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Is high-speed rail a sustainable mobility option? A life-cycle assessment of the Basque Y project in Spain

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ABSTRACT

The Basque Y High Speed Rail connection between Madrid and the Basque Autonomous Community is, quite exceptionally, a mixed freight and passengers HSR line, that has been presented as a fundamental step towards a more sustainable mobility. In this paper, a life-cycle assessment (LCA) is conducted to assess the environmental performance of the line throughout its lifetime, based on the latest data available, including both construction and maintenance burdens. Results show that this new corridor is not justified in terms of reducing emissions and energy consumption, mainly due to its low transport density. It also has a negligible impact on Spanish current low rail freight traffic. We conclude, therefore, that Spain needs to reconsider its AVE network expansion if aiming at increasing rail's modal share and meeting the emissions targets set by the EU. From a policy perspective, many information inconsistencies have been found regarding the demand projections of freight transport, which cast serious doubt about the decision-making process behind Trans-European transport projects.

1. Introduction

The increase in the global average temperature of planet Earth as a result of climate change is part of a global environmental crisis that is increasingly threatening the survival of the human race (United Nations, 2022a). Its serious consequences require not only long-term plans and actions, but also immediate and urgent measures. Consequently, the European Union (EU) and its Member States have agreed, under the European Green Deal, to reduce their greenhouse gas (GHG) emissions by 2030 by at least 55% compared to 1990 and achieve emissions neutrality by 2050 (European Union, 2021; European Commission, 2020a).

Mobility and the transportation of passengers and freight play a key role in this crucial human strategy (Pons et al., 2020). The transportation sector, mainly powered by fossil fuels derived from oil (95% of transportation energy in Europe), accounts for around a quarter of GHG emissions in Europe and, far from decreasing, these have increased by 29% from 1990 to 2018 (European Environment Agency, 2019). Thus, in terms of a common strategy for sustainable mobility, more environment-friendly modes of transport should be promoted (European Commission, 1992), and High-Speed Rail (HSR) seems to fill that gap, since rail transport is generally assumed to have a great capacity to achieve considerable reductions in GHG emissions and energy consumption (California High-Speed Rail Authority, 2016; European Court of Auditors, 2018; Jehanno et al., 2011). Since HSR is powered by electricity, it is argued that the environmental benefit is clear, because it shifts passengers and freight from more polluting modes of transport (car, aeroplane, etc.) to one with lower environmental impacts. Thus, the HSR project in the Basque Country, also known as the Basque Y, has often been presented as the most important step towards the ecological transition of the region (SPRI, 2020) and, therefore, as fundamental in order to meet the GHG emissions reduction objectives set by the EU for 2050. For these reasons, the Basque Climate Change Strategy 2050 (Basque Government, 2015) concludes that this new high-speed project would be crucial for the fulfilment of those goals. However, these alleged benefits come from analysing just the network's operation and do not take into account the environmental burdens related to building and maintenance phases of the infrastructure (Kortazar et al., 2021a). It

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is quite common to find analyses that do not count the impacts from construction of the infrastructure and therefore underestimate the total life-cycle emissions (Chester and Horvath, 2009; Jones et al., 2016).

There are several very interesting Life-Cycle Assessment (LCA) papers ((Kaewunruen et al., 2020b, Kaewunruen et al., 2020a; Lee et al., 2008; Lin et al., 2019; Rungskunroch et al., 2021)) but they only partially cover the scope of this paper. In fact, few studies have attempted to include in their analysis such impacts from construction of the infrastructure. Bueno et al. (2017) performed a limited environmental LCA of the Basque Y HSR, a small corridor of the Spanish AVE network, which included the construction and maintenance phases of the infrastructure in its analysis. Similarly, the LCA methodology was more recently used by Kortazar et al. (2021a) to assess the environmental performance of the complete AVE project, including the construction and maintenance phases of the high-speed infrastructure. The authors concluded that the building of the Northern and Levante lines would not be justified in terms of GHG emissions reduction and energy demand decrease, and that this is mainly due to its low transport density. The indicator used to compare the transport service on networks of varied extension is annual transport density: the transport/extension ratio of the network, which is equivalent to the number of passengers that would annually travel over the complete infrastructure. The transport density of an HSR project is an indicator of the service provided by the infrastructure and would behave as production does under the Law of Diminishing Returns of classical economics. This law states that, in all production processes, increases in one of the productive factors (while keeping the others constant) will give progressively smaller increases in production per unit (Samuelson and Nordhaus, 2001). Furthermore, investments in transport infrastructure tend to have diminishing returns, too (Rodrigue, 2020). Initial investments in transport infrastructure usually have a high economic return, since they cover a gap in terms of mobility, but as the infrastructure improves, these investments have less and less economic return. Therefore, transport density of HSR networks shows diminishing returns, too. In other words, beyond a certain extension threshold, adding more length to the network inevitably causes the transport density to decrease: once the areas with the highest population density have been connected and the peak of demand is reached, subsequent connections will only decrease the overall transport density of the infrastructure. Such is the case of the AVE network in Spain, where the maximum transport density was reached in 2009 with 9.2 Mp (million passengers) and subsequent expansions have reduced the density to almost 6 million passengers (Fundación de los ferrocarriles españoles, 2021; UIC, 2020).

The Basque Y HSR will be an extension of the Northern line in the Spanish AVE network, but with a unique difference, since it has been designed for the mixed transport of people and freight. However, it seems that this new line will not improve the results in terms of transport density, nor in terms of emission reduction and energy savings for the corridor and the network. In light of this, the present work attempts to answer to the following questions: What would be the transport density of the Basque Y HSR? What would be the environmental impact balance of the infrastructure when it is put into operation? Would the implementation of the infrastructure lead to a sufficient reduction of GHG emissions to meet the targets set by the European Union?

1.1. Context of the Basque Y HSR line

The Basque Autonomous Community (BAC) is one of the most populated and industrialised regions in Spain (300 inhabitant·km^{-2}). It has always been a strategic area for the transportation of people and goods between Spain and France. Its 2.2 million inhabitants account for 4.6% of the Spanish population and it is one of the areas with the highest income per capita in Spain and its economy contributes to 6.3% of the Spanish GDP.

The Basque Y HSR line was designed to be part of the Northern Corridor[2] of the Spanish HSR network, popularly known as the AVE network, aimed at connecting Madrid to the BAC and to France via the west end of the border. The state-owned company ADIF-AV is responsible for the management of the entire HSR infrastructure, thus managing the second longest HSR network in the world, with >3000 km already in operation in 2022 (ADIF, 2022), and more sections are being built or projected. After China, Spain is the country with the most high-speed kilometres built and in operation (Albalate and Bel, 2016; European Court of Auditors, 2018). Exhaustive information of the Spanish AVE HSR project can be consulted in Kortazar et al. (2021b).

The Basque Y line will connect the region's three capitals in a three-pointed star network design and will cover 190 km of the region's complex orography (see Fig. 1). Its construction began in 2006 and the line was expected to be operational by 2015, but continuous delays have postponed this to at least 2027.[3] This line is designed with the European high-speed rail characteristics: 14-m wide platform, 1435 mm international gauge track and electrified at 25 kV and 50 Hz. But it also has an exceptional feature: it is designed for combined passenger (230–250 km/h) and freight (90–110 km/h) traffic. It should be noted, however, that the Spanish AVE trains operate exclusively for passenger traffic (Kortazar et al., 2021a). Therefore, it remains unclear whether and how much cargo would finally run along the Basque Y HSR, especially after the Spanish government has confirmed that its Southern connection with the AVE network (Burgos–Vitoria-Gasteiz) will only be compatible with passenger transport (INECO, 2017). A similar situation can be found at the French border, since the TGV network was not designed for freight transport and, furthermore, French authorities do not plan to initiate any action on the section in Aquitaine, between Dax and Hendaye, before 2037 (European Court of Auditors, 2020). Meanwhile, the construction works for a mixed traffic network continue, and this requires very demanding geometric path parameters, with wide curvature radiuses and very small slopes in an environment of complex geomorphological characteristics. Due to these restrictive parameters, the majority of the route is made up of tunnels and viaducts that allow these huge orographic barriers to be overcome. (See Fig. 2.)

1.2. Objective and structure of this article

The fundamental goal of this research is to evaluate the capacity of the Basque high-speed rail line to mitigate global warming and reduce energy demand in the Basque Country, and to verify whether it will contribute to the accomplishment of the environmental objectives set by the EU for 2050. To this end, this work studies the environmental performance of the Basque Y HSR line in its estimated useful life of 60 years and including the building and maintenance phases of the infrastructure, following the Life-Cycle Assessment (LCA) methodology, and using the latest data available. This article is the continuation of several previous works carried out by the authors. The first work on the analysis of the high-speed rail began in 2016 as part of an interdisciplinary study on HSR transport (Albalate and Bel, 2016). The methodology follows the same model designed by Kortazar et al. (2021a), updating and expanding upon the research gathered by Bueno et al. (2017) by increasing the number of environmental impact indicators analyzed and using the latest published data available on future passenger and freight demand. The environmental loads generated throughout the life-cycle of this line are presented for the same environmental impact categories and elementary flows selected by the European Commission for the evaluation of external costs of transport (European Commission, 2020b). The

[2] The four corridors of AVE network: Madrid-Catalonia, Madrid-North, Madrid-Levante and Madrid-Andalusia.

[3] Latest statements set 2027 as the new start year (Gómez Camacho, 2021).

