Sections of the state-owned inland transport infrastructure network that merit priority attention because of climate variability and change

FINAL REPORT
June 2018

Document prepared by CEDEX with the collaboration of:

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Supported by:

GOBIERNO DE ESPAÑA
MINISTERIO PARA LA TRANSICIÓN ECOLÓGICA
Fundación Biodiversidad 20 AÑOS
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1. BACKGROUND AND SCOPE OF THIS DOCUMENT

The goal of this document is to present the results obtained in the exercise of identifying the sections of the state-owned road and railway networks in Spain that merit priority attention because of their vulnerability due to current climate variability and its possible evolution as a consequence of climate change.

The exercise presented in this document takes as its starting point the results of the analysis conducted in 2013 by the Spanish Ministries of Transport (*Ministerio de Fomento*) and the Environment (*Ministerio de Agricultura, Alimentación y Medio Ambiente*) regarding the need to adapt the core network of transport infrastructures in Spain to climate change[1]. Said analysis enabled a preliminary identification, of a qualitative nature, of the expected climate change impacts and risks to consider in the stages of planning, design and operation, using as a basis average projections of some of the most relevant climate variables for transport infrastructures. It also permitted the recommendation of several adaptation measures geared both to the design of new infrastructures and the operation of the existing ones.

Based on the analysis conducted in 2013, the objective is now to identify which parts of the current state-owned inland transport infrastructure network require priority attention to adapt to the effects of climate.

This exercise has been carried out with the participation of Ministerio de Fomento's Directorate General of Roads, ADIF and ADIF Alta Velocidad (the managers of the transport networks), the Spanish Meteorological State Agency, AEMET (the institution providing the basic information on climate change scenarios for Spain), and the Centre for Public Works Studies and Experimentation, CEDEX (the promoter and coordinator of the initiative).

The exercise was also supported by Ministerio de Fomento's *Subdirección General de Planificación de Infraestructuras y Transporte* and by *Ministerio para la Transición Ecológica* through the *Fundación Biodiversidad*. The grant given to CEDEX by the latter Foundation plus CEDEX' own funds have served to meet the cost of certain specialised technical support tasks, of the translation of this document to English and of travel expenses, the overall amount of which has been nearly €35,000. The rest of the work has been carried out internally thanks to the dedication of the staff of the organisations involved in this exercise.

Finally, it is worth mentioning that this exercise was developed in parallel to the Ministerio de Fomento's participation in the Group of Experts TRANS/WP.5/GE.3 of the United Nations Economic Commission for Europe (*Group of Experts on climate change impacts and adaptation for transport networks and nodes*), with the intention of ultimately making it available to the Group as a practical experience of a study at network level.

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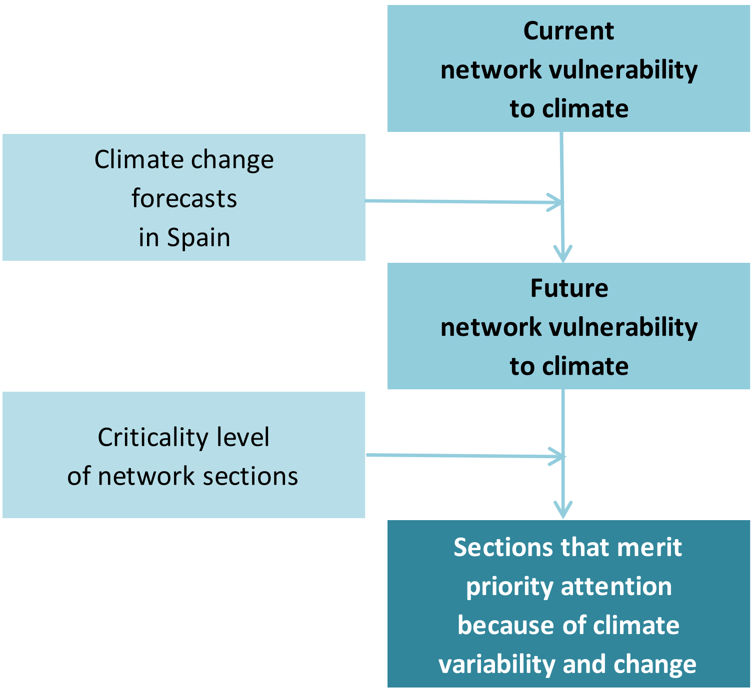
[1] *Final Report of the Working Group for the analysis of the climate change adaptation needs of the core network of transport infrastructure in Spain.* September 2013.

2. METHODOLOGY USED

Figure 1 summarises the way in which the exercise has been structured. In the first stage, we evaluated the current vulnerability of the state network of inland transport in respect of climate events, i.e., to what extent the network is capable of absorbing the negative effects of climate, often associated to its variability and to extreme phenomena (chapter 4). Next, we estimated how that vulnerability may be affected in the future because of climate change (chapters 5 and 6). Last of all, we tried to identify which network sections merit priority attention because of said vulnerability (chapter 8), given the degree of vulnerability that is acceptable in each section according to its criticality level (chapter 7).

Figure 1
Outline of the methodology used



It can often be read in the analytical corpus that the current vulnerability of a system can be assessed by combining the magnitude and nature of current climate conditions with the sensitivity of the system to climate and its capacity of adapting. In the case of a section of the inland transport network, it can easily be imagined that this sensitivity will largely depend on the time elapsed since it was built, on the characteristics of the site where it is located, on the standards considered in its design, on the way in which the construction was executed, and on how the different assets have been maintained throughout its lifetime. Even if this information were available for all the sections of the state network, we would then have to face the challenge of estimating how the vulnerability of each asset of a section is affected by each one of the current climate variables, according to all the determining factors mentioned above.

In light of the difficulty of applying this theoretical approach (probably not only for a network analysis, but also for the evaluation of the vulnerability of a specific road or railway section), in this exercise we have chosen to seek a way to directly characterise the vulnerability of each network section.

This often requires the exploitation of systematic records allowing us to identify the weather events that most frequently affect the network sections, and assessing their impact on users and on the infrastructure. However, the availability of said records for the state network in Spain is quite limited.

Because of this, to assess the current vulnerability of the network, in the end we decided to resort directly to the knowledge of the staff that manages and operates the network. In the case of the road network, its vulnerability has been characterised with the support of technical staff of the *Demarcaciones de Carreteras del Estado*, the decentralised road services of the Ministerio de Fomento's Directorate General of Roads; in the case of the rail network, we have benefited from the collaboration of the technical staff of the Maintenance Directorates of ADIF and ADIF Alta Velocidad.

To assist in evaluating the network vulnerability in the future because of climate change, we have had at our disposal data on climate projections furnished by AEMET and maps on changes of exposure prepared by CEDEX using said data. The significance of the change of vulnerability due to this change of exposure has been estimated taking into account the perceptions of the same technical staff mentioned above, qualified in some cases with the judgment of experts regarding the behaviour of a specific infrastructure asset. In this process we have tried to bear in mind that the exercise is meant to be a preliminary examination or screening allowing us to identify the network sections whose resilience should be analysed later in greater detail, therefore it is essential to prevent the exclusion of sections or possible impacts as a consequence of an underestimation of the evolution of vulnerability caused by climate change.

3. THE TRANSPORT NETWORK BEING ANALYSED

The state-owned road network

The state-owned road network (*Red de Carreteras del Estado*, RCE) comprises nearly 26,400 km of a total of almost 165,500 km of roads in Spain. Out of the state-owned network, nearly 12,000 km are high-capacity roads (motorways and other dual carriageway roads) and 14,400 km are conventional single carriageway roads. The RCE includes roads in all the Autonomous Communities on the Spanish mainland, as well as just over 30 km in the Autonomous cities of Ceuta and Melilla, which have not been considered for this exercise. In the Basque Country and Navarre, the state only owns two toll motorways under concession (AP-1 and AP-68).

Despite the fact that it only comprises 16% of the total length of roads in Spain, the RCE bears more than half of the total volume of interurban traffic and around two thirds of the heavy-vehicle traffic.

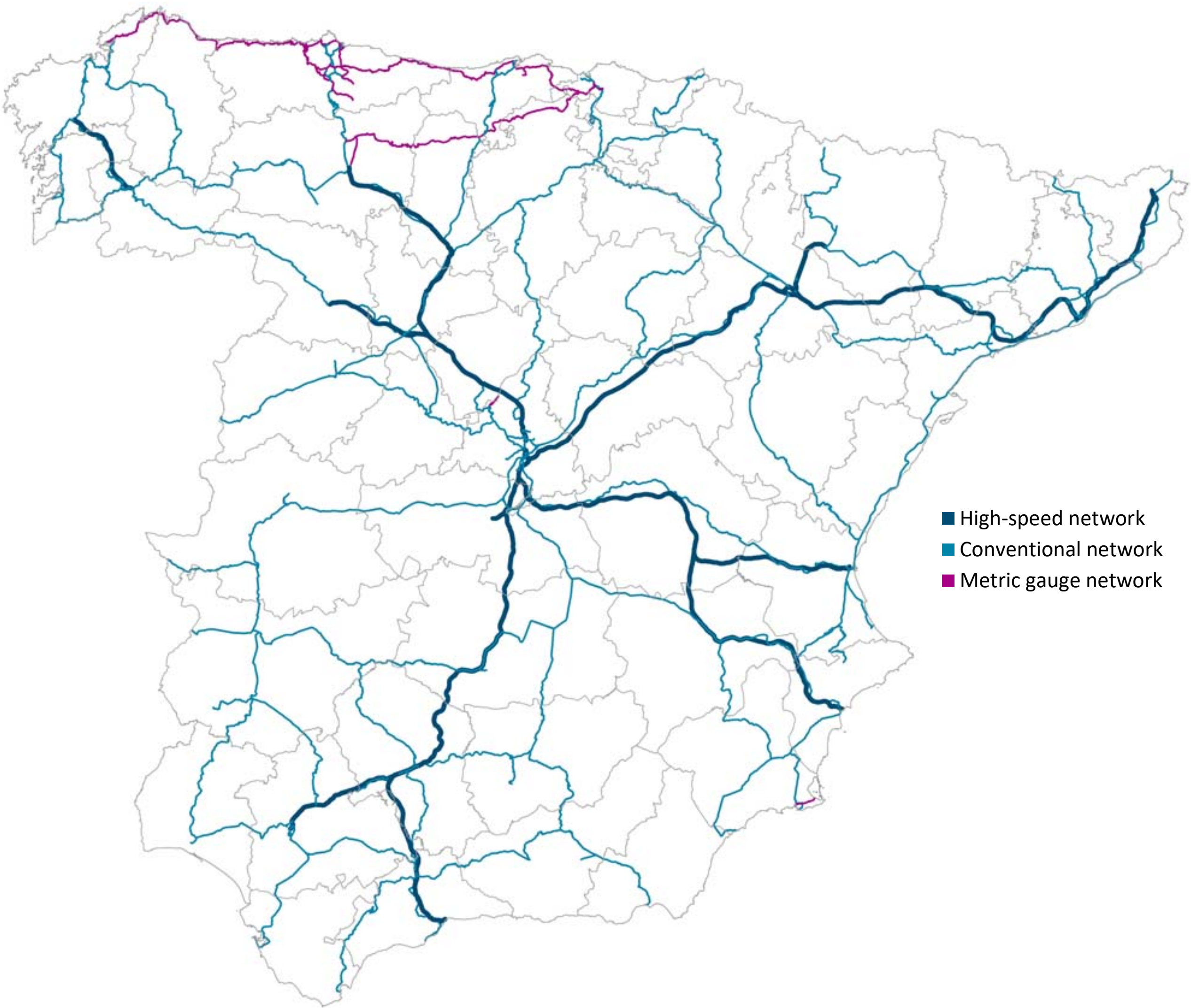
Figure 2
The state-owned road network

The state-owned rail network

The state-owned rail network (*Red Ferroviaria de Interés General*, RFIG) comprises the railway infrastructures that are essential to guarantee a common railway transport system throughout the Spanish territory and those managed by the Port Authorities of the state-owned port system connected to it. The RFIG comprises nearly 15,300 km of railways, equal to over 96% of the total Spanish rail network. 79.4% of these railways belong to ADIF and the remaining 20.6% belong to ADIF Alta Velocidad.

Of all the railways in the RFIG, 2,655 km correspond to the high-speed network, 11,249 km correspond to the conventional network with Iberian gauge, 190 km correspond to the mixed network (combining the Iberian and standard gauges), and 1,207 km feature metric gauge railways. For the purpose of the presentation of results of this exercise, the conventional Iberian gauge network and the mixed network have been grouped together under the label 'conventional network'.

Figure 3
The state-owned rail network



37.4% of the RFIG railways are electrified with a double track, 26.1% are electrified with a single track, and 36.5% are non-electrified single-track railways. Regarding their age, it should be noted that there is a great difference between the conventional and the metric gauge networks compared to the high-speed network. While the conventional and the metric gauge rail lines in many cases are over a hundred years old, the first high-speed railway was inaugurated in 1992, and the time elapsed since the entry into service of 82% of the high-speed network is 15 years or less.

The RFIG is found solely on the Spanish mainland. The high-speed and conventional networks cover a significant part of the territory, whereas most of the metric gauge network is located in northern Spain.

The RFIG is connected with the French rail network in the standard gauge at Figueres-Vilafant through the infrastructure manager Línea Figueras Perpignan, S.A., and in the Iberian gauge at the borders in Irun/Hendaye, Portbou/Cerbere and Puigcerdà/La Tour de Carol (these access points require trains to switch to the standard gauge). The connection with the Portuguese network, in the Iberian gauge, takes place at the borders in Badajoz/Elvas, Tuy/Valença do Miño and Fuentes de Oñoro/Vilar Formoso. The metric gauge network is connected with the regional network in the Basque Country at Áriz (Basauri).

Integrating both networks in a Geographic Information System

The spatial component of this exercise made it necessary, as a first task, to integrate the RCE and the RFIG in a Geographic Information System (GIS). To this end, we used the geo-referenced definition of both networks furnished by the Directorate General of Roads and ADIF.

Once the two networks integrated in the GIS, a preliminary list of sections within each network was defined. In general, it was sought to avoid sections covering stretches of different roads or railway lines, and to make the sections as long as possible, thereby avoiding a division into too many sections with the goal of facilitating the subsequent tasks.

This preliminary list of sections was afterwards reviewed by the technical staff of the regional services of the Directorate General of Roads and of the Maintenance Directorates of ADIF and ADIF Alta Velocidad, with the intention of avoiding significant differences in terms of impacts of current climate conditions within the same section. After this review, the number of sections we obtained was 710 in the road network and 290 in the rail network, meaning that the average length of a section is just over 35 km for roads and 50 km for railways.

4. CURRENT VULNERABILITY OF THE NETWORK

Method used to characterise vulnerability

The characterisation of the road and rail network vulnerabilities was done based on a **pre-established typology of impacts**. Tables 4 and 5 list the impacts considered. All of them are impacts which, according to the results of the report conducted in 2013, may in principle be relevant because of their potential effect on traffic conditions and/or the significance of the damage caused in the infrastructure. Some of the impacts are common to the road and rail networks, whereas others are specific of each type of infrastructure.

Table 4

Pre-established list of impacts on roads because of climate events

Landslides and erosion and falling of materials of ***slopes*** *as a consequence of* ***heavy rain***
Erosion of slopes in ***embankments*** *by the course of a river as a consequence of* ***extraordinary floods***
Insufficient capacity of the ***drainage works*** *due to* ***heavy rain***
Erosion of abutments, undermining of foundations and impacts from debris materials on ***bridges and viaducts*** *due to* ***extraordinary floods***
Development of ruts on the ***pavement*** *as a consequence of* ***high temperature***
Insufficient ***road surface drainage capacity*** *as a consequence of* ***heavy rain***
Impact on the ***road traffic conditions*** *due to* ***wildfires***
Impact on the ***road traffic conditions*** *due to* ***snow***

Table 5

Pre-established list of impacts on railways because of climate events

Landslides and erosion and falling of materials of ***slopes*** *as a consequence of* ***heavy rain***
Erosion of slopes in ***embankments*** *by the course of a river as a consequence of* ***extraordinary floods***
Insufficient capacity of the ***drainage works*** *due to* ***heavy rain***
Erosion of abutments, undermining of foundations and impacts from debris materials on ***bridges and viaducts*** *due to* ***extraordinary floods***
Strain in the ***fastening rail system*** *and track buckling as a consequence of* ***high temperature and/or extreme thermal oscillation***
Dragging and movement of the ***track ballast*** *as a consequence of* ***heavy rain***
Impact on the ***rail service conditions*** *due to* ***wildfires***
Impact on the ***rail service conditions*** *due to* ***snow*** *in the conventional and metric gauge networks*
Impact on the ***rail service conditions*** *due to* ***ice*** *in the conventional and metric gauge networks*
Impact on the ***rail service conditions*** *due to* ***very strong wind***

Generally, we have tried to get each impact to link an infrastructure asset (or the infrastructure serviceability) with a major climate factor, although this does not mean that said factor is necessarily the sole cause of the impact. The list of impacts concentrates on the direct impacts, without trying to assess any possible side effects or synergy effects (for instance, the negative effect that using salt to melt ice may have on the road pavement, or the impact a wildfire may have on the runoff of a watershed and the drag of materials). Last of all, it should not be forgotten that the impacts considered in this exercise are only those caused by climate events; therefore, it is not a comprehensive list of all the impacts that may affect traffic conditions and/or damage the infrastructure.

