of territorial cohesion policies, this could increase the existing differences between both Extremaduran provinces. Furthermore, and surprisingly, the connections typology between freeways are not clearly defined in the planning documents, although some of the existing ones are not well resolved for the moment.

Moreover, some following matters has been suggested in the discussion. The HSR network should be taken on board as the basis for launching a suburban service, thanks to the location of HSR in town centers; however, they should have been designed as a transport and urban node. Lastly, it has been argued that if a new airport is finally built, it should be designed near the HSR rail line, which should have its own rain station for improving the intermodality.

The research has only considered three networks developments—freeways, HSR and airports. Future research could take in account some other parameters, such as rural and urban transportation infrastructure and service, for evaluating the first and last mile connectivity, maybe examining the urban context in one or even the three biggest cities or in a particular county. In addition, future research could look at whether these planned infrastructures would meet the development needs to some extent and what would be the impact on economy, tourism and social development.

Furthermore, the act of selecting a limited number of parameters is a sort of bias. It is clear that there are a huge number of parameters for evaluating the effects of transportation networks in a territory or in a city. Future research could take for comparing some other socioeconomic parameters such as population serves, transport demand, passenger/freight volume, key transport routes, etc.

Another bias is the construction of nonplanned infrastructures due to political or technical decisions which can modify the theoretical final scenario (for instance, the A-58 and the EX-A4 freeways could be modified in their itinerary or even suppressed). Moreover, some itineraries of the future freeway system remain undefined, as it has been already stated, and our hypothesis of considering that future freeways will have the same route of the existing roads could be erroneous. Also, the research was completed while the Portuguese PETI 3+ 2014–2020 plan was in force; however, the country has developed a new planning document in the last months.

Additionally, the future detailed research on the HSR effect in Extremadura should be done, but it should wait to the final location of the stations, too; it is well known that whilst there are great potential gains from access to HSR, these are not automatic, and impacts are not always positive [113]. Another pending research, in the whole of Spain, is the analyses of the effect of current HSR planning network and tone of the biggest problems in rural Spain: the *España Vaciada* (or Emptied Spain) [114–116]. Likewise, this research has detected the lack of a compared study on real distances covered by HSR between consecutive stations and the commercial speed developed: clearly, shorter distances generate slower commercial speeds, and these data would be really useful for planning future regional rail services in HSR lines. In this research, some data from different countries have been selected, but it would be practical a kind of curves linking distances and commercial speeds based on real cases. Additionally, this text has underlined the great differences between the length of the traditional non-HSR railways and the new projected HSR lines in Spain, and it could be a first stone topic for developing future research on the differences between both systems.

In addition, this research proves the importance of taking into consideration the transport planning documents of neighboring countries in the transport analysis of bordering regions and the negative consequence of designing national and regional transport plans without considering the neighbor own plans. It would be desirable for national and regional authorities to take decisions more closely together, looking beyond the international summits and establishing, in this particular case, a common Iberian transportation master plan.

Finally, the research has stated the importance of evaluating several transportation systems at the same time; despite the arise of some biases, questions such as intermodality, the emplacement of nodes, the rise of different axis or the possibilities for combining different modes of transportation will be clearly identified. Future research over other territories could take this one as an example for evaluating, through an ex ante analysis, the strengths and weaknesses of planning documents.

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