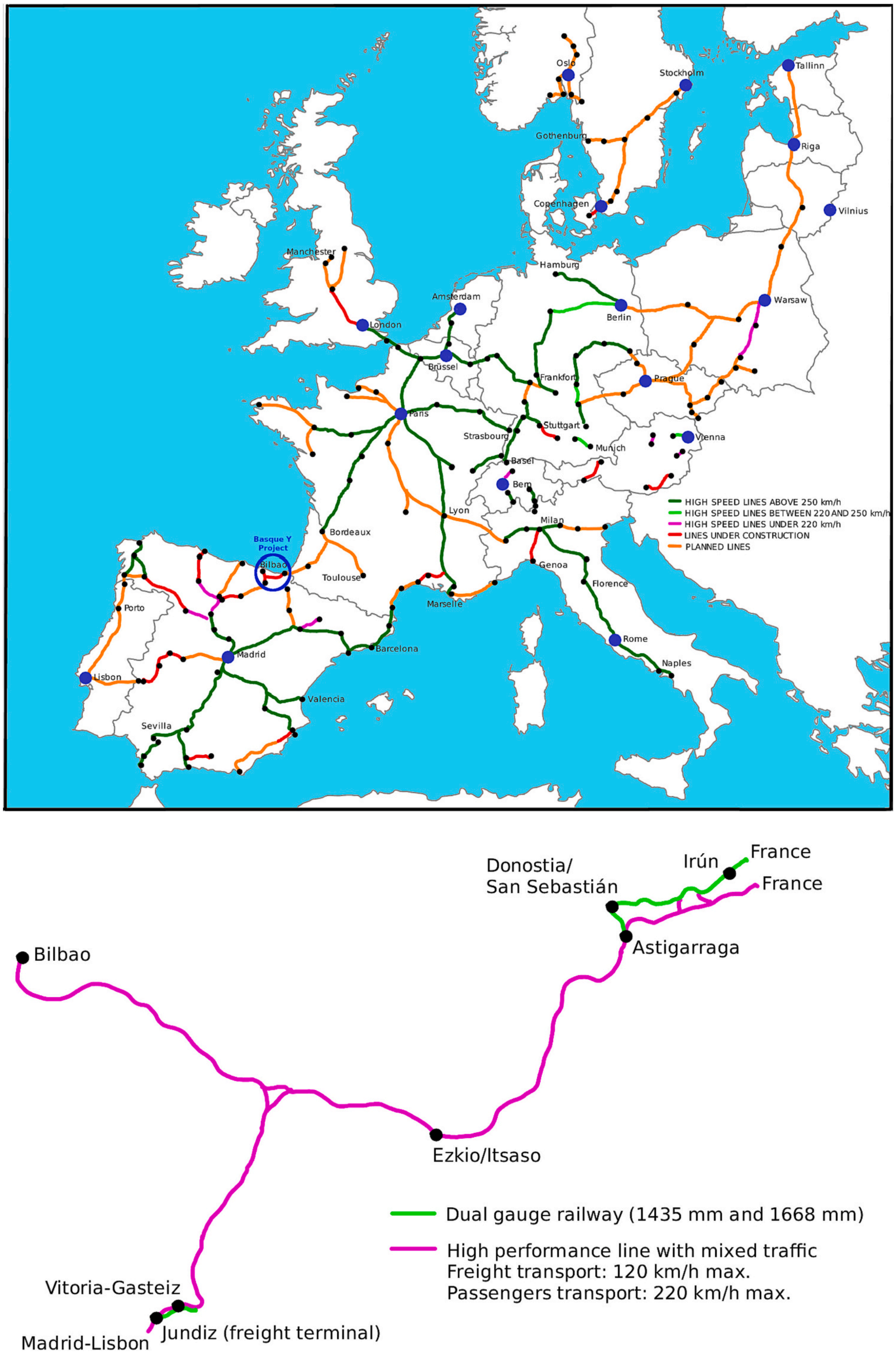

Fig. 1. (a) European HSR network map in 2018. Own elaboration based on UIC (2021). (b) Layout of the Basque Y HSR network.

geographic scope coincides exactly with the 190 km projected in the design of the line and still under construction in 2023.

As a secondary objective, this work calculates transport density, measured in equivalent passengers and equivalent tonnes over the complete infrastructure, in order to assess the environmental profitability of this high-speed line. This allows us to evaluate whether the connection of the Basque Y with the AVE network in Spain and with the TGV network in France will be capable of increasing transport density.

This paper applies the methodology developed in Kortazar et al. (2021a) to the Basque Y HSR, which has the particularity that it will also carry freight. To our knowledge, there are no precedents for an LCA study of a high-speed infrastructure for passengers and freight. As the network is still under construction, the passenger and freight traffic estimates used are based on the forecasts made by the promoters. The results of this study question the environmental viability of the project and could influence the future operation of the line. This article is structured as follows: Section 1 presents the introduction of the current Basque Y HSR situation and description of objectives, followed by Section 2, which presents the data, methods and information used in the environmental analysis as well as the characteristics and properties of

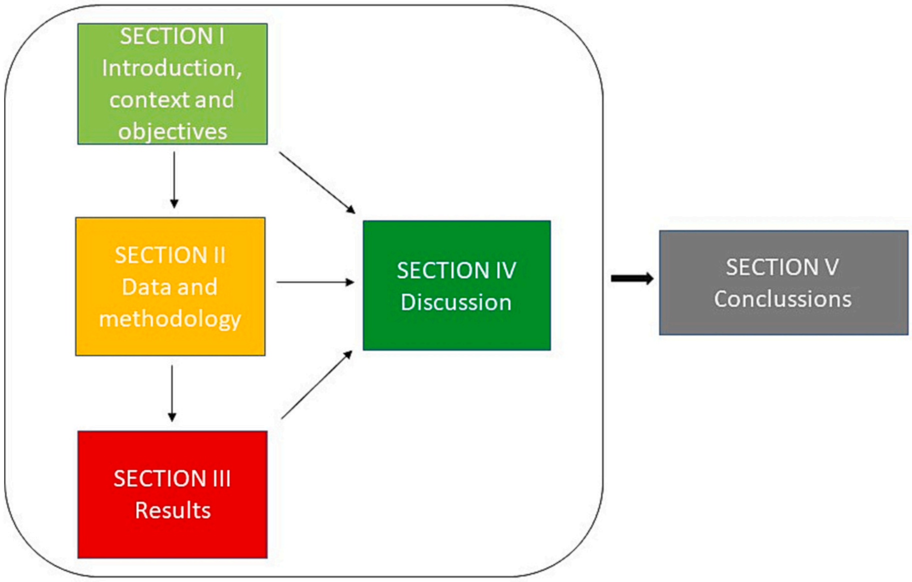

Fig. 2. The structure of this article.

the different scenarios. Next, Section 3 presents the study's main findings, of which Section 4 provides a detailed discussion. Finally, Section 5 gathers the main conclusions drawn from this research. Further details on the application of the methodology, the data used etc. can be found in the "Data in Brief" article (Kortazar et al., 2023).

2. Methods and data

In order to verify the potential displayed by the Basque Y HSR line for mitigating climate change and increasing energy savings in the BAC, an exhaustive environmental study has been carried out based on the LCA methodology developed by Kortazar et al. (2021a) to assess the environmental burdens of the AVE network.

This LCA collects and analyses the main inputs (energy and material consumption) and outputs (emissions, waste and by-products) of the Basque Y project throughout its entire life-cycle. System boundaries considered in this LCA encompass transport infrastructure within the Basque Y network throughout the calculation period, including operation, construction, maintenance and disposal of vehicle fleet, track system and main buildings, following the approach adopted by Tuchschmid et al. (2011); production of traction energies for all transport modes follows ecoinvent v3.7 (Steubing et al., 2016); and system boundaries for transport services shifted from other modes to the Basque Y also follow ecoinvent v3.7 (operation, construction, maintenance and disposal of vehicles and other infrastructure). The functional unit for this analysis is the passenger and freight transport service provided by the Basque Y HSR line during the calculation period for the operation phase of the LCA, of 60 years, as in the environmental product declaration (EPD) of passenger transport on the Bothnia Line (Stripple and Uppenberg, 2010; The International EPD system, 2010). Since passenger and freight transport evolves over the years, our modelling is annualized. Tables 2 and 3 show the annual densities of passenger and freight transport considered, and thus define the functional unit. Impact results are also calculated annually (as shown in Tables 8 and 9 and Figs. 3 and 4).

The reminder of this section describes the Life-Cycle Inventory (LCI) data used and the modelling approach followed to be able to analyse the environmental performance of the HSR project.

2.1. LCA modelling approach

The LCA allows for the calculation of the net balance of Environmental Impacts (EI) of any high-speed rail project from a life-cycle perspective. The net EI of any new HSR project for a particular environmental indicator, i.e. PM10 or NMVOC emissions can be expressed as:

$$NetEI = \sum EI^{HSR}_{Construction \wedge Maintenance} + \sum EI^{HSR}_{Operation} - \sum_i EI^{i}_{i \rightarrow HSR} \quad (1)$$

where i stands for different modes of passenger and freight transport (Kortazar et al., 2021a).

For the calculation of the net environmental impacts of this project, the construction, maintenance and operation phases have been considered separately; subsequently, all the environmental impacts related to the shifted transport of passengers and freight from any mode of transport to the HSR have been subtracted. As these modal shifts from conventional modes of transport to the HSR constitute environmental benefits that must be attributed to the HSR. If all these environmental burdens related to this shift of passengers and freight from conventional transport modes to the HSR in a sector without HSR project are higher than the annual environmental burdens linked to all phases of the HSR, the net EI balance in a particular category will provide an environmental benefit (i.e. Net EI < 0) (Kortazar et al., 2021a). Thus, environmental performance of a high-speed rail project on a specific indicator depends primarily on the power to shift significant quantity of passengers and freight from other conventional transport modes to the high-speed rail (Kortazar et al., 2021c).

2.2. LCI data on the construction and maintenance phase

To calculate the environmental loads of the construction and maintenance phases of the HSR project, it is necessary to have a detailed description of the layout, which includes infrastructures details and its measurements. To that end, it has been possible to carry out an aerial review of each meter of the route based on the work developed by stakeholder "AHT gelditu!". This social movement carried out a detailed diagram of the line using the GoogleEarth tool, and collected all the information in a file that is available on their website (AHT Gelditu, 2019). This meticulous work allowed us to depict the whole infrastructure in detail (see the Data in Brief article (Kortazar et al., 2023)).