The next step was to **characterise the level of the impact** (limited/non-existent, moderate or important) **of the current climate conditions on each of the sections defined**, using a scale similar to that shown on figure 6. The level of the impact will usually be determined not only by the entity of the weather events, but also by the age of the infrastructure, the design criteria employed, the construction methods used back in the day, and the manner in which the infrastructure has been maintained over the years. Nearly a hundred technical staff from the road regional services and from the Maintenance Directorates of ADIF and ADIF Alta Velocidad (Annex V) have taken part in this task of characterizing vulnerability.

Figure 6

Scale used to characterise the level of impacts on the inland transport network

SCALE OF IMPACTS									
Inexistent/limited effect on traffic and/or on the infrastructure			Moderate effect on traffic and/or on the infrastructure			Important effect on traffic and/or on the infrastructure			
1	2	3	4	5	6	7	8	9	10
The effect on the infrastructure and/or its functionality is non-existent or limited throughout the section. Repair is compatible with routine maintenance actions. Road/Rail traffic conditions may be affected by speed limits and/or traffic and/or access control measures during a short period of time (hours).			The effect on the infrastructure and/or its functionality is moderate at some point of the section, requiring modest repairs and/or replacements. Road/Rail traffic delays and/or traffic deviations may be required lasting hours or days.			The effect on the infrastructure and/or its functionality and/or its security is significant or complete at some point of the section. The repair requires the rehabilitation/ reconstruction of one or several infrastructure assets. Road/Rail traffic delays and/or traffic deviations may be required lasting weeks or months.			

The level of the impact is graded with 1 when the effect is null, irrelevant or negligible. The numerical scale helps to qualify, within the same level of effect, the nearness to a contiguous level or the frequency of the impact.

In order to prevent the omission of impacts that may be significant for network vulnerability, we asked the technical staff who carried out the evaluation to incorporate to the list of pre-established impacts any other impact whose effect on traffic and/or the infrastructure is considered moderate or important.

With the purpose of unifying criteria among the technical staff during the evaluation, thereby limiting subjectivity when qualifying the level of each impact and guaranteeing the comparability of the evaluation results, meetings were held with all the road regional services and departments of ADIF and ADIF Alta Velocidad that participated in the vulnerability assessment. At these meetings, technical staff were reminded that the vulnerability of a section will be determined by the maximum effects on one or more points thereof. This criterion is especially relevant for a correct interpretation of the figures on the length of the network affected appearing throughout this document, which are significantly higher than the length of road or railway line where the effects on traffic and/or the damage to the infrastructure actually take place.

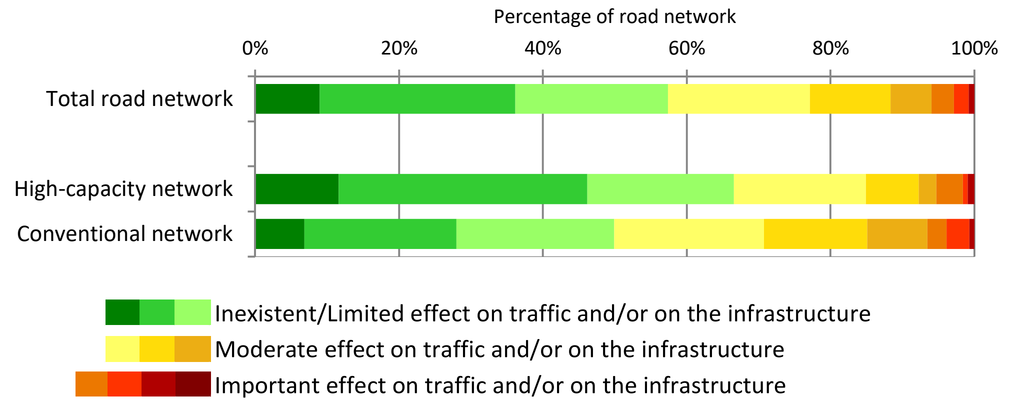
At the end of the process described here, we had information on 98.2% of the RCE (a few short stretches of cross-town links or roads with a change of ownership pending are left out) and 97.6% of the RFIG (three sections on which no trains run at present[2] and just over 250 km of conventional railway that belong to ADIF Alta Velocidad and are currently maintained by ADIF are left out).

At present, is the road network slightly or very vulnerable?

Based on the information obtained, it is inferred that the road sections that are not affected by any weather event, or which are affected in a limited manner according to the definition established in the scale of impacts used, represent 57% of the length of the network (figure 7). In the case of the high-capacity network, the percentage rises to 66%. The road sections in which there is an important impact due to some weather event account for 6% of the length of the network.

In light of the temptation of considering whether these percentages are low or high, it should be noted that the evaluation of the level of network vulnerability, for the purpose of this exercise, is a merely instrumental item. The characterisation that has been provided is not meant to contribute to a discussion on the level of vulnerability of the state network, which in any event would be fruitless because of the lack of own experience in respect of similar evaluations in the past, and because of the absence of references to results from other infrastructure managers regarding the evaluation of the vulnerability of their network.

Figure 7
Current maximum effect[3] on the road network because of weather events



Figures I.1 to I.8 of Annex I show the percentage of the state road network in which the level of effect is limited or non-existent, according to the type of impact. As a general rule, this percentage is over 80%, and it is always higher in the high-capacity network than in the conventional network. Figure 8 compares in greater detail the percentage of the road network represented by sections in which each impact may be presented as moderate or important.

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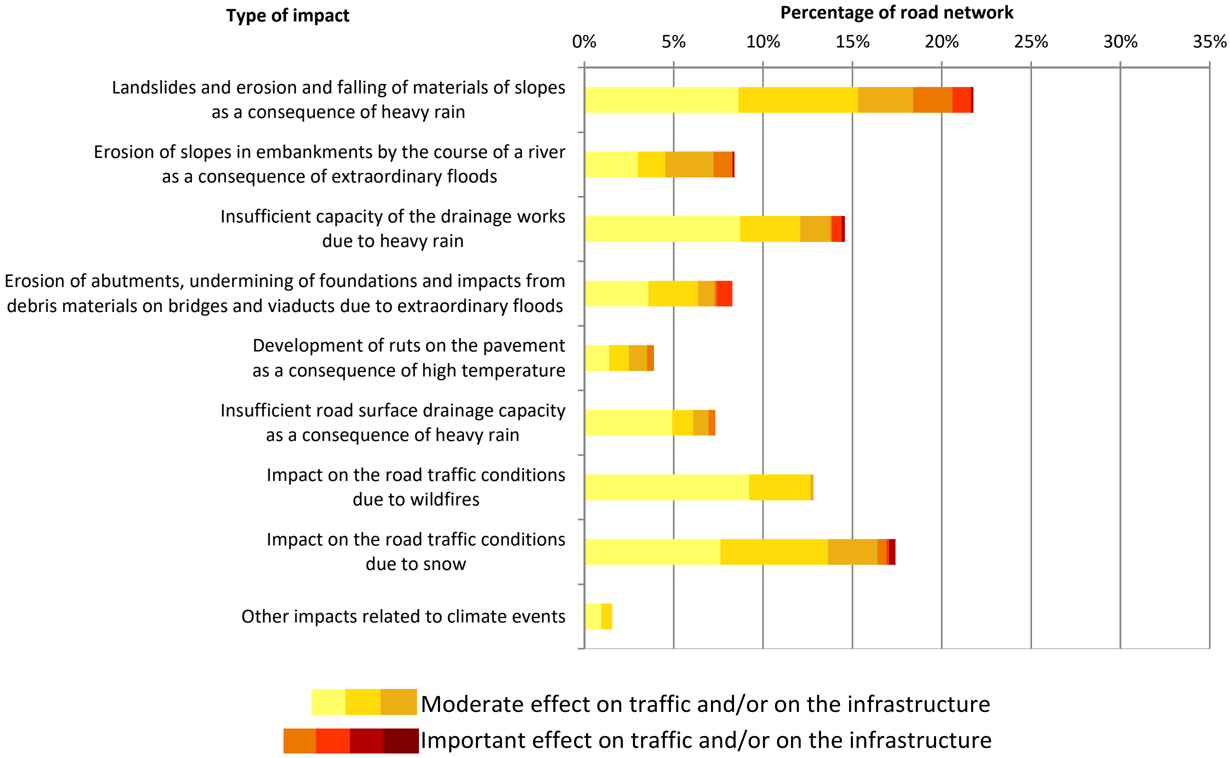
[2] Bustarviejo-Linares on railway line 102, Soria – Cervera del Río Alhama on railway line 202, and Huéneja-Dólar – Minas del Marquesado on railway line 412.

[3] The *maximum effect* on a section is the maximum of the effects caused by each type of impact on the section.

Figure 8
Current vulnerability of the road network, according to type of impact



Because of its incidence, the vulnerability of the earthworks stands out, especially the problems associated to landslides and rockslides on slopes. The effect on embankments and their protections of the river-beds running along their side is less extended, although it remains significant on conventional roads. In some specific road sections, the geotechnical problem of instability is not necessarily linked to heavy precipitation or extraordinary floods. This is the case of a road section running alongside a dam, where the risk is associated to prolonged drought. In that stretch, slopes are highly unstable. When the water level of the dam falls, there tend to be more slope movements and landslides may occur, because the stabilising effect of the water in the dam disappears.

In relative terms, there is also the relevant effect of the insufficient capacity of drainage works, especially in the conventional network, where we can still find drainage works designed according to the criteria of decades ago, and/or whose size has not yet been possible to adapt to the changes in land use that may have been developed in the surroundings of the road.

The impact on the network due to the development of ruts on the pavement is presently very small, despite the fact that the virtual entirety of the RCE is paved with bituminous materials. Among the non-pre-established impacts with a moderate or important effect, some road regional services mention, although for a non-significant length of the network, deterioration of the pavement due to heavy rain. However, no significant effects on the pavement subgrade have been identified due to swelling of expansive soils in areas susceptible to such swelling.

Regarding road traffic conditions, snow is the weather phenomenon with the greatest effect on the network, normally because of traffic restrictions for heavy vehicles and the mandatory use of snow chains (such restrictions that may last for quite some time in certain sections) and, exceptionally, due to the full shutoff to traffic. In a small number of sections there is also the risk of avalanches.

The risk of fire may also affect a considerable length of the network, although the consequences on road use conditions, in the event a fire breaks out, are foreseen as moderate at the most, given the time normally required by fire fighters to put out a fire. There is a greater perception of risk when the road runs along important forest areas, especially in protected natural areas.

The number of sections where there are points of the road surface with insufficient drainage capacity and risk of aquaplaning is much lower than the sections affected by snow or the risk of fire. On high-capacity roads, the impact is moderate, whereas in some sections of conventional roads the effect on traffic may last longer. The effects are usually very located and are the consequence of an inadequate or insufficient design of the road camber, or of insufficient drainage capacity in the ditches running alongside the carriageway. In a very limited number of sections it may be caused by the flooding of rivers in the surroundings of the road during episodes of heavy rain.

Although there are other impacts besides those mentioned above, their effects on road serviceability or on the integrity of the infrastructure are limited and/or located in a small number of sections. This is the case, for instance, of wind gusts, which can knock over vegetation and road signalling or may require temporary traffic speed reductions in specific points of the network. As far as fog is concerned, there is a particular section of the A-8 motorway when going through the municipal district of Mondoñedo (Lugo), where traffic is quite often interrupted and vehicles are deviated to the N-634 road due to heavy fog, sometimes for over 24 hours.

In some cases, there are problems with water leaks and its evacuation in tunnels. Damages and/or floods in coastal areas are likewise exceptional, because there are few stretches of the state network running very close to the sea. Only two sections have been identified where the sea may occasionally have a moderate effect on the road because of the action of waves.

Is it relevant that the current vulnerability of the rail network is higher than that of the road network?

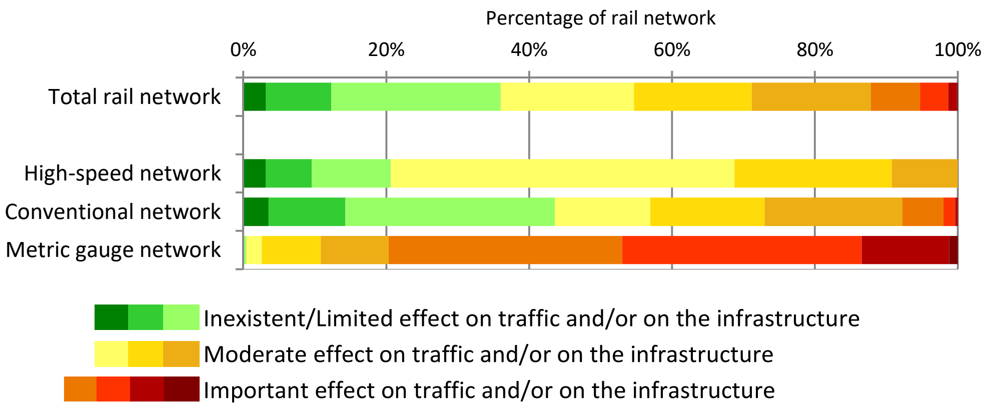
As far as the railway is concerned (figure 9), the current effect of weather events is null or limited in 36% of the length of the network. The rail sections in which there is an important effect due to some type of weather event represent 12% of the network.

On this occasion one may be tempted to compare these percentages with those obtained for the road network. It should be noted, however, that the fact that the current vulnerability of the rail network appears as being higher than that of the road network is not substantial in itself, because the sensitivity to climate of some infrastructure assets and the operating protocols of the two networks cannot be equated.

The fact stands out that, in the case of the high-speed network, the percentage of the network in which the effect is null or limited falls to nearly 20%. By analysing the effect according to the type of impact, it is found that it is due especially to the incidence of heavy rain on slopes and on the ballast.

Regarding the metric gauge network, in all the sections considered there is some type of impact on traffic and/or on the infrastructure with a significant effect. It should be borne in mind that over 93% of the length of this network is made up by single-track railway lines, which undoubtedly has a repercussion on their degree of vulnerability (this is the case, at least, in the conventional network, where the effect is null or limited in 33% of the single-track railway lines, compared to 69% of the double-track railway lines). The difference in the level of effect on the metric gauge network compared to the conventional network may also be explained by its age, by the topography and geology of the geographical area where it is mostly present, or by the history of the intensity of its maintenance. The degree of vulnerability of the metric gauge network is also affected by the criteria that were used in its planning and design, which sought to economise as far as possible, using strict platforms and layouts that closely follow the ground so as to avoid, in the extent possible, resorting to large structures.

Figure 9
Current maximum effect on the rail network because of weather events



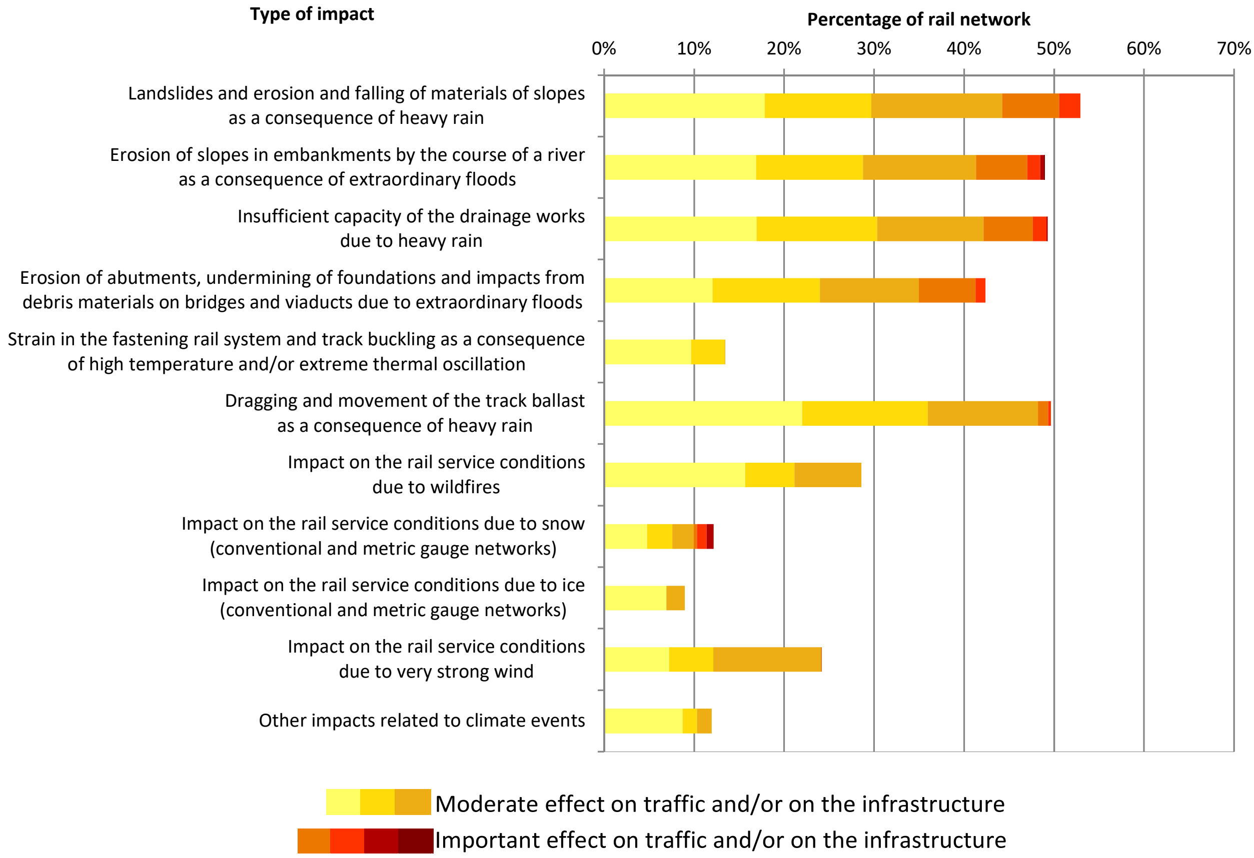
On figures I.9 to I.18 of Annex I we can see the percentage of the rail network in which the effect is estimated to be limited or null according to the type of impact. Figure 10 shows in greater detail the percentage of the network with sections in which the presence of each impact may be moderate or important.