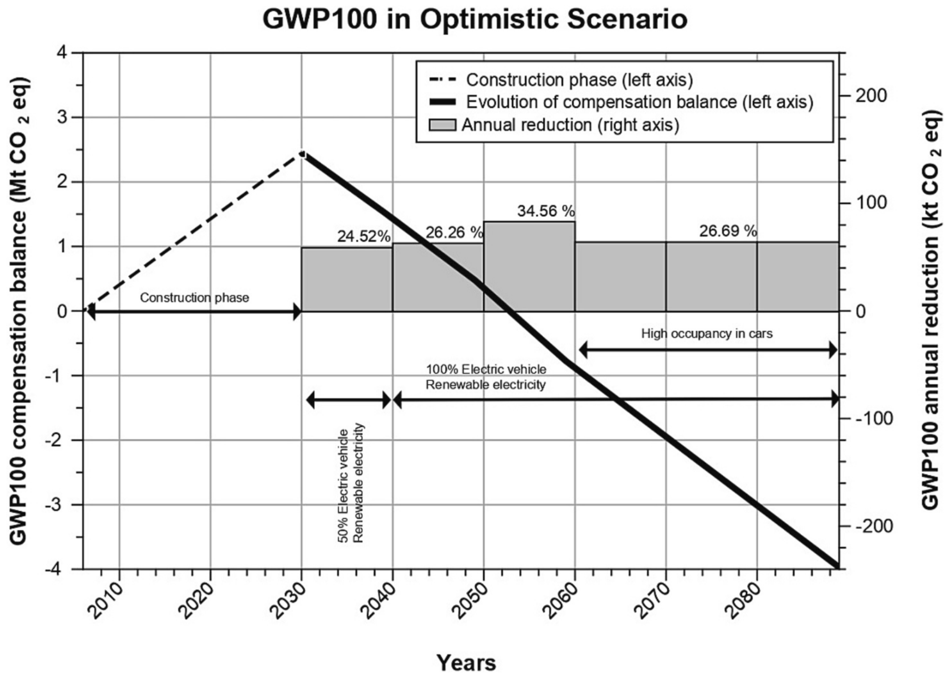

Fig. 3. GWP100 compensation balance and annual reduction in the Optimistic Scenario.

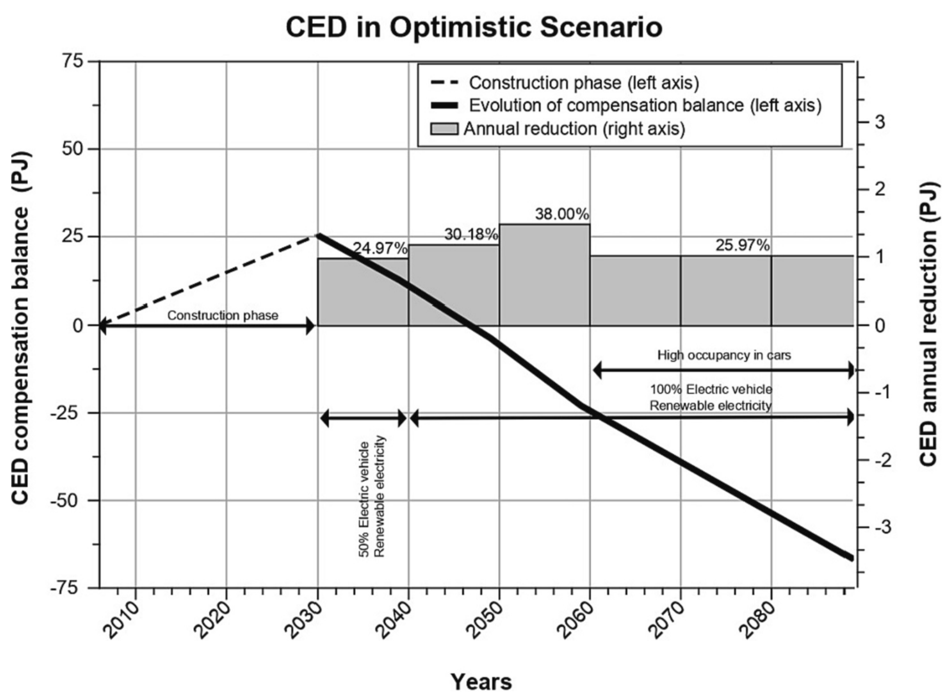

Fig. 4. CED compensation balance and annual reduction in the Optimistic Scenario.

The Basque Y was designed to have an extension of 190 km in a three-pointed star shape to connect the three main stations of the capitals of the region: Bilbao, Donostia-San Sebastian and Vitoria-Gasteiz. Another two minor stations have been planned in Ezkio-Itsaso and Astigarraga. Two multimodal terminals will also be installed to allow the freight transport in 750 m long trains, as well as four signaling posts and two overtaking and parking posts. There is also a long interchanger of 10 km in Bergara, where the three branches of the line intersect. In order not to have to build level crossings in a very demanding landscape, this junction has a high level of complexity.

Most of the line was designed over a double track in international gauge. A third track over old conventional track (1645 m) will be installed in the section between Astigarraga and Irun. Except for that section (14 km), most of the line is of new construction. Furthermore, this new line is configured for mixed freight and passenger transport, which involves more technical complexity in its design: a minimum radius of 3.2 km, maximum cant of 160 mm, maximum gradients of 15 thousandths and, exceptionally, 18 thousandths, thus enabling speeds in a range between 90 km/h for freight transport and 250 km/h for passenger transport.

The uneven relief of the landscape and the abrupt orography of this territory demand a technically complicated construction with a high requirement of construction materials and energy resources. Most of the approximately 190-km layout runs through tunnels (104.9 km, 56%) and over viaducts (24.55 km, 13%), and just 60.55 km (31%) is in open air (see Table 1). These construction parameters make this project one of the most technically complicated transport infrastructures in Europe (Gobierno Basque Government, 2012).

The LCI for the building and maintenance phases of the Basque Y line is based on the work of Tuchschmid et al. (2011). Impact coefficients collected therein have been found to be precise and transparent while providing the most reliable results (Cuenot, 2016) (see Data in Brief for more details).

2.3. LCI data on the operation phase

The calculation of the environmental burdens of the operation line requires some key data. First, accurate passenger and freight transport data over the HSR line are essential. Second, it is crucial to identify how much of the HSR total demand is shifted to the HSR; and third, it is necessary to provide the LCI data for the service phase of the Basque Y HSR and for all conventional transport modes from which freight and passenger transport are shifted.

2.3.1. Passenger and freight transport demand

Transport demand is a key factor for the calculation of the socio-economic and environmental benefits and costs of an infrastructure. As the Basque Y HSR line is still under construction, there are no real data available on transport demand. Therefore, this section quantifies passenger and freight transport demand based on the latest official projected data provided by public administrations. However, a sensitivity analysis for different demand scenarios will be conducted, given the increasing literature showing that promoters of transport infrastructures may be prone to overestimating demand (see e.g. Flyvbjerg, 2007).

Passenger and freight transport depend on two main factors; first, the amount of persons and tonnes moved, and second, their corresponding travelling distances. Notably, the Basque Y star topology penalises line exploitation, since any passenger or good only uses, at most, two thirds of the layout on each journey.

An estimation for passenger transport demand is available in ADIF (2015a), which provides estimates of the annual volume of displacements by train for the years 2020, 2030, 2040 and 2049 in a scenario with the Basque Y in operation (Table 90, page 164). In order to compute future transport demand for this project, these annual passenger flows must be multiplied by the distance travelled on the line. For those years, a transport density of 3.8, 5.8, 6.9 and 7.6 million passengers annually are expected in the Optimistic Scenario. For the passenger transport estimation in a more realistic or moderate scenario, passenger demand has been reduced (Table 2) to reflect the degree by which freight transport may be also reduced, according to a report from ADIF and the Basque Government (ADIF-Gobierno Vasco, 2019).

Said report provides information on the future demand (for the period of 2023–2050) for freight transport at the freight terminal located in Jundiz, just at the border between the Basque Y and the Spanish AVE network. Since the AVE network does not allow for freight transport, the traffic through this terminal is a good indicator of the traffic on the whole Basque Y. Table 3 gathers the estimation for freight transport density for the period 2023–2050 on the Basque Y for three scenarios (Optimistic, Moderate and Baseline).

It is important to put this piece of data into context. According to the Secretaría General de Transporte (2018), the onroad freight transport that crosses the Pyrenees from or to the Basque Country accounted for 47 million tonnes in 2015. So, according to these estimates, the new HSR infrastructure would (under the most optimistic scenario conditions) absorb in 2030 around 2% of the freight demand on the corridor (conventional rail currently accounting for <5%). This freight demand data differs substantially with respect to other estimations previously published. For example, it is much lower (and more reasonable) than the estimation made four years earlier by ADIF (2015a) of 9 million tonnes of goods per year. It is quite surprising to find a ninefold gap between the two administrations regarding such critical input for the environmental (and economic) evaluation of the project. And, also, sometimes it has been argued that the main contribution of the Basque Y to freight transport would be freeing the current Iberian gauge line from passengers so it could be used exclusively for freight. However, it is important to note that the current network is highly underused, so the main problem for Spanish rail cargo does not seem to be capacity (Antigüedad et al., 2016).

In any case, it is certain that these infrastructure start-up forecasts will not be met (passengers in 2020, freight in 2023). At the end of 2022 the platform is still not completely built in all sections; access to the capitals seems to be initially achieved with provisional stations outside the urban centres, since the works are not expected to start for a few years; and the Jundiz logistics terminal is in the expansion phase, and its rolling highway terminal[4] has not yet reached the construction phase. For all these reasons, this study will assume that the infrastructure will be put into operation in 2030 (although it is likely to be later).

2.3.2. Environmental burdens of the transport shifted to the HSR

The main environmental benefit that may arise from the construction of an HSR infrastructure comes from passengers or freight shifted from other conventional modes to the HSR. The percentages of passenger and freight transport shifted have been taken from Kortazar (2021), where they were calculated based on the data on passenger and freight traffic available in ADIF (2015a, 2015b). These are: 46.7% from cars, 9.9% from buses, 27.3% from conventional trains, 4.5% from aeroplanes, and

Table 1
Details of the Basque Y HSR line.

	km	%
Tunnels	104.90	55.52%
Viaducts over 250 mt	18.23	9.65%
Small Bridges under 250 mt	6.32	3.34%
Total tunnels & viaducts	129.45	68.52%
Open air	59.48	31.48%
Basque Y HSR total km	188.93	100%

Table 2
Passenger transport density estimation measured in millions of passengers. This passenger transport density also defines the functional unit of the system under analysis.

	2020–29	2030–39	2040–49	2050–59	2060–89
Optimistic Scenario	3.79	5.84	6.88	7.60	7.60
Moderate Scenario	2.12	3.27	3.85	4.26	4.26

Table 3
Freight transport density estimation measured in millions of tonnes of goods per year. This freight transport density also defines the functional unit of the system under analysis.

	2023	2024	2030	2040	2050
Optimistic Scenario	0.55	0.65	1.05	2.38	3.02
Moderate Scenario	0.39	0.46	0.73	1.67	2.12
Baseline Scenario	0.31	0.37	0.59	1.34	1.70

[4] The semi-trailers would be transported on railway wagons (Euskal Trenbide Sarea, 2019).