Just as with roads, the vulnerability of the earthworks is notorious. The length of the sections with slopes where the effect is moderate or important represents over 50% of the network. In the high-speed network there are no important effects on the slopes, but there is an extensive presence of moderate effects, probably due to the construction of big slopes as a consequence of alignment requirements. The incidence on embankments and their protections of the river-beds running near the railway is likewise significant, especially in the metric gauge network, where the alignment tends to adapt to the terrain and often runs near rivers down in a valley.

In relative terms, the problems caused by insufficient capacity of drainage also stand out, as well as the impacts on bridges/viaducts, and the effect of dragging and movement of the railway ballast. It must be taken into account that the age of the conventional railway lines and the metric gauge railways (which represent over 82% of the RFIG) is often around one hundred years, and this can have an incidence in terms of the inadequate design of certain drainage works, or in the deterioration of certain bridge elements. It is worth noting, however, that insufficient drainage capacity, even though the effect is quite moderate, is also extended in the high-speed network, despite being a network of recent construction and the fact that the criteria used for the design of the drainage are similar to those of the road network. Regarding the dragging and movement of ballast, it is greater in the high-speed and the metric gauge networks, possibly because of the demanding conditions of high-speed in the former case, and because of the delay that may cause the problem resolution in a single track line in the latter case.

On the contrary, the effect on the track as a consequence of high temperature and/or extreme thermal oscillation is always limited, except in the conventional network, where in some sections it may be considered moderate.

Figure 10
Current vulnerability of the rail network, according to type of impact



Of the rest of factors with an incidence on rail traffic, the risk of fire and the strong wind stand out. The alteration of the rail service due to fire is moderate at most, being scarce in the high-speed network and more extended in the metric gauge network. Very strong winds hardly affect rail traffic in the high-speed network, but they do have a moderate incidence on circulation in part of the conventional and metric gauge networks, especially on single-track railway sections. In most cases, the effect is usually caused by fallen trees or other objects on the track, that may even affect the electrification system. Exceptionally, there have been breakdowns of cargo in a section particularly exposed to strong wind gusts.

According to the results of the report conducted in 2013, the effect of snow and ice on the high-speed network is perceived by the rail manager as negligible. The results obtained in this exercise suggest that the incidence of snow and ice may be moderate in some sections of the conventional network, and important in the sections of the metric gauge network running alongside the Cantabrian Mountains in the north of the provinces of León, Palencia and Burgos.

Last of all, the information compiled has allowed us to confirm that, although there are impacts other than the pre-established ones on the rail network, their repercussions on the traffic conditions or on the integrity of the infrastructure are limited. Only in a small number of sections of the conventional network can the effect be moderate basically due to lightning, fog, waves (due to erosion of slopes in embankments that are near the coast in the event of storm, or because of the rise of the sea level in spring tides) or the corrosion of some components in areas close to the sea or in coastal lagoons.

5. CHANGES IN THE LEVEL OF EXPOSURE OF INFRASTRUCTURES DUE TO CLIMATE CHANGE

This chapter describes the forecast of the climate conditions that the RCE and the RFIG may have to face because of climate change. Said forecast has been obtained from the information on climate change provided by AEMET. In assessing the possible effect of climate change on the vulnerability of the network that is currently in operation, we have estimated that it is sufficient to consider a **time horizon of 30 years**.

Improvement in the characterisation of extreme weather events and their spatial distribution

The analysis conducted in 2013 of the need for the Spanish network to adapt to climate change allowed us to confirm certain limitations regarding the availability of projections for some variables of interest for the management of transport infrastructures. Efforts have been put forth in this exercise to try to mitigate two of those limitations:

- On the one hand, the characterisation of changes in extreme events, which is essential from the standpoint of the transport infrastructure manager. In this respect, AEMET has provided the following information on air temperature, precipitation and surface wind:
  - Annual data on the 95th percentile of the maximum daily temperature.
  - Annual data on the number of days with minimum temperature below 0ºC.
  - Annual data on the 99th percentile of the maximum daily thermal oscillation.
  - Annual data on the 95th percentile of the daily precipitation.
  - Monthly data on the maximum precipitation in 24 hours.
  - Monthly data on the maximum wind speed.

  The data on the 99th percentile of the maximum daily thermal oscillation were generated by AEMET on an *ad hoc* basis for this exercise, because they are not available on its web server. The data on the maximum wind speed were likewise generated by AEMET *ad hoc*, because by default it only provides data on the average monthly value.

- Secondly, for each of the variables mentioned above, we tried to get projections with a level of spatial definition suited to the geographical dispersion of the state transport network in the territory. To this end, AEMET has extracted, based on the results available in Euro-Cordex[4], projections obtained with dynamic simulation for ten regional models embedded in different global climate models, with a spatial resolution scale of 0.11 degrees (about 12 km).

It is worth noting that the analysis of the adaptation needs conducted in 2013 allowed us to confirm other limitations regarding the availability of climate change projections, which still remain in place five years later. On the one hand, there are still no projections on some variables or phenomena mentioned then, for instance, on snow, fog or lightning. And advances have hardly been made in the availability of projections of some parameters pertaining to engineering that are of particular interest for the infrastructure manager, in the calculation of which climate variables are considered, for instance the maximum flow in floods.

[4] Euro-Cordex is a program sponsored by the World Climate Research Program (WRCP) to organise an internationally coordinated framework to produce improved regional climate change projections, so that they may serve as input for climate change adaptation studies within the timeline of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

To what extent is it useful for the infrastructure manager to consider more than one climate change scenario?

In order to facilitate the task of reflecting on and analysing what the foreseeable consequences of climate change may be, in this exercise we have considered a single climate change scenario. This scenario has been defined as the **most unfavourable situation of those foreseen by the RCP4.5 and RCP8.5 scenarios**. RCPs or "representative concentration pathways" constitute the group of scenarios used by the scientific community to prepare the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). RCPs represent the total radiative forcing calculated for the year 2100 in respect of the preindustrial level (for instance, RCP2.6 means 2,6 W/sq. m). Of the four RCPs used in the Fifth Assessment Report of the IPCC, we could say that RCP2.6 represents a mitigating scenario, RCP4.5 and RCP6.0 are stabilisation scenarios, and RCP8.5 corresponds to a scenario with a very high level of greenhouse gas emissions.

Moving towards greater availability of climate change projections

AEMET has provided the information on climate change in the form of text files, suitable for integration in a GIS after being transformed to raster format (one file for each climate variable, regional model, scenario and periodicity of the datum). The 30-year forecast change of exposure maps have been obtained as differences in the projections in the 2040-2050 and 2010-2020 periods. The use of data from a given decade seeks to tone down the effect of the climate variability usually shown by the results of the models. Working with anomalies (increases in a period) rather than with absolute values contributes to limiting the negative effects of the lack of calibration of the regional models. With these criteria, the preparation of each map has required the processing of 440 text files in the case of the climate data provided by AEMET on an annual basis, and 5,280 in the case of monthly data. Figures 11 to 15 show the maps obtained, as finally incorporated to the GIS. These maps represent the change of intensity of each variable in 30 years, in absolute figures, calculated as the average of the ten models considered, and in the most unfavourable scenario. In order to facilitate the assessment of the change of vulnerability, similar maps have been prepared in terms of relative change of intensity in respect of the current climate situation.

Maps have also been prepared to try to display the uncertainty associated to the simulation of the ten models considered. It is interesting to confirm that, for temperature, the standard deviation of a projection in respect of its average value obtained from the ten models is usually lower than the absolute value of said average variation, but it is often higher when we consider precipitation and, to a lesser extent, wind. In the 2013 report it was already suggested that the results on precipitation present a substantial uncertainty, not only because of the error introduced by downscaling methods when they are applied to precipitation, but also because of the position of the Iberian Peninsula in the transition zone between higher latitudes, where precipitation increases, and the subtropical zone, where precipitation will be reduced. Even though it is not the purpose of this exercise, being aware of said uncertainty and handling it appropriately is essential in the event it is decided to evaluate different adaptation options to increase the resilience of the infrastructure.

It is worth noting that the spatial distribution of the change of intensity obtained for the maximum precipitation in 24 hours is different depending on whether we worked with annual data on the 95th percentile of the daily precipitation, or with monthly data on the maximum precipitation in 24 hours. In the first case, the most intensive changes are obtained in the Mediterranean coast, and in the latter case in the north-western mainland. In this situation we have used the same criterion as in the case of the scenarios of climate change, considering the most unfavourable situation of both projections.

Preparing the collection of maps described above was an arduous task. Several national and international initiatives that are currently underway, however, suggest that the infrastructure manager will soon benefit from maps with climate change forecasts developed by climate service providers, without the need to dedicate its own staff to this task.

Forecast changes in the level of exposure

The evaluation of the change of vulnerability that may be experienced by the state-owned inland transport network in forthcoming decades has been done using climate change forecasts contained in the maps shown in figures 11 to 15. These forecasts have been supplemented, where necessary, with information included back in the day in the report on the need to adapt to climate change conducted in 2013, updated with some trends that the AEMET website currently provides aggregated for all Spain[5] or that are available through the scientific literature[6].

The projections on the **average temperature** indicate that throughout Spain there will be an increase of the average surface temperature. The average warming will be greater in summer than in winter. Not all regions will experience the same degree of average warming: while the thermal increase projected in winter will be quite similar in all regions, the increase in summer will be different between regions, with greater rises in the average temperature in the inland and southern regions of mainland Spain than in coastal areas. In all the regions, the **maximum daily temperatures** will tend to increase slightly more than the average temperatures. This increase will be more pronounced inside the upper third of the mainland, especially in the interior part of Galicia (figure 11).

The minimum daily temperatures will also rise, although somewhat less than the average temperatures. As a consequence, throughout mainland Spain there will be a reduction in the annual average of **days with frost risk**, i.e., days with a minimum temperature below 0º C. This reduction will generally be more notable in mountain areas (figure 12). There will also be a tendency for the **maximum daily thermal oscillation** to increase slightly, especially in the northern half of mainland Spain (figure 13).

Regarding the **accumulated annual precipitation**, the general projection is that of a gradual tendency for it to decline, more notably in the southeast mainland that in the north and northwest, with decreases by around 5 or 10% depending on the region.

As far as **extreme precipitation** during short periods is concerned, its intensity is forecast to increase, especially in the northwest and east of mainland Spain (figure 14), meaning that there could be an increase of the risk of **flash floods**. There are likewise forecasts of an increase in the intensity of **electrical storms**[7] during the convective storms that usually occur in the summer-autumn period. The greater irregularity of precipitation will cause an increase in the irregularity of local flooding, the magnitude of which may increase in the Mediterranean area.

Generally, no significant changes are projected in the **intensity of surface wind**. From the analysis of the available regional data it arises that there is a general trend towards a decrease of wind speed and of

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5 http://www.aemet.es/es/serviciosclimaticos/cambio_climat

6 *Regionalización de escenarios climáticos para la evaluación del riesgo de fuego: Desarrollo y Aplicaciones.* Doctoral Thesis. Joaquín Bedia Jiménez. Universidad de Cantabria.

7 An electrical storm is the name given to one or several sudden discharges of atmospheric electricity that manifest as flashes of light, i.e. lightning, and a sound in the form of thunder. Bolts are lightning discharges that reach the ground.

maximum gusts, except for some areas where there is a tendency towards an increase, although moderately (figure 15), normally during episodes of intensive convective storms.

In general, there is a forecast of a clear increase of the potential risk of **fire** in large areas of Spain, heightened in inland areas, with a gradual increase in the duration of the potential risk. As a consequence, there will be a foreseeable increase in the number of fires and the fire season will grow.

Regarding **snowfall**, it is forecast that the frequency will decline as a consequence of the decrease of precipitation and the rise in temperature.

Last of all, a rise of the **sea level** is forecast. In order to assess the effect of this in the sections of the state road and rail networks running near the coast, we have used as a reference a 20-cm rise in the average level. This rise in the sea level will not only affect the rise of water during spring tides but it will also heighten the effect of the waves on the infrastructure in the event of storms.

Figure 11
Change in the maximum daily temperature in 30 years

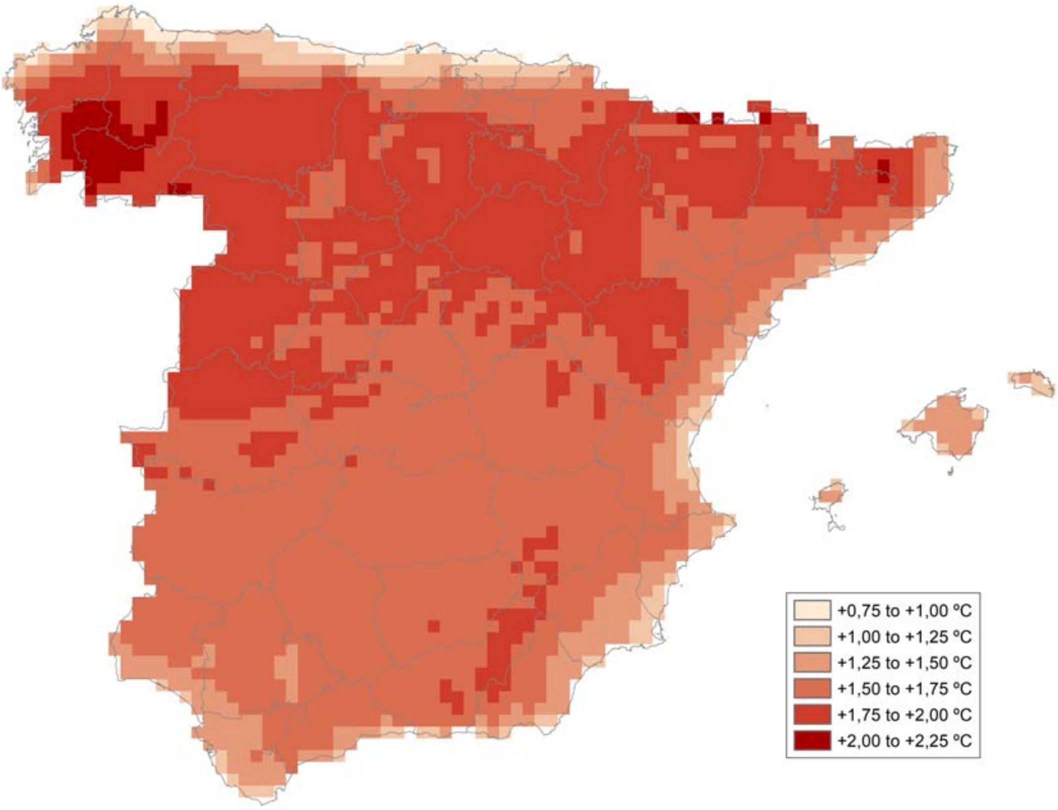


Figure 12
Change in the number of days in a year with minimum temperature below 0ºC in 30 years