11.4% for induced demand. The percentages of shifted freight transport have been set as follows: 5% from container ships, 80% from lorries, 10% from conventional freight trains, and 5% for induced demand.

2.3.3. LCI data for the different transport modes

The life-cycle inventories of the means of transport involved in the operational phase of the Basque Y were collected from ecoinvent, version 3.7 (Steubing et al., 2016), and processed with the openLCA software (Ciroth, 2007) (see Table 4). This data is derived from Kortazar et al. (2021a), where the coefficients for the different freight transport modes have been added. The impact coefficients obtained from the ecoinvent database include the environmental impacts associated with the building and maintenance of both, infrastructures and vehicles (Kortazar et al., 2021a). Therefore, to avoid double counting, ecoinvent impact coefficients have been previously adjusted.

2.4. Description of scenarios

Two dynamic scenarios—an Optimistic Scenario and a Realistic Scenario—have been designed, making the following assumptions:

- Freight and passenger transport over the HSR line starts in 2030.
- At the beginning of train operation (2030s), 28% of private vehicles are diesel cars, and 22% are petrol cars, following DGT (2018).
- 50% of private vehicles are electric until 2039; 100% of private vehicles are electric from 2040 onwards.
- Private vehicles will carry an average of 1.68 passengers per vehicle until 2060 (1.68 p/v) following the Ministerio de Transportes, Movilidad y Agenda Urbana (2018). From 2060 onwards, this average is double (3.36 p/v).
- Transport demands shifted from other conventional modes to high-speed rail are taken from Section 2.3.2.
- Passenger and freight transport demand is incorporated according to Table 2 and Table 3, according to the latest government forecasts from 2030 onwards; transportation in each decade is assumed to be constant.
- Electricity production is 100% of renewable origin (ecoinvent v3.7).
- The temporal scope of this analysis is 60 years since this is the useful life of many of the components of the railway sector (Stripple and Uppenberg, 2010).

Based on these initial conditions, changes are applied to different variables that may occur during the operation years of the project in order to evaluate their effects on the results. These alternative changes have no effects on the construction and maintenance impacts of the project, affecting only the operation burdens and those associated with shifted demand. In both scenarios, passenger and freight transport demand increase throughout the useful life. Also, it is considered a more realistic future scenario where fuel cars are replaced by electric cars powered with a 100% renewable electricity mix. In addition, following Adra et al. (2010), this model also considers the situation where the vehicle occupancy rate increases to 3.36 p/v. **Tables 5 and 6** show the main characteristics of the optimistic and realistic scenarios on a decade-by-decade basis. Since there are no passenger or freight traffic forecasts beyond 2050, the scenarios assume that these remain at 2050 levels. (See Table 7.)

3. Results

This section outlines the modelling results for each of the scenarios presented above. Detailed information about the modelling strategy and all the results are available in the related Data in Brief article (Kortazar et al., 2023).

The mountainous orography of the Basque Country (traversed by 55% tunnels and 13% viaducts) critically influences the results. Error! Reference source not found.**7** shows the environmental balance for each impact category of the construction and maintenance phases of the infrastructure of the Basque Y HSR measured in annual tonnes per kilometre. Average CO_2 emissions (224.79 t/km·y) are above the upper limit of the bounds proposed by Tuchschmid et al. (2011) for traditional railway lines (39–71 t/km·y), although slightly below the upper limit proposed by Baron et al. (2011) for high-speed lines (ranging between 79 and 270 t/km·y) (Kortazar et al., 2021a). Therefore, the environmental burdens of constructing and maintaining the Basque Y are high and will require a high transport demand if it is to compensate for these loads.

The result of the net EI balance for the Basque Y HSR line is beneficial (negative value) for all impact categories, because the environmental burdens avoided from shifted demand are higher than those related to the building, maintaining and the operation of the project. More detailed results can be found in the Data in Brief. However, to better understand them, as the LCA methodology is based on a temporal horizon and the environmental objectives related to atmospheric emissions and energy consumption set by the European Union (European Commission, 2018a) have a temporal deadline too, these results can be presented as the HSR operation years required in order to compensate the environmental burdens of constructing and maintaining the infrastructure (Table 8 and Table 9). Most of these impacts have occurred before the trains start

Table 4
LCI data obtained from ecoinvent v3.7. Own elaboration (p/v: passengers per vehicle).

Transport mode	Global warming gCO_2eq/pkm	Cummulative energy demand MJ/pkm	Particulate matter g/pkm	Sulphur oxides g/pkm	Nitrogen oxides g/pkm	Non methane volatile organic compounds g/pkm
Passenger airplane, very short haul	159.37	2.41	0.04	0.22	0.72	0.10
Passenger coach	49.44	0.82	0.03	0.05	0.47	0.05
Passenger car mix for 1.68 p/v occupancy	187.39	2.86	0.11	0.31	0.46	0.17
Passenger car mix for 3.36 p/v occupancy	93.69	1.43	0.05	0.16	0.23	0.08
Electric car passenger, electricity production 100% renewable and 1.68 p/v occupancy	56.30	1.40	0.10	0.18	0.17	0.07
Passenger train, Spanish electricity mix	54.65	1.18	0.05	0.19	0.31	0.03
Passenger train, electricity production 100% renewable	27.12	0.73	0.04	0.05	0.22	0.03
Passenger high-speed rail, Spanish electricity production, (HSR infrastructure excluded)	32.91	0.86	0.03	0.15	0.10	0.01
Passenger high-speed rail, electricity production 100% renewable (HSR infrastructure excluded)	6.42	0.43	0.02	0.02	0.02	0.00
Freight container ship	9.31	0.13	0.01	0.12	0.19	0.01
Freight lorry 16–32 metric ton, EURO6	161.40	2.65	0.11	0.21	0.23	0.13
Freight train (Electricity Spain)	25.04	0.57	0.03	0.10	0.11	0.01
Freight train (Electricity Spain-REN)	10.12	0.33	0.02	0.03	0.06	0.01

Table 5
Description of the optimistic scenario, for each decade.

Optimistic scenario	2030–2039	2040–2049	2050–2059	2060–2069	2070–2079	2080–2090
Passenger transport density (Mp)	5.84	6.88	7.60	7.60	7.60	7.60
Freight transport density (Mt)	1.05	2.38	3.02	3.02	3.02	3.02
Renewable electricity	100%	100%	100%	100%	100%	100%
Electric vehicles	50%	100%	100%	100%	100%	100%
Occupancy per vehicle (p/v)	1.68	1.68	1.68	3.36	3.36	3.36

Table 6
Description of the realistic scenario, for each decade.

Realistic scenario	2030–2039	2040–2049	2050–2059	2060–2069	2070–2079	2080–2090
Passenger transport density (Mp)	3.27	3.85	4.26	4.26	4.26	4.26
Freight transport density (Mt)	0.59	1.34	1.70	1.70	1.70	1.70
Renewable electricity	100%	100%	100%	100%	100%	100%
Electric vehicles	50%	100%	100%	100%	100%	100%
Occupancy per vehicle (p/v)	1.68	1.68	1.68	3.36	3.36	3.36

Table 7
Results of the environmental balance of the building and maintaining phases of the Basque Y high-speed rail.

	CO_2	Cummulative Energy Demand	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Non Methane Volatile Organic Compounds
	t/km·y	TJeq/km·y	t/km·y	t/km·y	t/km·y	t/km·y
Basque Y HSR line	224.79	2.37	0.23	0.35	0.60	0.10

Table 8
Results in the optimistic scenario.

	Global warming	Cummulative energy demand	Particulate matter	Sulphur oxides	Nitrogen oxides	Non methane volatile organic compounds
Optimistic Scenario	kt CO_2eq/y	TJ/y	t/y	t/y	t/y	t/y
Annual emissions reduction with respect to the same scenario without HSR (in the compensation year)	82.96	1178.16	64.02	154.61	301.27	84.19
Compensation year	2053	2047	2059	2051	2050	2041

Table 9
Results in the realistic scenario.

	Global Warming	Cummulative Energy Demand	Particulate Matter	Sulphur Oxides	Nitrogen Oxides	Non Methane Volatile Organic Compounds
Realistic Scenario	kt CO_2eq/y	TJ/y	t/y	t/y	t/y	t/y
Annual emissions reduction with respect to the same scenario without HSR (in the compensation year)	17.24	634.79	−1.88	23.55	106.51	39.11
Compensation year	2071	2059	2086	2068	2066	2049

running on the infrastructure. Furthermore, any new high-speed rail project begins its activity with an environmental negative result caused by its building phase. This deficit will be compensated over the years but only if the environmental burdens derived from the operation of the train are lower than the environmental impacts derived from the shifting demand from other transport modes (Kortazar et al., 2021a). Otherwise, compensation would not take place within the useful life of the line and the environmental performance would be detrimental.

In the Optimistic Scenario, the initial GHG emissions would be compensated in 2053, and Cumulative Energy Consumption (CED) in 2047. Then, if the project started running in 2030 and given the conditions and assumptions of each period of time, GHG emissions and CED would not achieve neutrality until around 2050 (Fig. 3 and Fig. 4). Compensation for the rest of the indicators also occurs around those years: PM10 in 2059; SO_2 in 2051; NO_X in 2050 and NMVOC in 2041. These results imply that GHG emissions and CED would, by 2050, undergo an impact reduction of 34.6% and 38% each year with respect to the reference scenario without the HSR. Fig. 3 and Fig. 4 show, for the GWP100 and CED indicators and for the Optimistic Scenario, the evolution of the annual net balance over the 60-year life-cycle of the infrastructure, and the annual impact reduction provided by the operation of the infrastructure, compared to the scenario without HSR.

However, the results worsen considerably in the Realistic Scenario, as can be seen in Table 9, Fig. 5 and Fig. 6. In the same 2030–89 period of operation, and respecting the conditions and assumptions established for each period of time, GHG emissions and CED would not achieve neutrality until around 2071 (41 years) and 2059 (29 years), respectively. This means that, by 2050, with respect to the reference scenario without HSR, GHG emissions and CED would reach an annual impact reduction of 11.6% and 16.3%, respectively.

Finally, these results allow us to conclude that, in the best of cases, this project will not begin to have a positive contribution in terms of global warming mitigation and energy consumption until around year 2050, and in a probable more realistic case, until the year 2060. Fig. 7 and Fig. 8 show the critical contribution of the building and maintenance phases to the impact index of the HSR. These figures show the impact associated with each of the modes of transport considered, with a life-cycle perspective and including both the operation and building and

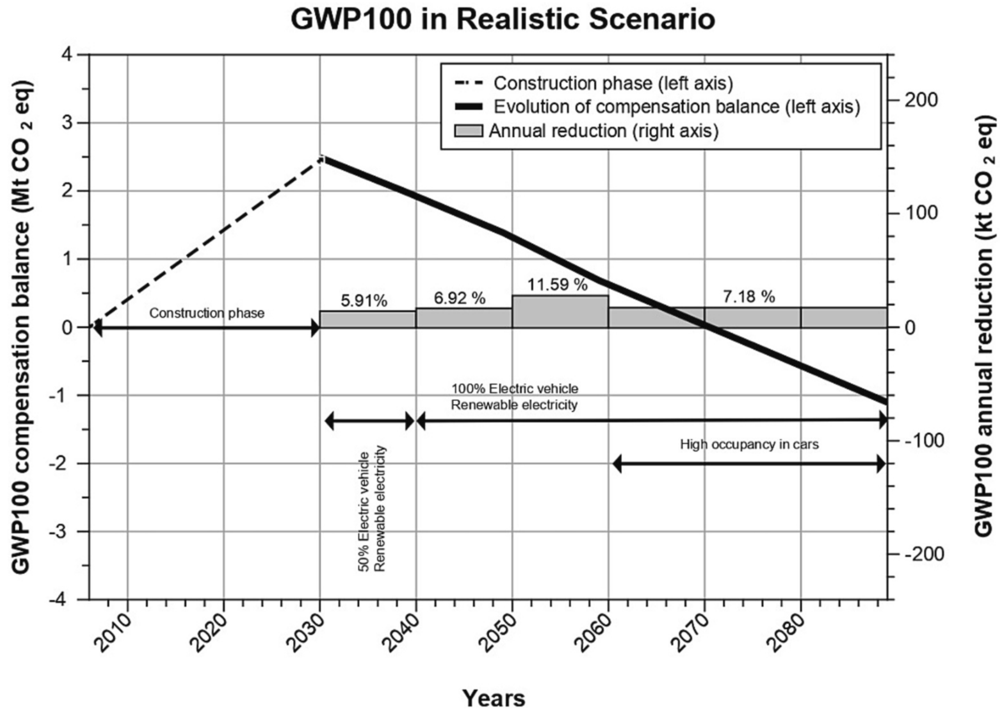

Fig. 5. GWP100 compensation balance and annual reduction in the Realistic Scenario.

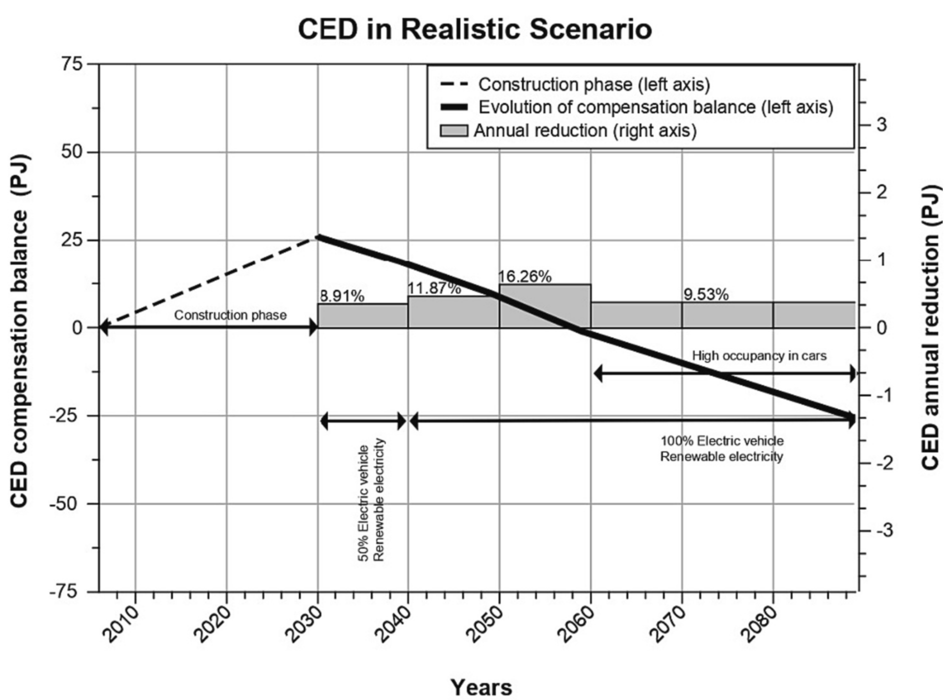

Fig. 6. CED compensation balance and annual reduction in the Realistic Scenario.

maintenance phases of the project, for each decade once the train is running. Although the impact of HSR operation is low, as it is powered by renewable electricity, the low density of passenger and freight transport in these scenarios has a significant negative effect on the total impact, which clearly harms the overall environmental profitability of the infrastructure.

4. Discussion

The LCA of the Basque Y HSR is clear concluding that the environmental loads of the construction phase are too high for the estimated insufficient passenger and freight traffic, both in the most optimistic scenario and in the realistic one, and this prevents the project from contributing significantly to mitigating climate change and other environmental impacts in an immediate and efficient way.

The performance of the Basque Y HSR line would be clearly penalised

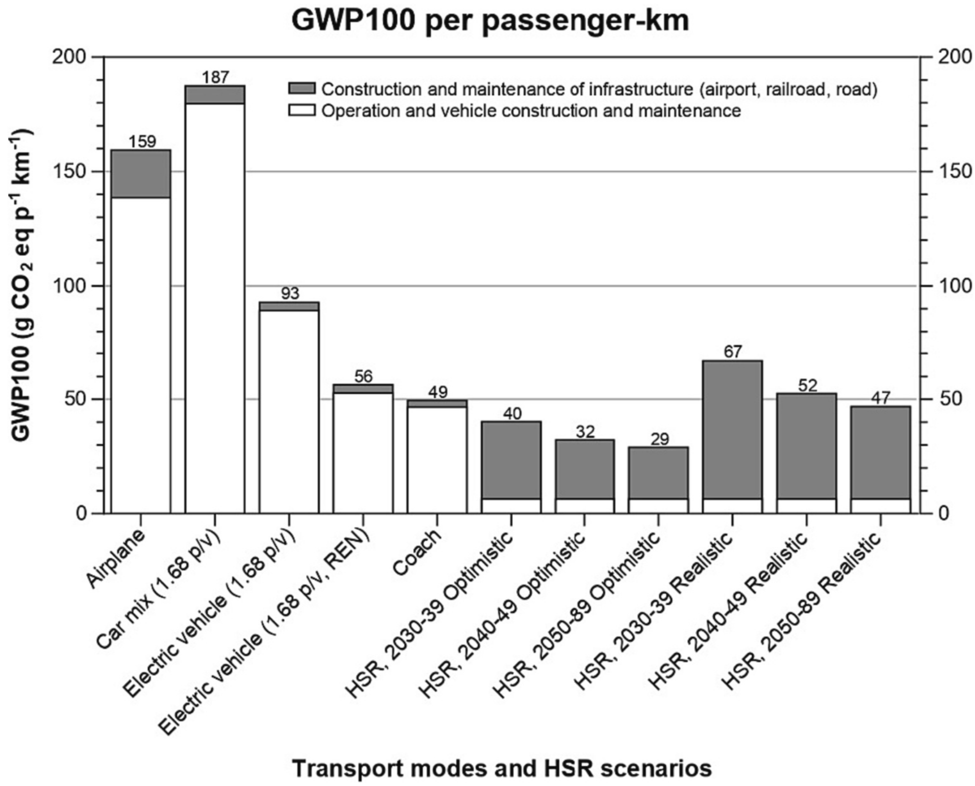

Fig. 7. Impact per passenger-kilometre on the GWP100 indicator of different modes of transport and the HSR in each scenario and period.

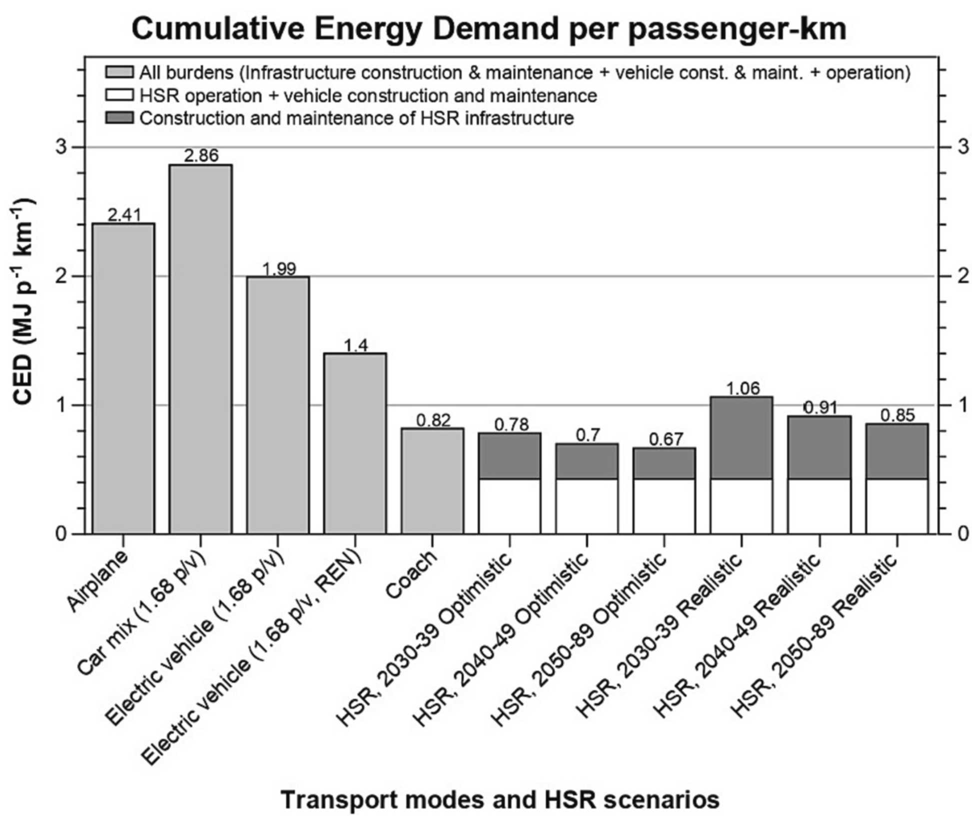

Fig. 8. Impact per passenger-kilometre on the CED indicator of different modes of transport and the HSR in each scenario and period.

due to the Basque Y high-speed line would be clearly penalised due to its low demand for passenger transport. In its first year of operation, this line would transport the equivalent of just 5.8 million passengers over the complete infrastructure in the optimistic scenario, and just 3.3 million passengers in a more realistic one. This density of transport would be significantly lower than those supported by networks elsewhere in the world: 22 Mp in France, 22 Mp in China, and around 35 Mp in Japan and Taiwan (UIC, 2020). Both economic (De Rus, 2011) and environmental analyses (Westin and Kågeson, 2012) have found that a minimum threshold of 10 million passengers in the first year of operation are required for a typical HSR line to be socially and environmentally viable. Furthermore, considering the technical difficulties presented by the Basque Y line (e.g. Westin and Kågeson (2012) assumed far fewer tunnels: 10% in comparison to 60% in the Basque Y), the abovementioned threshold would need to be higher.