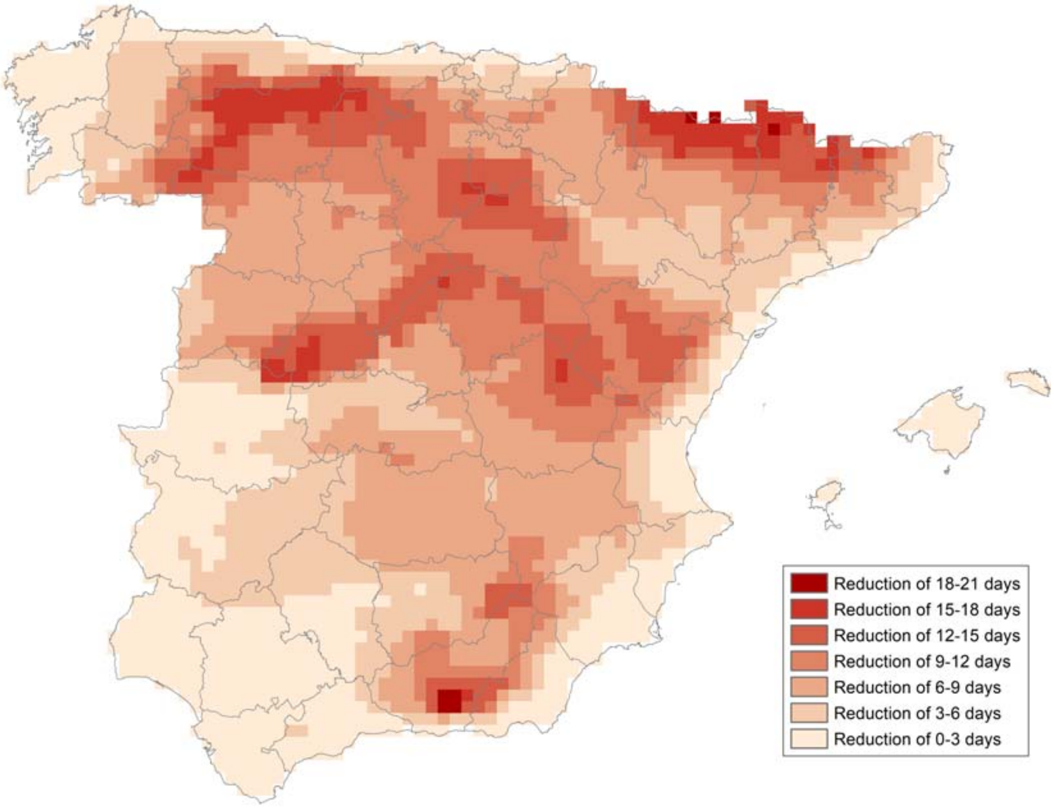


Figure 13
Change in the maximum daily thermal oscillation in 30 years

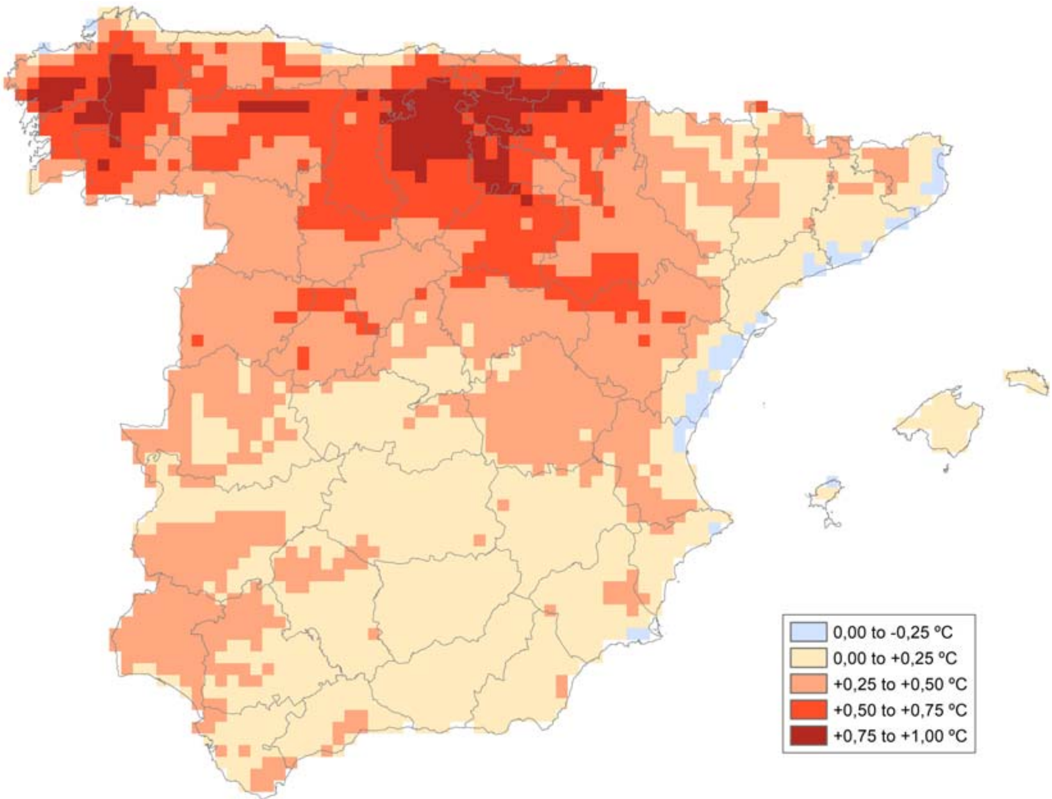


Figure 14
Change in the maximum precipitation in 24 hours in 30 years

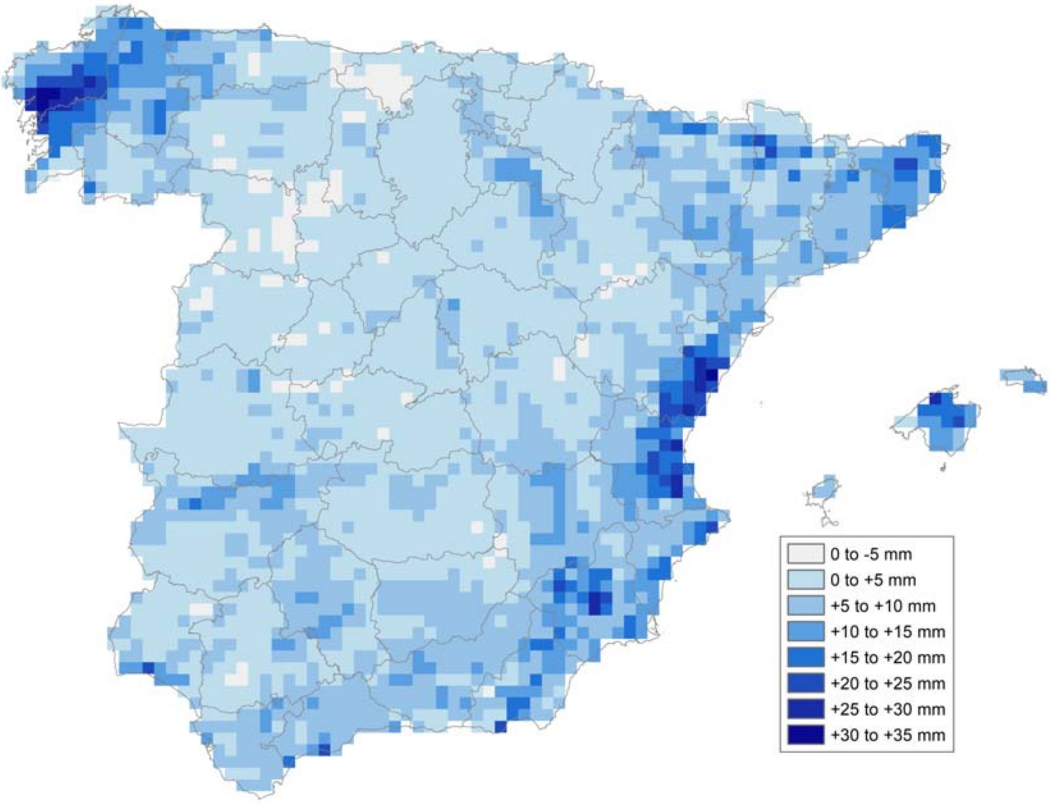
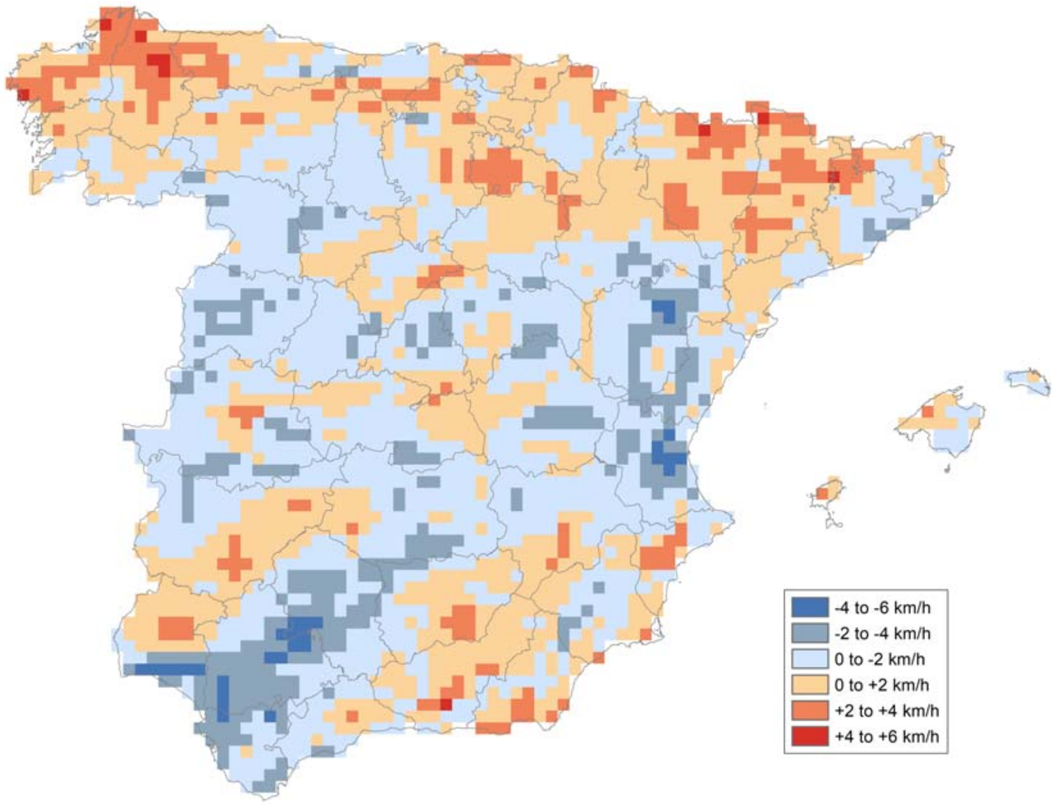


Figure 15
Change in maximum wind speed 10 meters from the ground in 30 years



6. NETWORK VULNERABILITY IN THE FUTURE

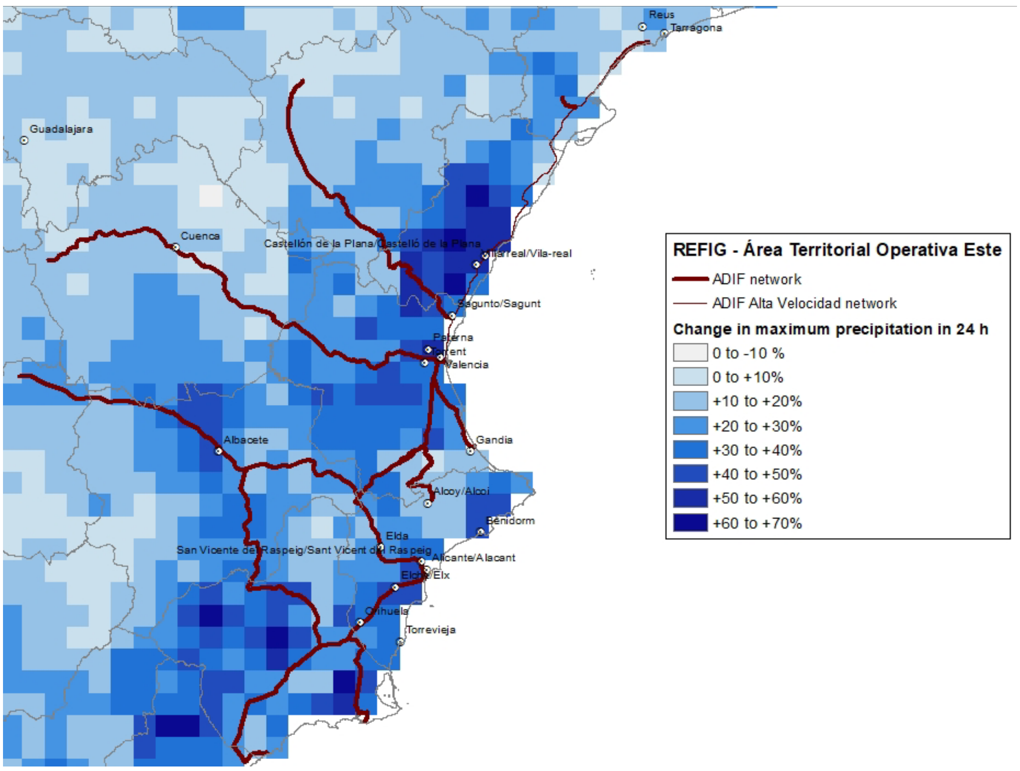
In this exercise, the characterisation of the network vulnerability in the future has been supported fundamentally by the expert opinion of the same technical staff from the Directorate General of Roads and from ADIF and ADIF Alta Velocidad who evaluated the current vulnerability of the network. Said technical staff were asked to estimate, using the same scale described in figure 6, what may be the level of effect on each section in the event the climate conditions in the future correspond to those described in the preceding chapter. To facilitate the task of the technical staff, the maps with climate change forecasts have been distributed at an appropriate scale, with the infrastructure network represented on those maps (figure 16).

It is foreseeable that, generally, the vulnerability of the transport infrastructure will vary over the years according to its current vulnerability, the effect that the passage of time may have in terms of ageing, the possible weather alterations that may take place as a consequence of climate change, and the maintenance, rehabilitation and/or improvement actions that any infrastructure manager normally carries out during the life span of the infrastructure, depending on the available budget.

In this exercise, when characterising network vulnerability in the future, we have assumed that the current conditions of the infrastructure will remain unaltered, that is, with a level of maintenance similar to the present one, and without carrying out rehabilitation and/or improvement actions. We have also brushed aside the effect that the passage of time may have on the ageing of some civil engineering assets (earthworks, structures and drainage works) and the wear and tear from the use of pavements and tracks, but not on the railway electrification, signalling and communication facilities.

Figure 16

Example of a map distributed to one of the Territorial Areas of Operations of ADIF



On the possible lack of objectivity of the method used …

The method used to evaluate the change of vulnerability is simple and pragmatic, in light of the goal of the exercise. It is true, however, that some objections may arise. In particular, it may be argued that there is a measure of subjectivity when judging the magnitude of the change of vulnerability. The results obtained from the evaluation conducted by a technical staff of over one hundred members, however, converge significantly regarding the incidence that climate change is expected to have on the current vulnerability of the network, granting a degree of reliability to the method used.

The charts in figure 17 give an idea of the dispersion obtained when qualifying the change of vulnerability of all the sections of the road and railway networks. In the impacts associated to the change of precipitation and temperature, the scale of change (according to the 1 to 10 scale described in figure 6) usually varies between 0 and +2 or, in a very small number of sections, +3. In the impacts related to winter conditions (snow and ice) and wind, it is estimated that the level of the effect may decline slightly in some sections, which is consistent with the reduction of the number of days in a year with a temperature below 0ºC and of the maximum wind speed reflected in the climate change forecast maps.

With the assistance of the GIS, we have tried to verify to what extent the change of vulnerability considered by the technical staff is related to a change of intensity of the climate events. The correlations obtained, although they point in that direction, are nonetheless weak. This may be due to the difficulty in scaling the magnitude of the change of the effect within such a limited range of options (the scores are generally 0, +1 or +2).

It is particularly interesting to look at the average scores of the estimate of the change of vulnerability represented in the charts in figure 17, because they show the resilience to climate change perceived globally for the network as a whole.

In the **road network**, this average score is around +0.6 in the impacts associated to an increase of heavy precipitation (somewhat less for insufficient drainage capacity of road carriageway), around +0.5 for an increase in the risk of fire, and around +0.4 for the potential development of ruts on the pavement due to temperature increases. These scores hardly change when distinguishing between the high-capacity network and the conventional network.

The change of effect of snowfall is null on average, although there is no unanimous criterion regarding the direction of the change, because clear forecasts on the effect of climate change on snowfall are not available. It is foreseen that there will be a general reduction of the number of days with temperatures below 0ºC, but at the same time there may be episodes of more intensive precipitation. Also, even if there is less snowfall, experience has shown that the effect on traffic on Spanish roads is not necessarily inferior with less intensive and/or frequent snowfall.