Moreover, the transport density of HSR networks shows diminishing returns. Once the areas with the highest population density have been connected and the peak of demand is reached, subsequent connections will only decrease the overall transport density of the infrastructure. Based on the data on the historical evolution of the extension of the network provided by the UIC (2021) and transport data measured in pkm and provided by UIC (2022), Fig. 9 gathers the evolution of the transport density by progressive geographical extension of the high-speed networks of China, Japan, France, Spain, Germany and Taiwan. In Japan, taking all the lines in the country combined, the transport density remains above 36 Mp. Similar densities have already been reached in Taiwan (almost 35 Mp in 2019). In France, after reaching a transport density of almost 29 million passengers in 2006, the lengthening of the network in subsequent years brought transport density down to 22 million passengers. A similar trend is observed in Germany, where the peak of 27 million passengers in 2001 on a short network (576 km) reduced to below 20 million passengers when the network length tripled (1571 km). The transport density peak has not yet been observed in China, but transport density seems to be stabilising just over 20 million passengers yearly (21 Mp in 2019, over a network of >35 thousand km). In Spain, when the line between Madrid and Barcelona was inaugurated in 2008, it reached the point of highest transport density with 7 million passengers. At present, and after doubling the extension of the AVE network to areas with lower population density, the density of transport has dropped to just below 5 million passengers. It is obvious that, as new sections are inaugurated, the density of transport will continue to decrease. The Basque Y will be an extension of the Northern corridor in the Spanish AVE network, and it seems that this high-speed project will not mean a significant improvement in terms of transport density, nor will it reduce energy demand and GHG emissions in the sector.

Insufficient passenger transport will not be compensated for by strong freight transport demand in the region. The freight demand data used in this work was provided by the infrastructure administrator ADIF and the Basque Government (ADIF-Gobierno Vasco, 2019), which expect the equivalent to between 0.6 and 1 million tonnes of freight to be transported annually over the complete infrastructure in 2030, an insufficient amount when compared with the 47 million tonnes of onroad freight traffic that crossed the Pyrenees in 2015.

It can be argued that in the future the demand for freight transport may increase, and to some extent it will surely do so. Nonetheless, there are some issues that cast serious doubt on the ability of the HSR to greatly increase freight transport in the future.

Firstly, there are some technical limitations linked to HSR infrastructures offering both freight and passenger transport. It is very challenging to coordinate the traffic of trains with very different speeds. Passenger HSR and slower freight transport will share the rail line, and this may result in a timetable and capacity conflict (Troche, 2005). If this freight operates at night, as in Germany, the intense maintenance that this infrastructure needs will reduce the time slots available for freight traffic. Instead, if freight traffic is programmed during the day, many sidings would be needed.

Secondly, although it has sometimes been argued that the main

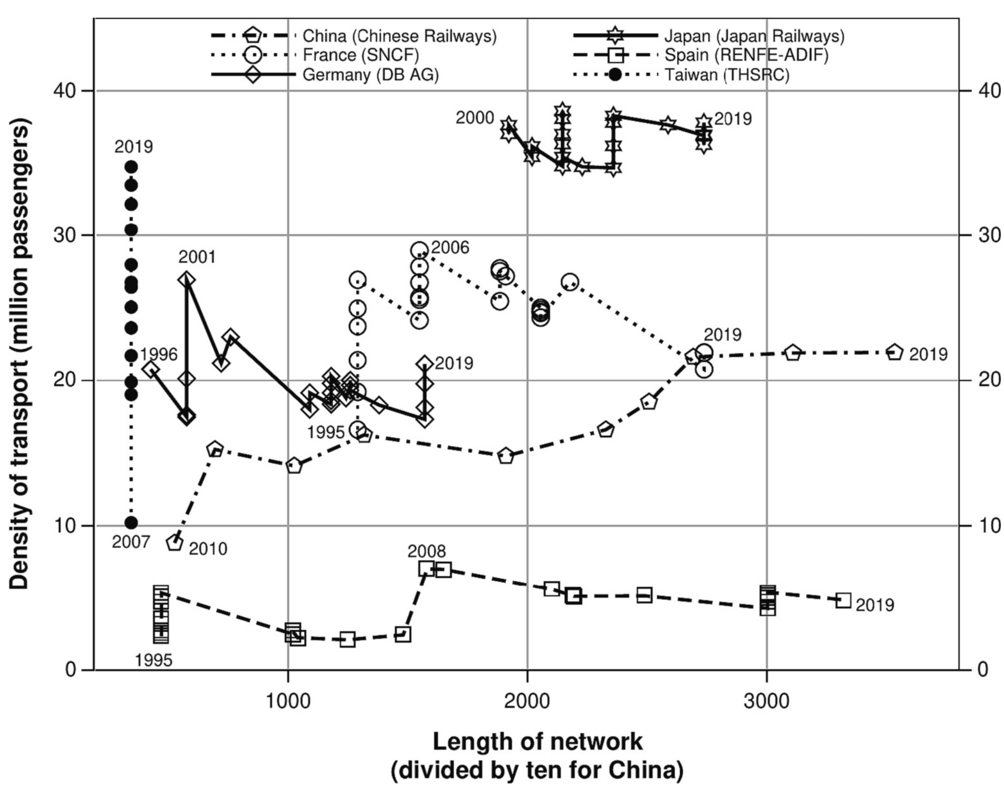

Fig. 9. High-speed transport density in various countries. Own elaboration based on the statistics provided by the UIC (2021, 2022). Transport density is given in million passengers.

contribution of the Basque Y to freight transport will be freeing the current Iberian gauge line from passenger traffic, so that it can be used exclusively for freight transport, but as mentioned before the main problem of current conventional rail cargo in Spain does not seem to be capacity but underuse. Conventional line 100, between Madrid-Chamartín and Irun-France, which currently carries the freight traffic that could, in the future, run along the Basque Y, had a saturation of 23% in September 2021 (ADIF, 2022). In other words, freight traffic through the conventional network could be tripled without reaching saturation.

And thirdly, it should be added that both networks connected to the Basque Y—the AVE network (Spain) in the south and the TGV network (France) in the north—were designed exclusively for the transport of passengers. The incentives for freight to circulate on the Basque Y are limited, since goods coming from France on the standard gauge network could continue on the Basque Y only up to the connection with the Spanish conventional network in Jundiz, and not without passing through an intermodal station to change to other modes of transport, or to Spanish gauge, in order to continue on the Spanish conventional network.

Another issue that requires specific attention is the number of years required to compensate construction emissions. This issue is critical in the current context of climate emergency. The results show that, in the best case, transport demand estimated by ADIF and the Basque Government would compensate the GWP deficit linked to build the infrastructure only after 23 years, and, in the most probable case, compensation would be achieved after 40 years of operation of the infrastructure.

Besides, the improvements in the reduction of impacts derived from train operation are very modest. The Basque Country emitted an average of 20 Mt. CO_2eq in the period 2006–2019, 5.9 Mt. (30%) of which corresponding to the transport sector, but only 240 kt CO_2eq to traffic affected by the Basque Y (other modes from which transport is shifted to the HSR).

The net yearly balance for GHG emissions (GWP100 indicator) in the Optimistic Scenario in the 2050s (Table 8) is −83 kt CO_2eq per year (only 1.4% of total emissions linked to transport in the Basque Country). Then, the GHG emissions mitigation provided by the Basque Y HSR would be just 34.6% when compared with the situation without the Basque Y in operation, when the overall objective set by the European Union in its carbon-neutral 1.5LIFE scenario for the transport sector is a 91% reduction (European Commission, 2018b).

In other words, in a context of global environmental crisis that requires urgent and drastic measures to be taken regarding GHG emissions, this Basque Y HSR line would not be an efficient solution to reduce those emissions. The large investments required, moreover, only affect a meager 1.2% of total GHG emissions in the BAC (see Fig. 10).

Finally, the existence of other alternatives that currently already obtain better results in terms of reducing atmospheric emissions in the transport sector and without having to invest in new projects should be assessed (Hoyos, 2009). Table 10 shows the environmental performance of the HSR connection between Bilbao and Donostia-San Sebastián (110 km) but by proposing three new future scenarios for the connection of the same cities along the same AP-8 motorway corridor and with a similar length (100 km). According to Interbiak's transport data (Diputación Foral de Bizkaia, 2019), the average daily traffic of light vehicles on this motorway was 30,532 units in 2018, which is similar to an annual transport of 11.14 million light vehicles over complete infrastructure. While this Basque Y HSR connection would reduce CO_2 emissions, annually, in the Optimistic Scenario, by 48 kt, a reduction of 175 kt of CO_2 would be achieved only by increasing (double) the occupancy of light vehicles driving on the AP-8 toll motorway (MC1 in Table 10). If these light vehicles were powered with electricity from renewable sources, a reduction of 245 kt of CO_2 would be achieved (MC2); and the reduction would be up to 300 kt CO_2 if the average occupancy of those electric vehicles were doubled (MC3).

5. Conclusions

The world is experiencing an unprecedented environmental crisis with continuous temperature records and an uncertain and worrying future. Global warming and climate change are realities that require immediate attention and efficient responses. In the words of United Nations secretary general António Guterres: "unless countries dramatically scale up their efforts to counter the climate crisis, the world faces a global catastrophe" (United Nations, 2022b).

The EU has set an ambitious carbon neutrality objective by 2050. Transport emissions account for one third of total GHG emissions in the Basque Autonomous Community, so transport policy plays a key role in climate change mitigation. Local and regional policymakers have often presented HSR as a sustainable mode of transport able to contribute

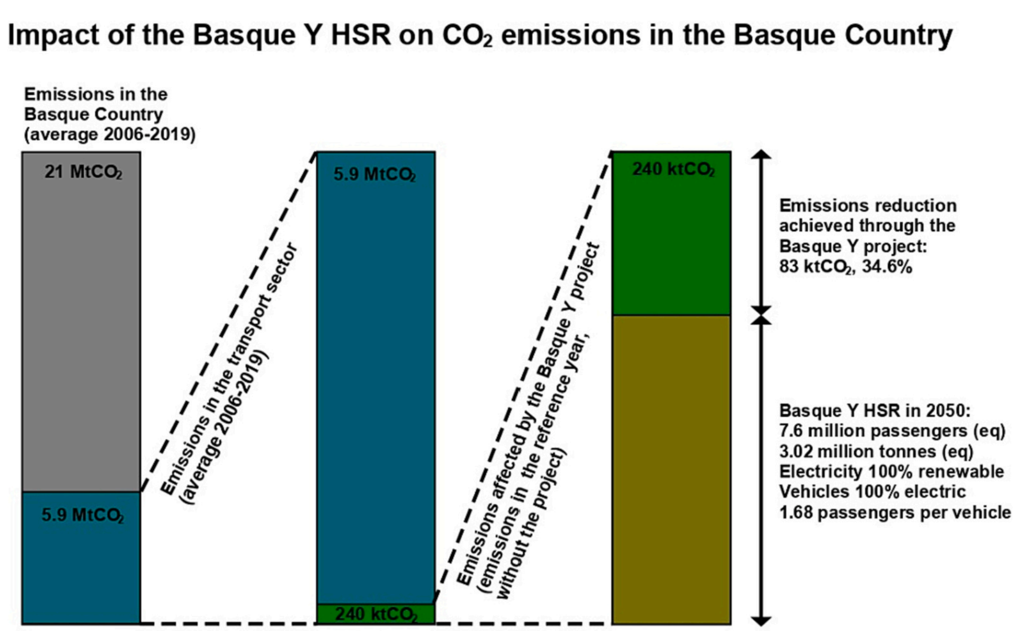

Fig. 10. Impact of the Basque Y HSR on CO_2 emissions in the Basque Country.

Table 10
Impact results of the Basque Y HSR connection between Bilbao and Donostia-San Sebastián (110 km) in the year 2050 of the Optimistic Scenario and the AP-8 motorway corridor also connecting both capitals (100 km) with scenarios of occupancy in private vehicles doubles (MC1), electric vehicle (MC2), and both occupancy doubles and renewable electricity production for electric vehicle (MC3).

	Global warming	Cummulative energy demand	Particulate matter	Sulphur oxide	Nitrogen oxide	Non methane volatile organic compounds
Bilbao – Donostia-San Sebastián connection	CO_2eq kt/y	TJ/y	t/y	t/y	t/y	t/y
Basque Y HSR (110 km, Optimistic Scenario in 2050)	48.25	863.41	37.26	89.98	148.32	59.32
MC1 – AP-8 toll motorway, 100 km (11.14 million v/y, double occupancy)	175.36	2677.58	101.78	294.35	432.97	155.24
MC2 – AP-8 toll motorway, 100 km (11.14 million v/y, renewable electricity, electric vehicles)	245.34	2736.13	17.88	253.24	538.79	180.60
MC3 – AP-8 toll motorway, 100 km (11.14 Mv/y, electric vehicles, double occupancy, renewable electricity)	298.03	4045.64	110.72	420.97	702.37	245.54

significantly to achieving those environmental goals. Furthermore, regional authorities have presented the Basque Y HSR as the most important step towards the ecological transition of the country (SPRI, 2020) however, it is clear that these HSR projects have major implications on the environment (Carvalho et al., 2017).

This paper analyses the environmental performance of the Basque Y HSR line using the LCA methodology to explore the capacity of this technology to reduce energy demand and mitigating climate change, and to test its potential contribution to the accomplishment of the emission reduction objectives set by the EU. The results show that the impacts generated in the construction phase of the Basque Y would be close to the upper limit of the range of loads associated with this phase, based on the literature for other HSR lines, mainly due to the mountainous orography of the region that requires building bigger and more complex structures that imply a greater consumption of resources and energy. In the Optimistic Scenario (best-case scenario considered) the Basque Y HSR line is found to compensate for its construction and maintenance GHG emissions in 24 years, while the rest of the environmental indicators would require between 12 (NMVOC) and 30 years (PM10). Although this finding may be seen as a potential benefit for the environment, it is negligible when considered in the broader context of climate emergency. It would contribute to reducing <1.4% of the annual GHG emissions of the transport sector and <0.4% of the annual GHG emissions of the region, when official targets currently require it to be climate neutral by 2050.

The environmental performance of this HSR would get worse when the transport demand acquires the lower values presented for the Realistic Scenario. It is not unreasonable to think that freight transport is not going to be able to grow much in the future, since the Spanish HSR network allows only for passenger transport, and the French connection will never be ready for freight transport before 2037. The Realistic Scenario shows that the infrastructure would require many more years of operation to compensate for its construction and maintenance impacts if transport were less than initially estimated for the Optimistic Scenario.

This means that the environmental balance of the Basque Y HSR line is affected by its insufficient passenger transport, equivalent to just 5.8 million passengers in the best case and just 3.3 million passengers in the more realistic case, at the time of starting its operation in the year 2030. This demand is far below the demand provided by the TGV network (22 Mp), the Japanese projects (36 Mp on average), China (22 Mp) and Taiwan (35 Mp). The Basque Y HSR will not have enough transport demand to provide an environmental benefit; in other words, the transport demand expected in the Basque Y is not high enough to justify the construction of the HSR infrastructure in terms of reduction energy consumption and atmospheric emissions. Besides, this means that the extension of the AVE network with the Basque Y HSR line would cause a decrease in the transport density of the Spanish network and would confirm that the transport density of high-speed lines clearly shows diminishing returns. These results and the methodology developed in this work open an interesting opportunity for the application in other LCA studies of high-speed rail projects or even in infrastructures of other transport modes. Also, it could be very interesting to include the results of this analysis in a broader socio-economic study, such as a Cost Benefit Analysis, of the Basque Y HSR line. It is unusual in CBA studies to see the monetary valuations of the environmental burdens analyzed in this study integrated into the balance. This work will also have to be updated according to the evolution of the European Union's energy and climate policy, which greatly conditions the evolution of the background scenario. The potential of the Basque Y HSR to mitigate climate change, reduce energy consumption and other environmental impacts is not sufficient. In a context of the global environmental crisis, this project, far from improving things, can make them worse. Transport policy remains inefficient, and the European Environment Agency (2019) makes this clear by stating "current efforts to limit the [transport] sector's environmental and climate impacts in Europe are not sufficient to meet the EU's long term climate and environmental policy objectives".

Credit author statement

Andoni Kortazar: Original draft preparation, Writing, Reviewing and Editing. Investigation, Data search, Software.

Gorka Bueno: Conceptualization, Methodology, Software.

David Hoyos: Supervision, Reviewing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data used is presented and explained in a Data in Brief article.

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References

ADIF, 2015a. Estudio de rentabilidad económico-social y financiera de la Línea de Alta Velocidad Vitoria-Bilbao-San Sebastián e implantación del ancho estándar UIC en los tramos Burgos-Vitoria y Astigarraga-Irún.

ADIF, 2015b. Estudio de rentabilidad económico-social y financiera de la Línea de Alta Velocidad Vitoria-Bilbao-San Sebastián y tramo en 3 carriles Astigarraga-Irún.

ADIF, 2022. ADIF: declaración sobre la red 2022 [WWW Document]. URL. https://www.adifaltavelocidad.es/documents/34745/5123208/20220223_01_DR_AV_2022_Libro.pdf/17edbfb8-5c5d-d3e2-fd39-b43f9ef5c9c5?t=1645621643082 (accessed 3.15.22).

ADIF-Gobierno Vasco, 2019. Estudio de demanda de mercancías para la terminal logística de Jundiz.

Adra, N., Michaux, J.-L., André, M., 2010. Analysis of the load factor and the empty running rate for road transport. In: Artemis - Assessment and Reliability of Transport Emission Models and Inventory Systems [WWW Document]. ResearchGate. URL. https://www.researchgate.net/publication/277183200_Analysis_of_the_load_factor_and_the_empty_running_rate_for_road_transport_Artemis_-_assessment_and_reliability_of_transport_emission_models_and_inventory_systems (accessed 2.10.20).

AHT Gelditu, 2019. AHT Gelditu-Paremos el TAV: TAV en Euskal Herria. AHT Gelditu-Paremos el TAV. URL. http://noaltavahtgelditu.blogspot.com/p/aht-en-euskal-herria.html (accessed 4.13.20).

Albalate, D., Bel, G., 2016. Evaluating High-Speed Rail: Interdisciplinary Perspectives. Taylor & Francis.

Antigüedad, I., Bermejo, R., Hoyos, D., Bel, G., Bueno, G., Capellán-Pérez, I., Gorostidi, I., Barcena, I., Larrinaga, J., 2016. Análisis transdisciplinar del modelo ferroviario de alta velocidad: El proyecto de nueva Red Ferroviaria para el País Vasco.

Baron, T., Martinetti, G., Pépion, D., 2011. Carbon footprint of high speed rail. International Union of Railways (UIC), Paris.

Basque Government, 2012. La Y Vasca: Un proyecto de país, una conexión internacional. Gobierno Vasco.

Basque Government, 2015. Climate Change Strategy of the Basque Country to 2050.

Bueno, G., Hoyos, D., Capellán-Pérez, I., 2017. Evaluating the environmental performance of the high speed rail project in the Basque Country, Spain. Res. Transp. Econ. 62, 44–56. https://doi.org/10.1016/j.retrec.2017.02.004.

California High-Speed Rail Authority, 2016. California High-Speed Rail Sustainability Report 54.