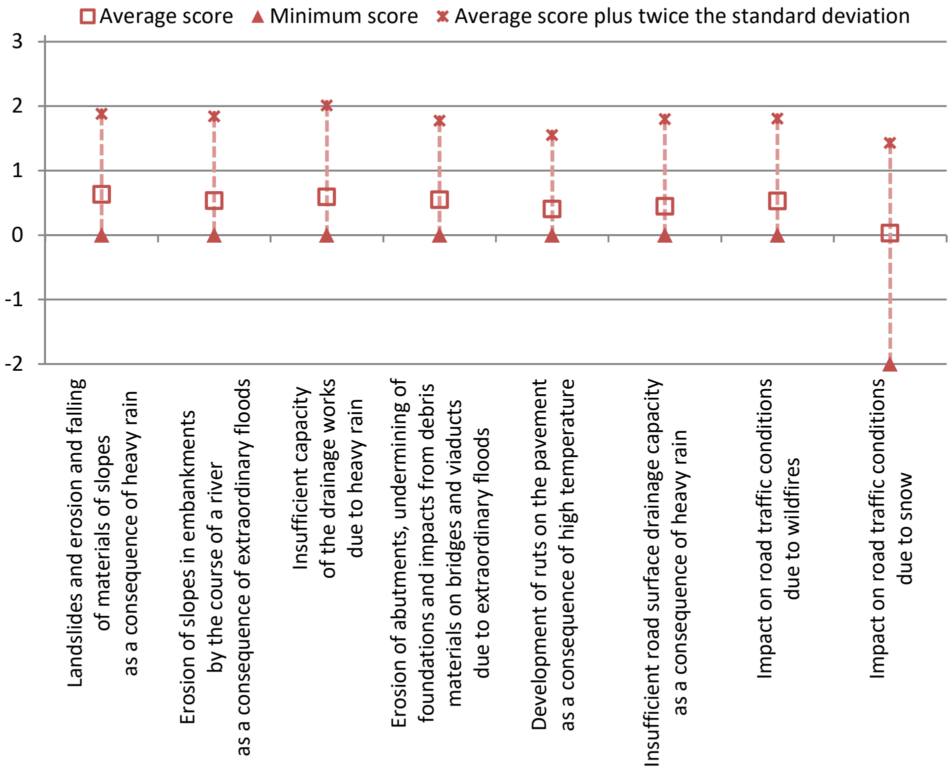
In the **rail network**, the average score of the change of effect is generally around +0.7 points, except in the case of the impacts of snow and/or ice on the conventional and metric gauge networks, for which it is perceived that the change of effect will be lower (+0.5).

In the rail network there is the notable fact that the effect of ice may increase in some sections despite the fact that climate forecasts point to a reduction of the number of days with frost risk across mainland Spain. Part of the technical staff feel that said reduction, in any case, will not offset the effect that the passage of time may have on the systems of some railway lines in the conventional network, which are old and in poor condition.

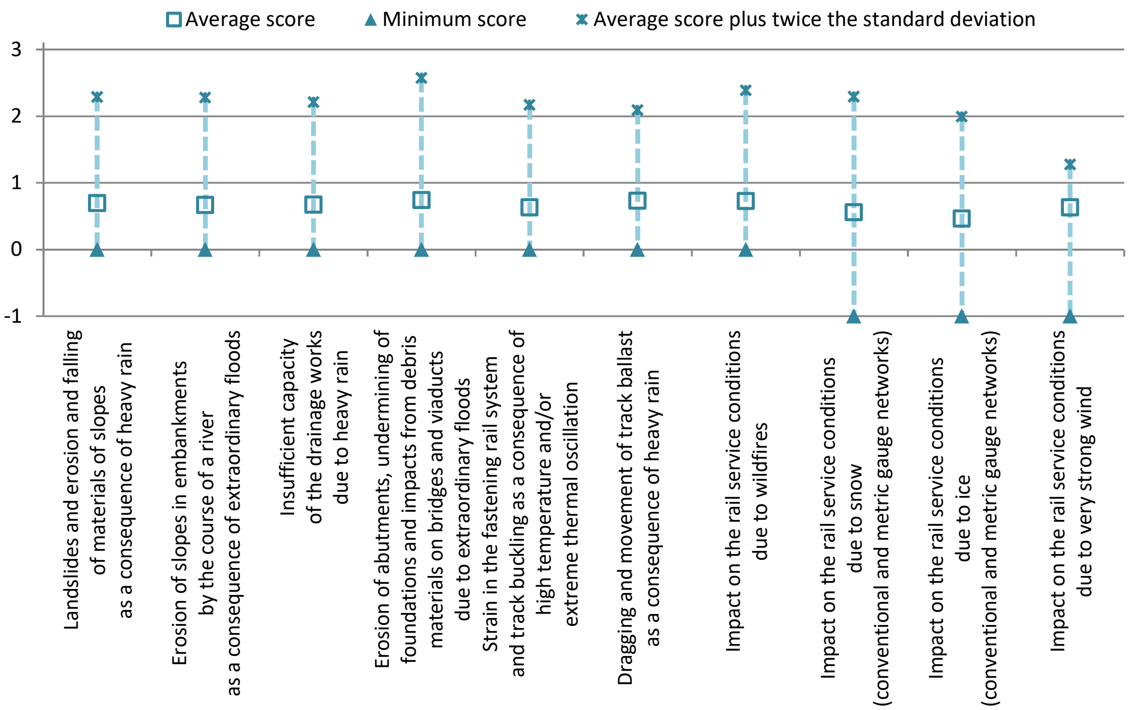
Figure 17

Estimate of the change of vulnerability of the state inland transport network, according to type of impact

Road network



Rail network

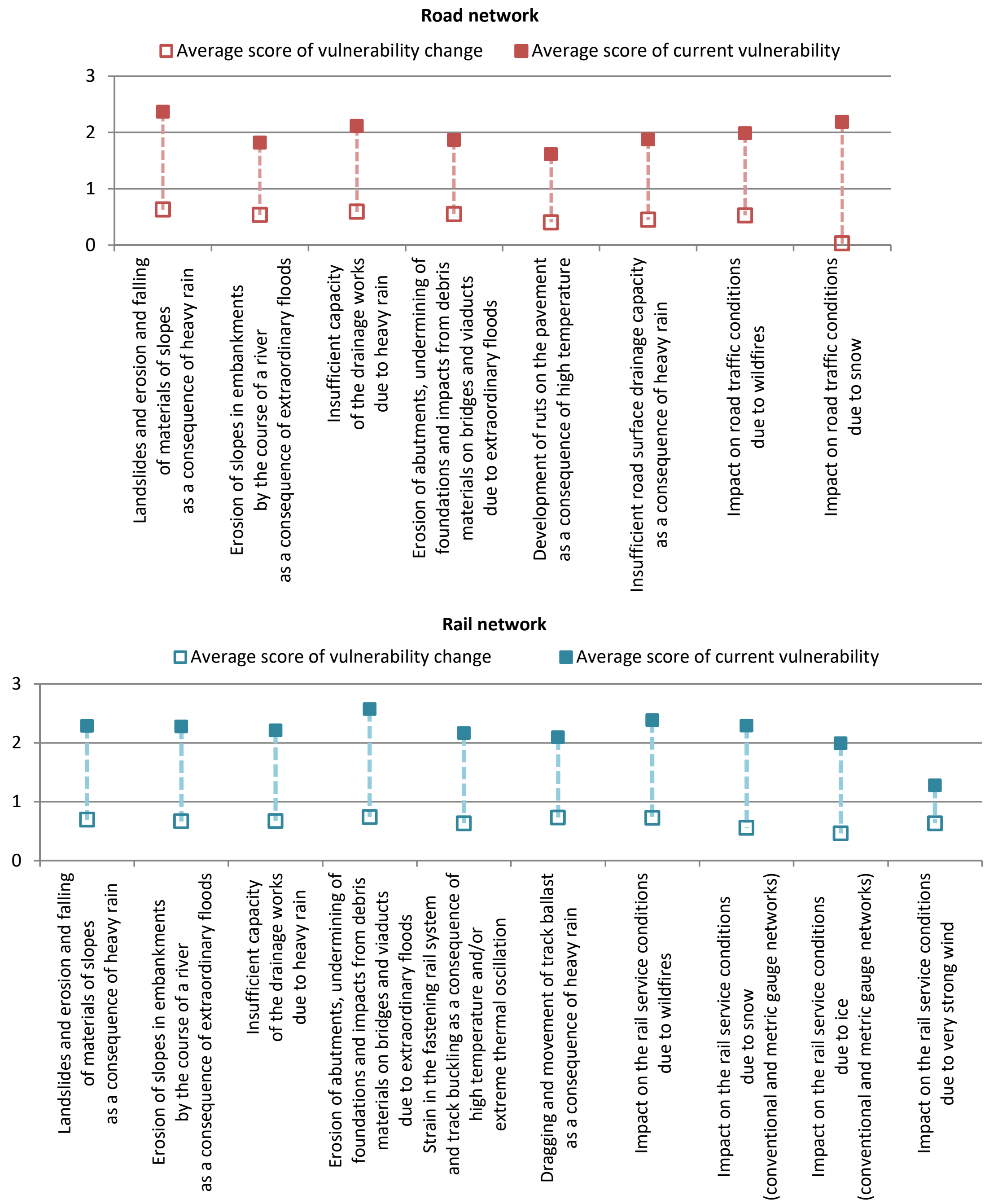


In the high-speed network, the average score of the change of effect is somewhat lower (+0.6), except in the case of the impacts on the railway ballast and because of wildfires and very strong wind, for which a average score of +0.9 points is found. The dispersion in the perception of the change of effect on the high-speed network is likewise lower than for the conventional and the metric gauge networks.

In light of the preceding data, it may be concluded that the general perception is that the effect of climate change on the vulnerability of the inland transport network may be somewhat greater on railways than on roads. This perception appears to be consistent with the results obtained in respect of the current vulnerability of both networks.

Figure 18

Comparison between the magnitude of the change of vulnerability of the state inland transport network compared to its current vulnerability, per type of impact



All in all, the most striking feature of the above data is that the magnitude of the change of vulnerability in 30 years is on average (both for the road and the rail networks) well below the current vulnerability of many of their sections, as shown by the charts of figure 18.

… or lack of completeness of the results obtained

Another possible limitation of the method used to estimate the change of the effect caused by climate change is that *underlying vulnerability* (understanding as such the vulnerability that may be hidden below an apparent resilience) may be underestimated. This limitation has been brought up by the technical staff who has participated in the evaluation of the vulnerability, and it seems difficult to avoid in an exercise at network level such as this one, without resorting to a detailed risk analysis at section level. The impression is that this limitation does not question the validity of this exercise, but the fact should be assumed that it is feasible that in some network sections there may be future effects that have not been identified within the scope of this exercise (as it might happen at present even though *a priori* the relevant precautions are taken).

In particular, one of the effects that is considered as possibly having been underestimated in this exercise is the damage to the road pavement caused by precipitation. The maintenance of the conditions of a pavement has the peculiarity of being carried out regularly, every several years. A reduction in the number of these periodic maintenance actions in recent years, coinciding with the worst years of the economic crisis, has brought along an increase in the presence of cracks on pavement surfaces which, combined with heavy rain, may be accelerating the degradation of the pavement in a considerable number of sections of the network.

The change of vulnerability of each section is limited, but there is an increase of the number of sections with moderate or important effects

The charts below show forecasts on the change of the vulnerability of the road network (figures 19 and 20) and of the rail network (figures 21 and 22) as a consequence of climate change. To obtain these charts, we have respected the perception of the technical staff regarding the change of vulnerability, except in a very small number of sections where the evaluations carried out diverged significantly from the general perception and they have been reviewed to bring them closer to the general perception.

Figure 19

Maximum effect on the road network in the future because of weather events

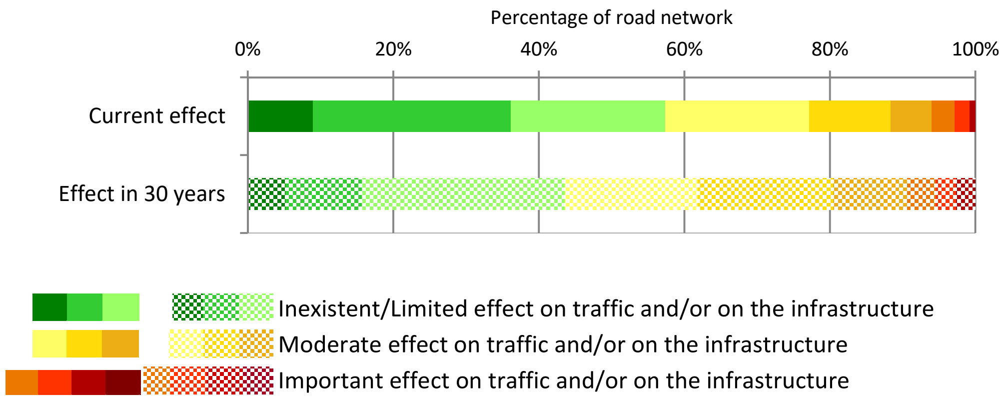
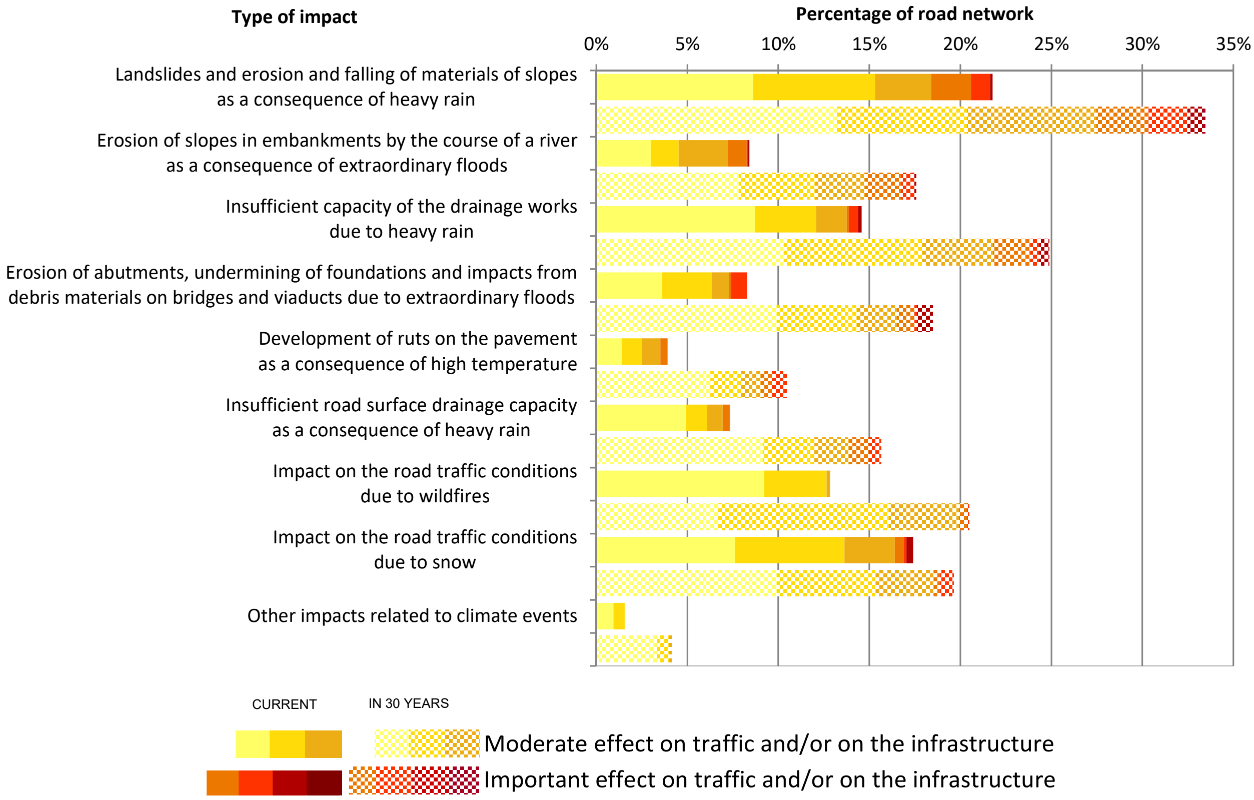


Figure 20
Changes in the vulnerability of the road network, according to type of impact



The length of the sections of the **road network** that will not be affected by any weather event, or that will be affected in a limited manner, drops from 57% to 44%. The magnitude of the reduction is similar in the high-capacity network (from 66% to 52%) and in the conventional network (from 50% to 37%). The length of the road sections in which some moderate effect is foreseen will increase from 37% to 46%, and that of the sections with important effects will go from 6% to 10%. Assisted by the GIS, it is easy to geographically locate the road sections according to the forecast on their level of vulnerability in the future (figure II.1 of Annex II).

On the roads, the increase of the effect on earthworks, structures and drainage works is foreseen as being somewhat higher than the rest of the impacts considered. In the case of these three assets, the length of the sections with potential moderate or important effects grows in absolute terms by around 10-11%, whereas for the rest of the impacts it rises by 7-8%.

As far as the **rail network** is concerned, the length of the sections that will not be affected by any climate event, or which will be affected in a limited manner, decreases from 36% to 18%. In the high-speed network, the percentage falls from 20% to 14%, and in the conventional network from 44% to 21%.

The change in the percentage of the rail network where the effect of a climate event may become important is greater than on the road network. In the high-speed network, this percentage goes from zero to representing 9% of the network, basically as a consequence of the incidence of heavy precipitation on slopes and of floods on structures. In the conventional network it goes from 8% to nearly 32%, fundamentally because of the incidence of heavy precipitation and floods on cut slopes and embankments, drainage works, structures and the dragging and movement of ballast. In the metric gauge network, the percentage, which is already very high today, goes from 80% to 83%.

It is also foreseen a significant growth in the extent of the effect of high temperatures on tracks and fastening rail systems, and on the rail service conditions due to the risk of fire and very strong wind, although the level of the impact will tend to remain moderate.

Just as with the road network, assisted by the GIS it is easy to locate geographically the rail network sections according to the forecast of their vulnerability in the future (figure II.2 of Annex II).