Carvalho, S., Partidario, M., Sheate, W., 2017. High speed rail comparative strategic assessments in EU member states. Environ. Impact Assess. Rev. 66, 13. https://doi.org/10.1016/j.eiar.2017.05.006.

Chester, M.V., Horvath, A., 2009. Environmental assessment of passenger transportation should include infrastructure and supply chains. Environ. Res. Lett. 4, 024008 https://doi.org/10.1088/1748-9326/4/2/024008.

Ciroth, A., 2007. ICT for environment in life cycle applications openLCA — a new open source software for life cycle assessment. Int. J. Life Cycle Assess. 12, 209. https://doi.org/10.1065/lca2007.06.337.

Cuenot, F., 2016. Carbon footprint of railway Infraestructure: comparing existing methodologies on typical corridors. UIC-ETF 51.

De Rus, G., 2011. The BCA of HSR: should the government invest in high speed rail infrastructure? J. Benefit Cost Analys. 2, 1–28. https://doi.org/10.2202/2152-2812.1058.

DGT, 2018. DGT- Parque de vehículos en España [WWW Document]. DGT- Tablas estadísticas. URL. http://www.dgt.es/es/seguridad-vial/estadisticas-e-indicadores/parque-vehiculos/tablas-estadisticas/ (accessed 2.14.20).

Diputación Foral de Bizkaia, 2019. La AP 8 en cifras 2018. In: Evolución de los datos de gestión de la autopista AP-8.

European Commission, 1992. Green Paper on the Impact of Transport on the Environment. A Community Strategy for "Sustainable Mobility".

European Commission, 2018a. Communication from the Commission to theEuropean Parliament, The European Council, The European Economic and Social Committee, The Committee of the regions and the European Investment Bank.

European Commission, 2018b. A Clean Planet for all a European Long-Term Strategic Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy.

European Commission, 2020a. 2050 Long-Term Strategy [WWW Document]. Climate Action - European Commission. URL. https://ec.europa.eu/clima/policies/strategies/2050_en (accessed 7.3.20).

European Commission, 2020b. Directorate-general for mobility and transport. In: Essen, H., Fiorello, D., El Beyrouty, K., Bieler, C., Wijngaarden, L., Schroten, A., Parolin, R., Brambilla, M., Sutter, D., Maffii, S., Fermi, F. (Eds.), Handbook on the External Costs of Transport: version 2019–1.1. Publications Office. https://doi.org/10.2832/51388.

European Court of Auditors, 2018. A European High-speed Rail Network: Not a Reality but an Ineffective Patchwork [WWW Document]. URL. https://www.eca.europa.eu/Lists/ECADocuments/SR18_19/SR_HIGH_SPEED_RAIL_EN.pdf (accessed 11.15.18).

European Court of Auditors, 2020. EU Transport Infrastructures: More Speed Needed in Megaproject Implementation to Deliver Network Effects on Time.

European Environment Agency, 2019. Greenhouse Gas Emissions from Transport in Europe [WWW Document]. European Environment Agency. URL. https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-12 (accessed 5.7.20).

Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 Establishing the Framework for Achieving Climate Neutrality and Amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'), OJ L, 2021. European Union.

Euskal Trenbide Sarea, 2019. Informe de situación NFRPV.

Flyvbjerg, B., 2007. Cost Overruns and Demand Shortfalls in Urban Rail and Other Infrastructure [WWW Document]. ResearchGate. URL. https://www.researchgate.net/publication/241059880_Cost_Overruns_and_Demand_Shortfalls_in_Urban_Rail_and_Other_Infrastructure (accessed 7.3.20).

Fundación de los ferrocarriles españoles, 2021. UIC, 2020. High-Speed Rail, Atlas.

Gómez Camacho, Z., 2021. El TAV llegará a Euskadi en 2027 pero con soluciones "provisionales" para Bilbao y Vitoria [WWW Document]. Crónica Vasca. URL. http://www.cronicavasca.com/sociedad/tav-llegara-euskadi-en-2027-pero-con-soluciones-provisionales-bilbao-vitoria_558459_102.html (accessed 3.15.22).

Hoyos, D., 2009. Towards an operational concept of sustainable mobility. Int. J. Sustain. Dev. Plan. 4, 158–173. https://doi.org/10.2495/SDP-V4-N2-158-173.

INECO, 2017. Estudio informativo del proyecto de la Línea de Alta Velocidad Burgos - Vitoria. Anejo 3: configuración funcional VF. Ministerio de Fomento.

Jehanno, A., Palmer, D., James, C., 2011. High Speed Rail and Sustainability.

Jones, H., Moura, F., Domingos, T., 2016. Life cycle assessment of high-speed rail: a case study in Portugal. Int. J. Life Cycle Assess. 22 https://doi.org/10.1007/s11367-016-1177-7.

Kaewunruen, S., Sresakoolchai, J., Peng, J., 2020a. Life cycle cost, energy and carbon assessments of Beijing-Shanghai high-speed railway. Sustainability 12, 206. https://doi.org/10.3390/su12010206.

Kaewunruen, S., Sresakoolchai, J., Yu, S., 2020b. Global warming potentials due to railway tunnel construction and maintenance. Appl. Sci. 10, 6459. https://doi.org/10.3390/app10186459.

Kortazar, A., 2021. Abiadura handiko trenak Espainiako garraio sektorearen trantsizio ekologikoari egiten dion ekarpena: bizi-zikloaren analisiaren ikuspegia. Universidad del País Vasco/Euskal Herriko Unibertsitatea, Bilbao.

Kortazar, A., Bueno, G., Hoyos, D., 2021a. Environmental balance of the high speed rail network in Spain: a life cycle assessment approach. Res. Transp. Econ. 101035 https://doi.org/10.1016/j.retrec.2021.101035.

Kortazar, A., Bueno, G., Hoyos, D., 2021b. Detailed Description of the Layout of the Basque Y HSR Project in Spain 1. https://doi.org/10.17632/7w4frwk7sb.1.

Kortazar, A., Bueno, G., Hoyos, D., 2021c. Dataset for the life-cycle assessment of the high-speed rail network in Spain. Data Brief 36, 107006. https://doi.org/10.1016/j.dib.2021.107006.

Kortazar, A., Bueno, G., Hoyos, D., 2023. Dataset for the Life-Cycle Assessment of the Basque Y High Speed Rail Line in Spain. Data in Brief.

Lee, C.K., Lee, J.Y., Kim, Y.K., 2008. Comparison of environmental loads with rail track systems using simplified life cycle assessment (LCA). In: Presented at the URBAN TRANSPORT 2008, Malta, pp. 367–372. https://doi.org/10.2495/UT080361.

Lin, J., Li, H., Huang, W., Xu, W., Cheng, S., 2019. A carbon footprint of high-speed railways in China: a case study of the Beijing-Shanghai line. J. Ind. Ecol. 23, 869–878. https://doi.org/10.1111/jiec.12824.

Ministerio de Transportes, Movilidad y Agenda Urbana, 2018. Anuario estadístico 2018. Capítulo 8 (Tráfico).

Pons, J.J., Villalba Sanchís, I., Insa Franco, R., Yepes, V., 2020. Life cycle assessment of a railway tracks substructures: comparison of ballast and ballastless rail tracks. Environ. Impact Assess. Rev. 85 https://doi.org/10.1016/j.eiar.2020.106444.

Rodrigue, J.-P., 2020. The Geography of Transport Systems, 5th ed. Routledge, New York.

Rungskunroch, P., Shen, Z.-J., Kaewunruen, S., 2021. Benchmarking environmental and economic impacts from the HSR networks considering life cycle perspectives. Environ. Impact Assess. Rev. 90, 106608 https://doi.org/10.1016/j.eiar.2021.106608.

Samuelson, P.A., Nordhaus, W.D., 2001. Microeconomics, 17th ed. McGraw-Hill Irwin.

Secretaría General de Transporte, 2018. Observatorio hispano-francés de Tráfico en los Pirineos. Ministerio de Fomento.

SPRI, 2020. Tapia: "La Y vasca es el salto cualitativo más importante en la transición ecológica de nuestro país" [WWW Document]. SPRI. URL. https://www.spri.eus/es/infraestructuras-comunicacion/tapia-la-y-vasca-es-el-salto-cualitativo-mas-importante-en-la-transicion-ecologica-de-nuestro-pais/ (accessed 3.31.20).

Steubing, B., Wernet, G., Reinhard, J., Bauer, C., Moreno-Ruiz, E., 2016. The ecoinvent database version 3 (Part II): analyzing LCA results and comparison to version 2. Int. J. Life Cycle Assess. 13 https://doi.org/10.1007/s11367-016-1109-6.

Stripple, H., Uppenberg, S., 2010. Life Cycle Assessment of Railways and Rail Transports - Application in Environmental Product Declarations (EPDs) for the Bothnia Line. Swedish Environmental Research Institute, Sweden.

The International EPD system, 2010. Passenger Transport Service on the Bothnia Railway Line [WWW Document]. URL. https://www.environdec.com/library/epd194 (accessed 7.21.23).

Troche, G., 2005. High-Speed Rail Freight Sub-Report in Efficient Train Systems for Freight Transport.

Tuchschmid, M., Knörr, W., Schacht, A., Mottschall, M., Schmied, M., 2011. Carbon Footprint and Environmental Impact of Railway Infrastructure.

UIC, 2020. High Speed Rail Lines in the World [WWW Document]. URL. https://uic.org/IMG/pdf/20200227_high_speed_lines_in_the_world.pdf (accessed 3.16.21).

UIC, 2021. Atlas: High-Speed Rail 2022. UIC-International union of railways, Paris.

UIC, 2022. RAILISA STAT UIC [WWW Document]. URL. https://uic-stats.uic.org/ (accessed 9.1.22).

United Nations, 2022a. The Future of the UN: Time to Think Big, Urges Guterres [WWW Document]. United Nations. URL. https://www.un.org/en/desa/future-un-time-think-big-urges-guterres (accessed 11.21.22).
United Nations, 2022b. World Headed for Climate Catastrophe without Urgent Action: UN Secretary-General [WWW Document]. URL. https://www.unep.org/news-and-stories/story/world-headed-climate-catastrophe-without-urgent-action-un-secretary-general (accessed 11.21.22).
Westin, J., Kågeson, P., 2012. Can high speed rail offset its embedded emissions? Transp. Res. Part D: Transp. Environ. 17, 1–7. https://doi.org/10.1016/j.trd.2011.09.006.