Figure 21
Maximum effect on the rail network in the future because of weather events

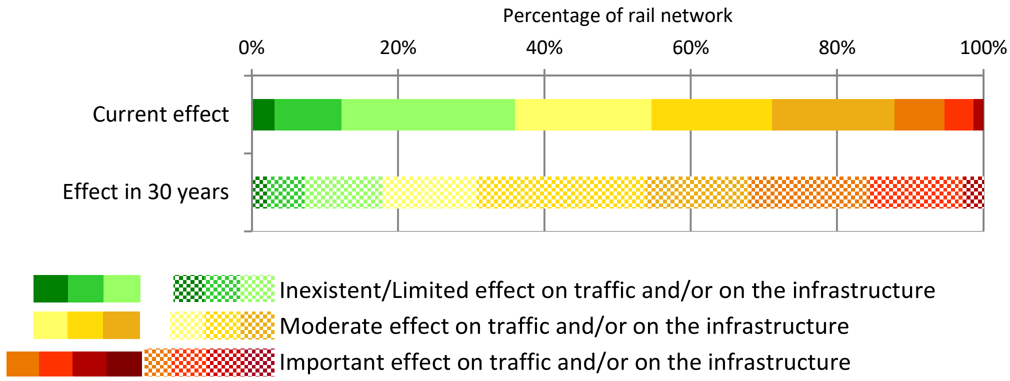
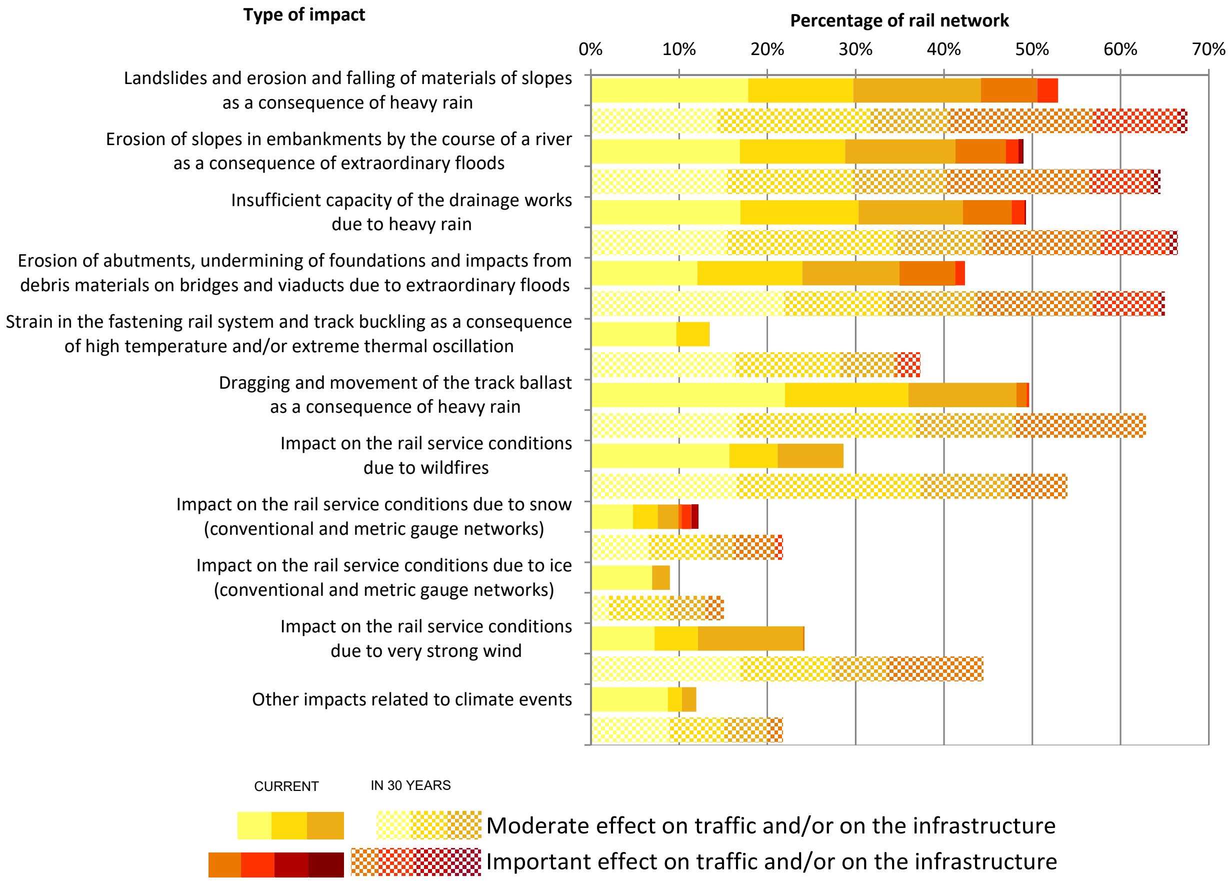


Figure 22
Changes in the vulnerability of the rail network, according to type of impact



7. DIFFERENTIATION OF CRITICALITY LEVELS IN NETWORK SECTIONS

Method employed to differentiate criticality levels

Considering different criticality levels in the network sections is an essential instrument for identifying which of the sections should receive priority attention because of their vulnerability, as it allows us to differentiate the degree of vulnerability that is acceptable in each section according to the possible repercussion of weather events on its functionality and/or integrity.

The classification of the network sections in several criticality levels as described below has been done solely with this goal. The notion of *criticality* employed in this exercise is therefore merely instrumental, and does not necessarily correspond to any classification in use by any of the infrastructure managers (Ministerio de Fomento's Directorate General of Roads, or ADIF and ADIF Alta Velocidad), nor is it related to the classification that may arise from the process of identifying critical European infrastructures in the transport sector established by Directive 2008/114/EC in order to assess the need to improve their protection. It is an *ad hoc* classification, obtained from the recommendations that the scientific literature usually proposes from an academic standpoint for purposes such as that provided here.

In this exercise, in order to differentiate the criticality levels in the sections of the RCE and of the RFIG, we have resorted to a mixed criterion in which, although what prevails is the consideration of the functionality of the infrastructure, we also take into account the integrity of the investment that is made.

In characterising the **functionality of the infrastructure**, the basis has been the use of the infrastructure. On roads this use has been equated to the average daily traffic (ADT), without distinguishing between traffic of light and heavy vehicles. The ADT figure was taken from the Traffic Map published by the Directorate General of Roads. In the rail network we have equated the use of each section to the average number of trains running along the section, including medium- and long-distance passenger trains, suburban trains and cargo trains. This figure was furnished by ADIF. The use of the GIS facilitates that the network sections defined to incorporate data on the use of the infrastructure do not necessarily have to coincide with the sections considered when evaluating the vulnerability of the network. ADIF, for instance, has furnished the traffic data according to a network classified in over 1,000 sections.

After analysing the traffic ranges per section with the assistance of frequency histograms, we ended up establishing five categories of use in each network, equating each one of them to a criticality level: high, medium-high, medium, medium-low and low criticality. When establishing the traffic ranges, we have taken into consideration that the RCE accounts for 16% of the road network in Spain, whereas the RFIG comprises 96% of the Spanish rail network. Because of this, in the case of roads we have privileged the low criticality level, defining traffic ranges so as to obtain above that level successive tiers with a decreasing network length. For the rail network, by contrast, the ranges have been chosen with reference to the average category, highlighting the sections that may clearly be considered as being of high or low criticality.

The aim of the state transport network, however, is not only to heed users' mobility demands, but also to serve as an instrument to boost economic development, territorial and social cohesion, and integration with Europe. Because of this, we considered it convenient to complete the characterisation of the functionality of each section of the network obtained by considering the traffic in that section, with other added functional criteria.

In the case of roads, the classification obtained according to the ADT has been refined by stating whether a section belongs to the network in service similar to that defined as the Trans-European Transport Network (TEN-T), based on the information that the Directorate General of Roads communicates to the Conference of European Directors of Roads. This network is made up by just over 10,500 km of state roads, of which nearly 9,100 km are high-capacity roads. Within this network we have also considered the different socio-economic function of some of the sections compared to others, characterised by the access they provide to the major business and service centres. The box included as figure 23 describes the method used to differentiate these levels of accessibility. Last of all, we have ensured that the application of that method in no way penalises the sections located in cross-border connections and have verified that the end functionality obtained for the road sections giving access to the state-owned airports and ports is consistent with the respective importance of each of these nodes in terms of air and maritime traffic.

In the case of railways, the classification obtained has also been refined depending on whether the section belongs to TEN-T (or currently fulfils the function of a section included in that Network), according to the information provided by the Ministerio de Fomento's Department for Infrastructure and Transport Planning. Just as with roads, in this network we have also attached greater importance to sections providing greater accessibility, although the way in which we have distinguished between levels of accessibility in the rail network is slightly different from how we did it in the road network, as explained in figure 23. Last of all, we have ensured that the cross-border sections allowing connections with France or Portugal, or which are part of the rail TEN-T for goods (including access to ports), will in no event be allocated a low criticality level. The idea is to incorporate to the notion of criticality the willingness to have a rail network that can guarantee minimum service conditions to be able to meet cross-border and goods transport requirements, regardless of the fact that the traffic at present is occasionally very limited. Last of all, it has also been ensured that the criticality of the sections corresponding to track gauge changeovers (from international gauge to Iberian gauge, and vice versa), which give access to a centre for train treatment, or those ensuring the movement of trains between two different lines is the same as the criticality of adjacent sections.

To characterise the **investment made**, we have used the relative difference of the average cost of construction of different sections of infrastructure. On roads we have differentiated between high-capacity and conventional sections, and in railways there are high-speed, conventional and metric gauge sections. In both networks we have distinguished between whether the infrastructure alignment mostly goes through flat, undulating or mountain terrain. The allocation of one category of terrain or another to each section has been done with the assistance of the GIS, calculating the average gradient of the terrain covered by the road or railway based on a Digital Elevation Model. To estimate the relative difference of the average cost of construction, we have used as the main reference the execution costs set down in the Ministerio de Fomento's Order FOM/3317/2010.[8]

[8] Order FOM/3317/2010, of 17 December, approving the Instruction on specific measures for the improvement of efficiency in the execution of public works on rail, road and airport infrastructure of the Ministerio de Fomento.

Figure 23
Method used to differentiate the level of accessibility to the main business and service centres provided by each section

The accessibility index has been calculated with a graph that includes: (i) the centroids of the major socio-economic activity centres, considering as such the towns on the Spanish mainland with more than 50,000 inhabitants; (ii) all the road sections in service that can be equated to the Trans-European Road Network, regardless of whether they belong to the state or an autonomous community; (iii) all the railway sections in service that can be equated to the Trans-European Rail Network for passengers; (iv) the main railway stations for passengers, classified according to the type of service they provide (conventional, high-speed or both); (v) the secondary roads giving access from the population nodes to the major railway stations; and (vi) the connections giving access from the population nodes to the nearest intersection points of the Trans-European Road Network. The graph arches have as their attributes the type of road (high-capacity, conventional) or railway (high-speed, conventional), their length and the maximum driving speed according to their type. On roads it has been considered that this speed is the maximum allowed according to the type of road; on railways, the speed considered corresponds to the maximum speed according to the information provided by ADIF; on secondary roads, the driving speed has been reduced to 2/3 of the maximum speed allowed. Impedances have also been allocated in the railway stations because of the modal shift and the frequency of trains.

With the help of the graph, built on a GIS, we have calculated the potential accessibility by road from each node *i* to the rest of the population nodes *j* according to the following expression:

$$Potential\ Acc_i = \sum_j \frac{P_j}{t_{ij}}$$

Then we have aggregated the results for all the nodes *i* in a single value of global accessibility of the road network according to the expression:

$$Global\ Acc = \frac{P_i \cdot Potential\ Acc_i}{\sum_i P_i}$$

where P_i is the population of node *i*, P_j is the population of node *j*, and t_{ij} is the minimum time required to cover the distance by road between node *i* and node *j*.

This global accessibility has been calculated for a situation of reference ($Global\ acc_{Reference}$) and in as many *k* scenarios ($Global\ acc_{Scenario\ k}$) as road sections appear on the graph (k ≈ 400), where each scenario is defined by the successive elimination of each one of the network sections (this elimination is equated to the event of collapse of section *k*). The index used to differentiate the level of accessibility to the major activity and service sections provided by each section *k* was finally calculated as:

$$Accessibility\ index_{Section\ k} = \frac{Global\ Acc_{Reference} - Global\ Acc_{Scenario\ k}}{Global\ Acc_{Reference}} * 100$$

A similar procedure has been used for the rail sections, with the difference that the number of scenarios considered was lower (k ≈ 190) and the routing was based on the full graph of roads and railways. In this case, the travel time t_{ij} is the lesser of the following two: (i) access times by road from the origin and destination nodes to the railway station closest to each one of them, plus the travel time on the rail network, and (ii) travel time on the road network, assuming that velocities drop to 2/3 of the maximum driving speed permitted.

To what extent are the criticality differences credible?

Figures 24 and 25 show the total length of the road or rail networks obtained according to the criticality level. Assisted by the GIS, it is easy to prepare maps such as those included in Annex III, indicating the criticality level obtained for each section.

Figure 24

Total length of the road sections by criticality level

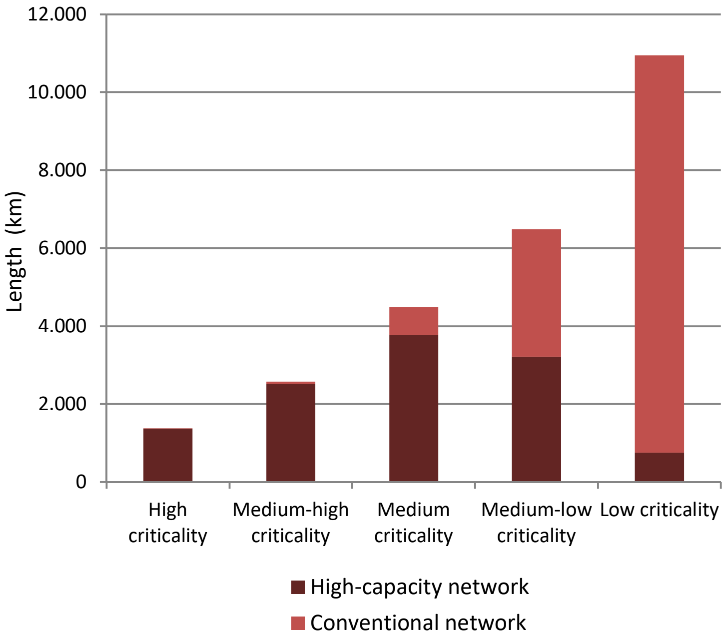
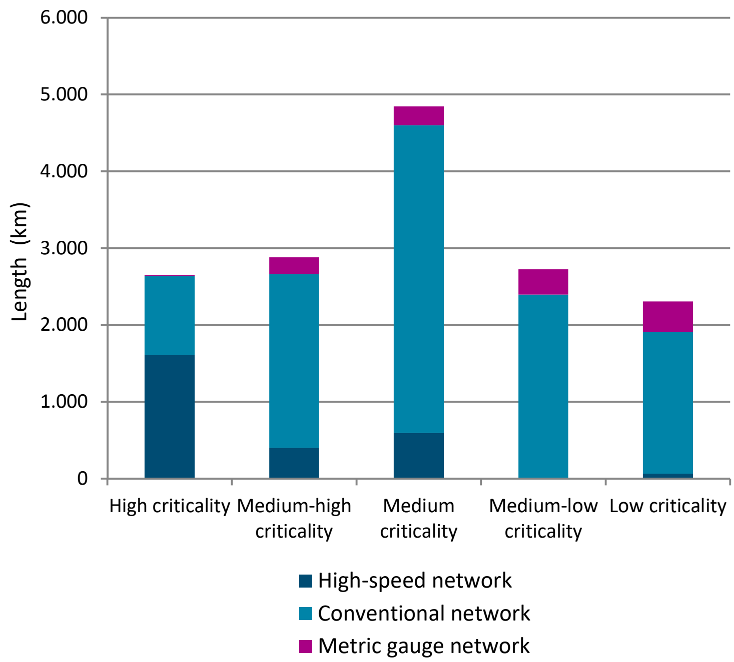


Figure 25

Total length of the rail sections by criticality level



In the road network, most of the roads with medium to high criticality are high-capacity roads. The most critical sections are near major cities. There is also a significant concentration of critical sections in the radial roads (especially those exiting from Madrid towards the Mediterranean coast in the regions of Levante and towards Andalusia) and in other corridors such as the one running along the Mediterranean coast.

In the rail network, the near entirety of the high-speed lines has a medium to high criticality level. There are also sections of the conventional network with high criticality, even some of the metric gauge network.

It is important to point out that the criticality level classifications in the two networks are not comparable because, even though the method used to differentiate levels is similar in the road network and the rail network, neither the criteria for setting traffic thresholds nor the values of said thresholds in the two networks can be equated. As a result, the priority obtained subsequently for the sections of the road and rail networks will not be comparable either. What will be comparable, on the other hand, are priorities within one same transport mode (for instance, between the high-speed, conventional and metric gauge rail networks).

To contrast the worthiness of the classification, we asked the technical staff that participated in the network vulnerability assessment about possible inconsistencies they may have observed in the differentiation of criticality levels, and they did not detect any noticeable inconsistencies in the results obtained. Also, we verified what percentage of the network, within each criticality level, is currently affected moderately or importantly because of weather events. In principle, it may be expected that this percentage will globally be lower when the manager considers the network sections more critical, given the close relationship between the acceptable degree of vulnerability and the level of service that is meant to be guaranteed. Figures 26 and 27 effectively show said tendency in sections of high and medium-high criticality (figure 27 does not include moderate effects of lesser importance in light of how extended it is in high-speed railway lines due to the effect, as we have seen, of heavy rain on slopes and on the ballast).

Figure 26

Current maximum effect on the road network because of weather events, according to the criticality of the sections

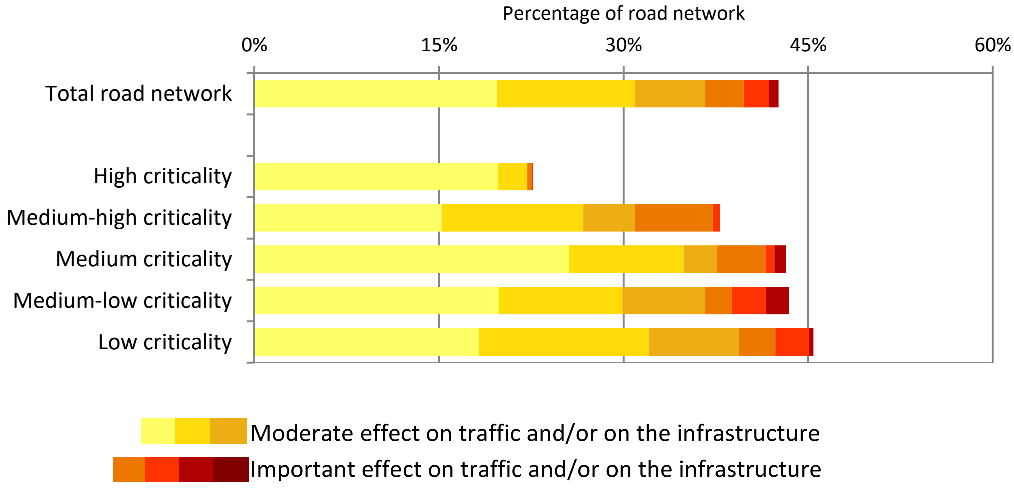
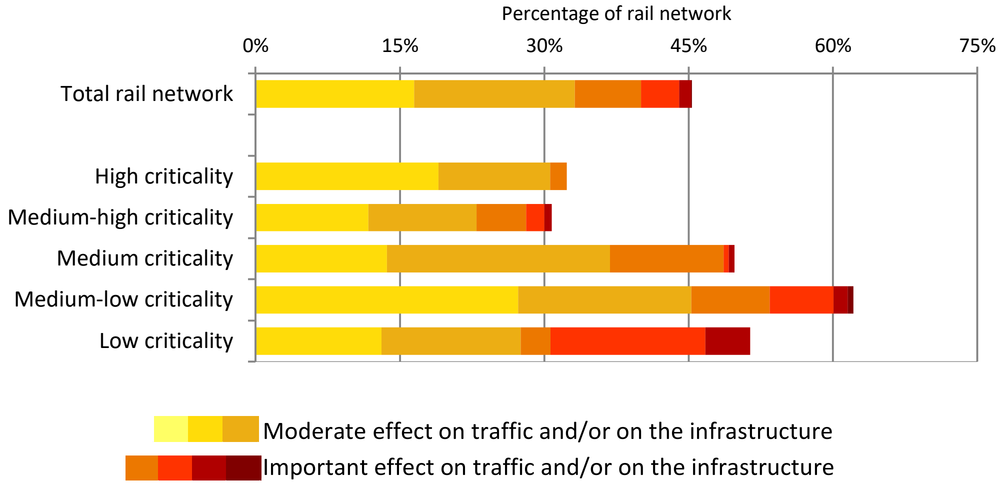


Figure 27

Current maximum effect on the rail network because of weather events, according to the criticality of the sections



8. NETWORK SECTIONS THAT MERIT PRIORITY ATTENTION DUE TO CLIMATE VARIABILITY AND CHANGE

To complete this exercise, the only thing left is identifying which are the network sections that merit priority attention due to their vulnerability to weather events, combining:

- the grading of the different criticality levels of the sections obtained in the preceding chapter, with
- the different degree of vulnerability estimated for each section after taking into account the effect of climate change.

Table 28 details the criterion used to do this. Four levels of priority have been established based on the maximum effect on the section. Priority criteria have not been differentiated according to the type of impact, nor have different weights been given to one particular impact compared to others (for instance, due to the degree of certainty of the projections of one climate variable vs. another one), although this could be done.

In the sections where the effect is limited a distinction has been made between values 1-2 and 3, in an attempt to consider society's high level of demand at present regarding traffic conditions in the infrastructure (patent, specially, in large metropolitan areas, or for toll roads and high-speed rail services). It should be acknowledged, however, that the method used to assess the vulnerability of the sections does not enable a precise analysis of these situations because the criterion used to grade a section within this range of effect is not sufficiently fine and strict for that purpose.

Table 28

Priority of the attention to be given to a section of the state inland transport network
due to climate variability and change

Road section			**Criticality**				
			High	Medium-high	Medium	Medium-low	Low
Maximum effect	Important		●●●●	●●●	●●	●●	●●
	Moderate		●●●	●●	●●	●	●
	Limited	3	●●	●	●	●	●
		1-2	●	●	●	●	●

Rail section			**Criticality**				
			High	Medium-high	Medium	Medium-low	Low
Maximum effect	Important		●●●●	●●●	●●	●●	●
	Moderate		●●●	●●	●	●	●
	Limited	3	●●	●	●	●	●
		1-2	●	●	●	●	●

●●●● 1st level of priority ●●● 2nd level of priority ●● 3rd level of priority ● 4th level of priority

Figures 29 and 30 show the length of the network represented by the sections once they have been grouped together by level of priority. The maps included in Annex IV provide the geographical location of the sections of the road and rail networks according to the level of priority obtained. The higher priority level includes only two sections of motorways and six railway sections (two high-speed and four conventional railway sections). The second level of priority comprises 66 road sections and 52 rail sections, out of the total 710 and 290 sections established respectively for these two networks. The sections included in this second level of priority add up to 800 km of roads (mostly in the high-capacity network) and 2,200 km of railway lines (1,250 km in the high-speed network, 800 km in the conventional network and 150 km in the metric gauge network). It is worth noting that the fact of having used different divisions of the network to evaluate the vulnerability of the sections and to differentiate criticality levels may lead to overestimates in the lengths provided above.

Figure 29
Priority of the attention to be given to the sections of the road network
due to climate variability and change

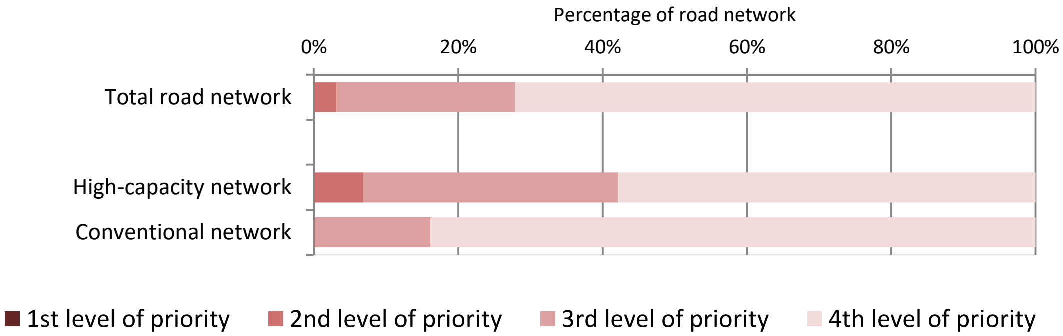
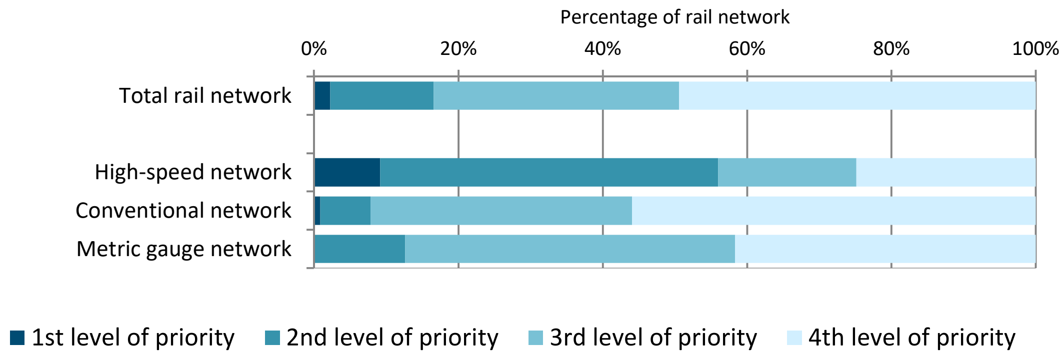


Figure 30
Priority of the attention to be given to the sections of the rail network
due to climate variability and change



9. CONCLUSIONS AND RECOMMENDATIONS

Priorities are currently well set in terms of attention to network vulnerability

In this exercise, the low percentage of the road and rail networks meriting attention with higher priority suggests, to begin with, that both the Directorate General of Roads and ADIF and ADIF Alta Velocidad rightly give priority to attending the points of their networks that are more vulnerable to climate events.

In any case, as we could expect, there is leeway to improve the resilience to climate of both networks. The scope of this improvement will naturally be conditional upon the budgetary resources that may be allocated for this purpose.

What are the most critical and vulnerable network sections?

When improving the resilience of the state transport infrastructure network, it is advisable to pay special attention to the vulnerability of the road and rail sections grouped together in the 1st and 2nd levels of priority.

How much would it cost to improve the resilience of the most critical and vulnerable sections?

To facilitate this task, we recommend putting together a proposal on actions for improving the resilience of the more critical and vulnerable sections via a scoping process that enables a rapid characterisation of the vulnerability problems existing in each one of these sections, proposing appropriate alternatives to reduce these problems and estimating their approximate cost of execution. This proposal should be drawn up in close collaboration with the technical staff of the regional services of the Directorate General of Roads and of the Maintenance Directorates of ADIF and ADIF Alta Velocidad. This will also guarantee that the alternatives and actions already considered by these organisations are taken into consideration.

We also recommend preparing, at the same time, a number of detailed studies of some of the more critical and vulnerable sections of the road and rail networks, to assess more precisely the vulnerability of the section and to define at project level the scope and cost of the actions that are proposed to improve their resilience. This task may be simplified if sections are selected from those for which the infrastructure manager already has a detailed study, in which the only requirement may be to incorporate the consideration of a possible change of vulnerability as a consequence of climate change.

The two actions stated above will contribute, regardless of the results, to advancing further in the development of methodologies to be used in studies on the adaptation to climate change at project level and in the appraisal of adaptation alternatives.

These two actions should be accompanied, as suggested in the report conducted in 2013, by an effort to improve early weather warning systems and to reinforce their integration with decision-making processes geared to minimising the effect of climate on traffic and/or on the infrastructure. The cost of implementing these systems is usually rapidly offset by the socio-economic benefits they bring to the operation of the infrastructure, especially when used in the most critical and vulnerable network sections. To foster their implementation in the road network (where the scope for improvement is probably larger), it would suffice to incorporate them as a requirement within the bidding conditions for road maintenance and operation currently used by the Directorate General of Roads, or to assess them as a possible improvement in the offers submitted by bidders in such tenders.

It is worthwhile to pay attention to the vulnerability of certain infrastructure assets …

The results obtained in this exercise show a greater incidence of climate conditions on certain infrastructure assets, in particular on earthworks, drainage works and, especially in the rail network, on bridges and viaducts. It is therefore recommended to promote, during the project stage of the infrastructure, an analysis of the alternatives that may be proposed to improve the resilience of these assets to climate variability and change.

In the proposal on measures for adapting to climate change drawn up in 2013, it was recommended to conduct in the short-term a review of the standards and regulations for the engineering of earthworks, and to pay attention as far as railways are concerned to the design of bridges and viaducts in respect of floods, because of the erosion of foundations, abutments and protective works. The process of reviewing the design standards and recommendations is usually toilsome and often requires extensive timescales. In the very short term it would probably suffice to replace that review with the preparation of criteria or guidelines geared to facilitating designers to analyse alternatives that will reduce the project's vulnerability to climate change as far as these infrastructure assets are concerned. These guidelines should particularly specify the climate scenarios to be considered.

In the 2013 report it was indicated that it is foreseeable that the design adaptation requirements of most drainage works will be met with the approval of the new 5.2-IC Instruction on road drainage (this instruction is also used as a reference for railways). However, it would be advisable to include among the support criteria for designers also those considered convenient for the analysis of options that may improve the resilience of the drainage works. In the case of railways, said criteria should also consider how to lessen the problems caused by the movement and dragging of ballast.

… and to enable a closer assessment of the incidence of climate change on vulnerability

The results obtained in this exercise suggest that the magnitude of the change of vulnerability of the state inland transport network in 30 years because of climate change is, on average, lower than the current vulnerability of a substantial part of its sections. This conclusion should not be an obstacle to try to continue improving the information on the expected evolution of the climate conditions that may affect the network as a consequence of climate change.

As we have shown, the operation of the state network is particularly sensitive to snowfall and to the possible effects of wildfires. Because of this, we should not neglect efforts to improve the information on the forecast evolution of the intensity and frequency of snowfall and the risk of fire, in respect of which we have not been able to avail of forecast maps in this exercise.

The information on the forecast evolution of the intensity and frequency of maximum precipitation in 24 hours should also be improved. As stated in this document, even though for this exercise a map has been prepared with a forecast on the change of intensity of maximum precipitation in 24 hours, we harbour doubts as to whether it is entirely valid. The availability of projections on maximum precipitation in 24 hours should also be completed with other projections that may be desirable to incorporate to the guidelines supporting the designers referred to above, namely those related to the assessment of risk of landslides on slopes and of floods.

Final reflection

In this exercise, the priority of the attention to be given to a section of the network has been estimated according to its level of vulnerability to climate conditions and its criticality level.

In this estimate we have only taken into consideration how said vulnerability may be affected in the future because of climate change. Throughout this document, however, we have insisted that the vulnerability of an infrastructure also depends on its location and on its design, construction and maintenance conditions. A part of these conditions remains unchanged over time but others, conversely, may vary as the years go by. This second group of conditions includes the manner in which the infrastructure is maintained, or even the characteristics of the site where it was constructed. The vulnerability of an infrastructure is therefore not a static characteristic thereof, but should be deemed an attribute that varies over time (even if there were no alteration of climate conditions as a consequence of climate change).

Neither is the criticality level of a section an attribute that must remain unchanged over time. It could occur, for instance, that there may be rail sections in which the number of trains may vary significantly due to the entry into service of new rail lines or rail services.

This entails that the results of this exercise regarding the sections meriting priority attention due to climate conditions, however valid they may be to guide the actions to be fostered currently to increase the resilience of the network to climate variability and change, must be updated once a certain period has elapsed. When doing this, it will be convenient to assess whether it is useful to review the methodology described in this document, as a way of getting around some of the limitations found when conducting this exercise.

As a way of enabling the update of the results of this exercise we suggest (as we did in 2013) that the managers of the road and rail networks favour the current systems for recording incidents caused by adverse weather events and for monitoring their consequences. The exploitation of these records will enable the subsequent analysis of the weather events that most frequently affect the network users and have a greater impact on the infrastructure itself, and will also help identify and adequately characterise the most vulnerable sections of the network.

ANNEX I – CURRENT VULNERABILITY OF THE NETWORK (FIGURES)

Estimate of the current vulnerability of the road network, according to type of impact

Figure I.1

Landslides and erosion and falling of materials in slopes as a consequence of heavy rain

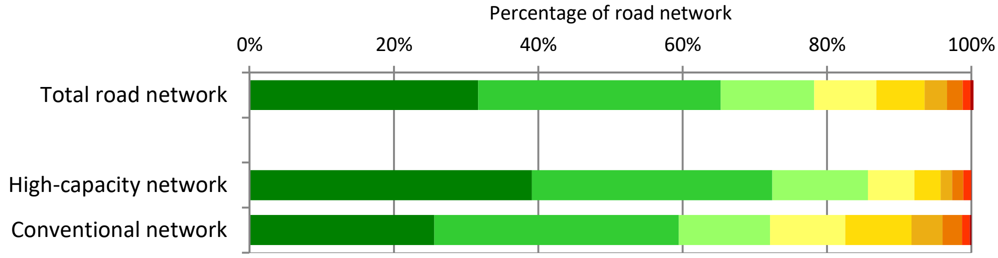


Figure I.2

Erosion of slopes in embankments by the course of a river as a consequence of extraordinary floods

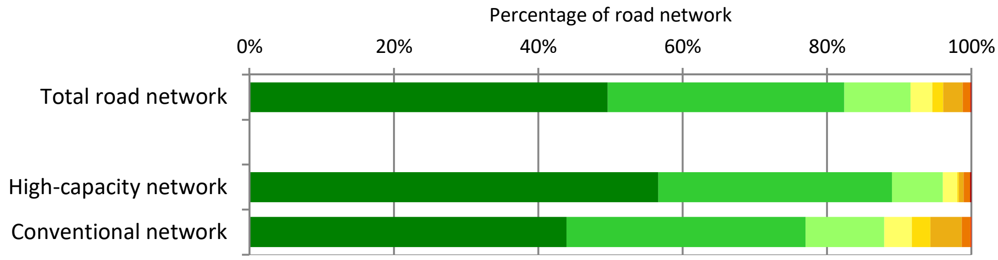
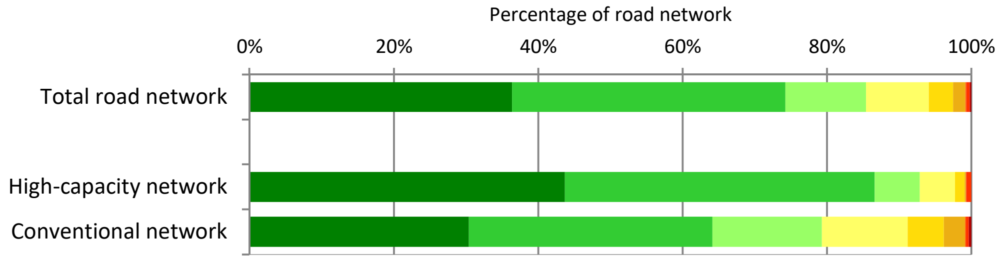


Figure I.3

Insufficient capacity of the drainage works due to heavy rain



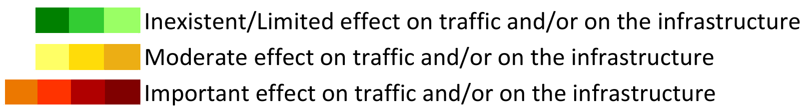


Figure I.4

Erosion of abutments, undermining of foundations and impacts from debris materials on bridges and viaducts due to extraordinary floods

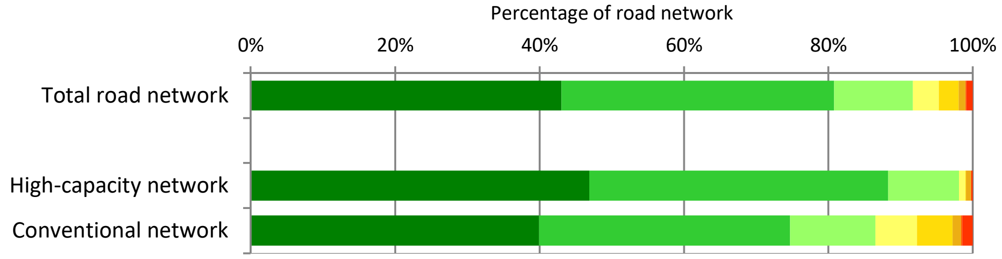


Figure I.5

Development of ruts on the pavement as a consequence of high temperature

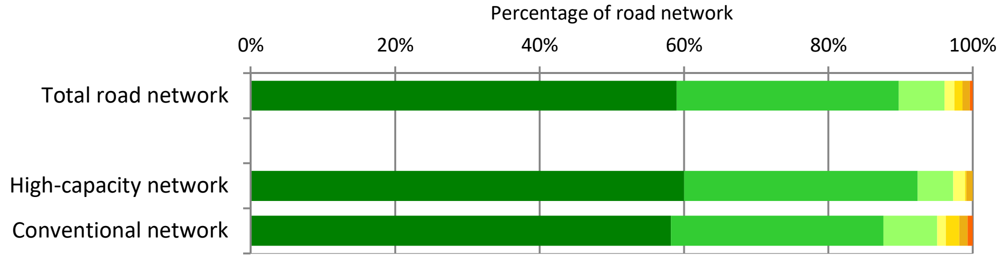
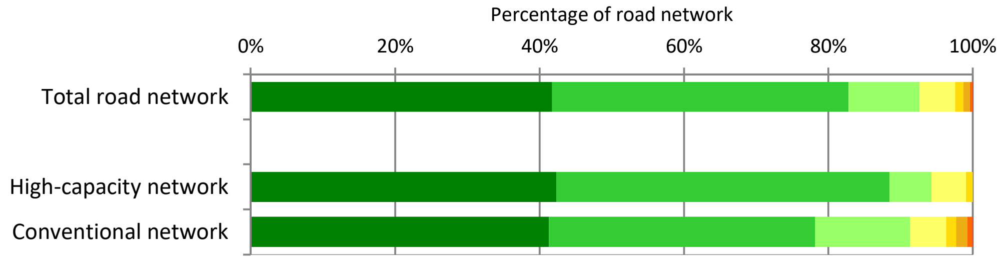


Figure I.6

Insufficient road surface drainage capacity as a consequence of heavy rain



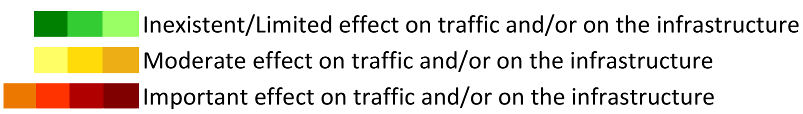


Figure I.7

Impact on the road traffic conditions due to wildfires

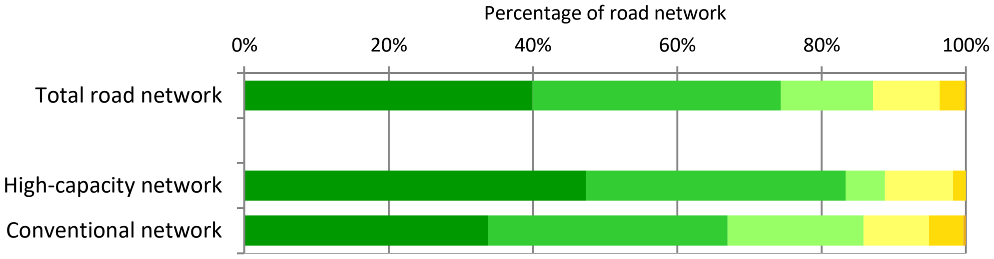
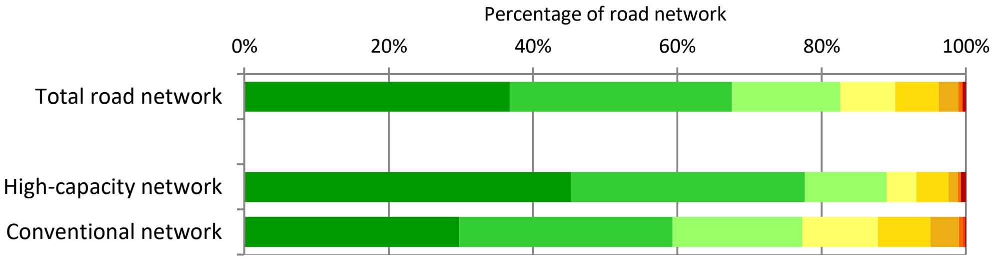


Figure I.8

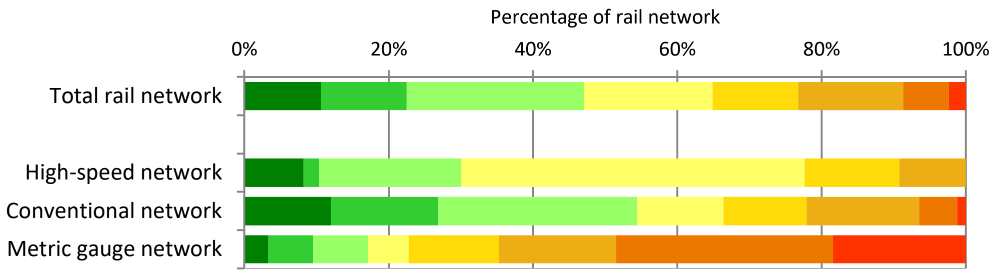
Impact on the road traffic conditions due to snow



Estimate of the current vulnerability of the rail network, according to type of impact

Figure I.9

Landslides and erosion and falling of materials in slopes as a consequence of heavy rain



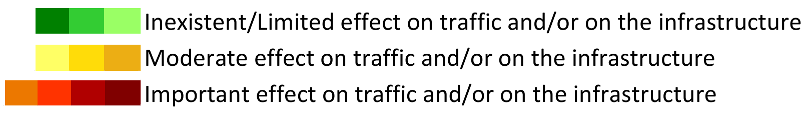


Figure I.10

Erosion of slopes in embankments by the course of a river as a consequence of extraordinary floods

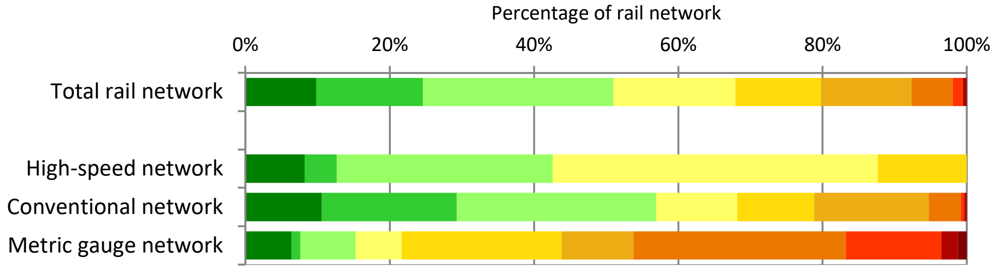


Figure I.11

Insufficient capacity of the drainage works due to heavy rain

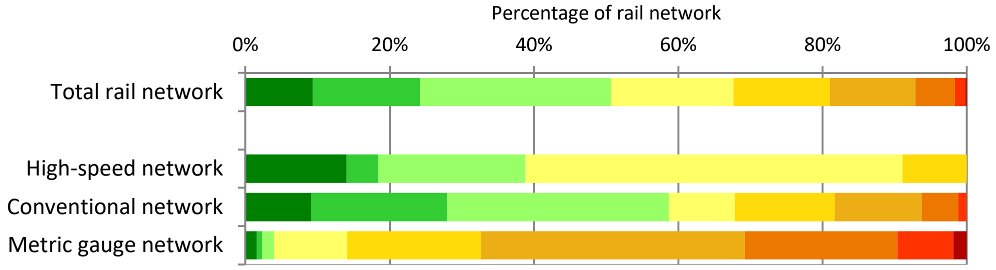
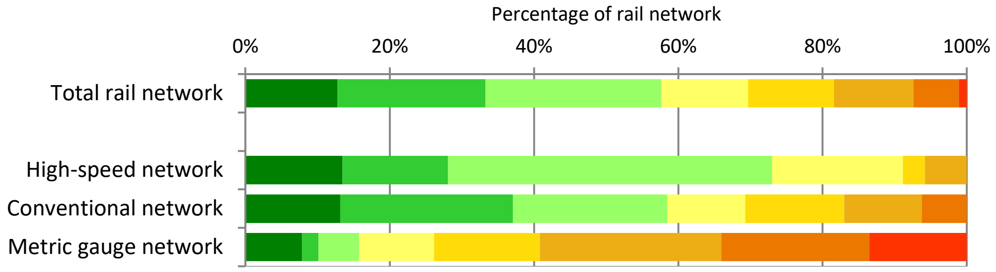


Figure I.12

Erosion of abutments, undermining of foundations and impacts from debris materials on bridges and viaducts due to extraordinary floods



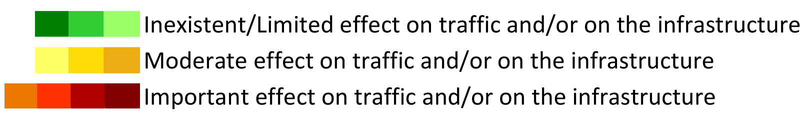


Figure I.13

Strain in the fastening rail system and track buckling as a consequence of high temperature and/or extreme thermal oscillation

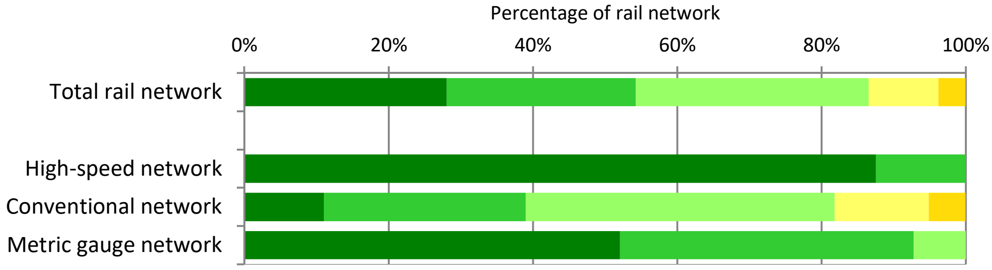


Figure I.14

Dragging and movement of the track ballast as a consequence of heavy rain

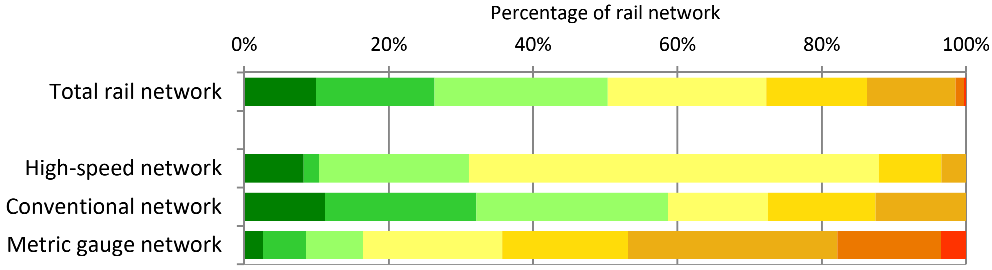
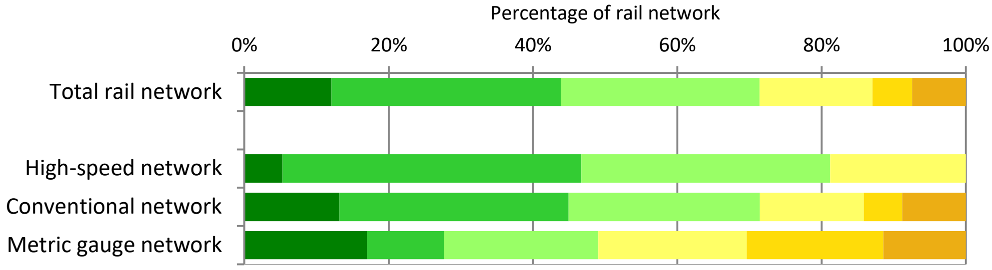


Figure I.15

Impact on the rail service conditions due to wildfires



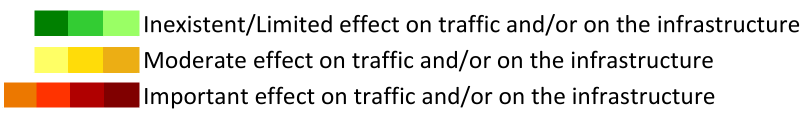


Figure I.16

Impact on the rail service conditions due to snow in the conventional and metric gauge networks

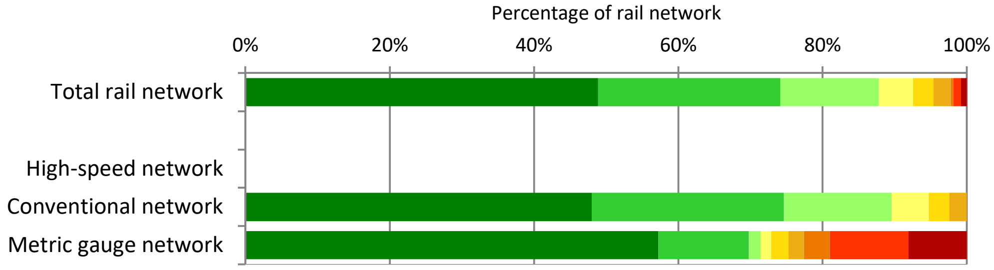


Figure I.17

Impact on the rail service conditions due to ice in the conventional and metric gauge networks

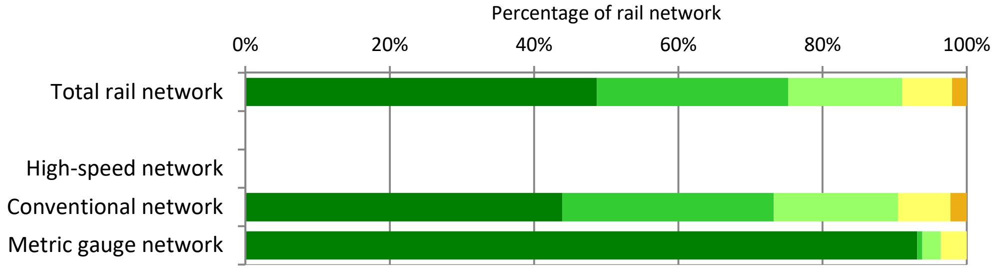
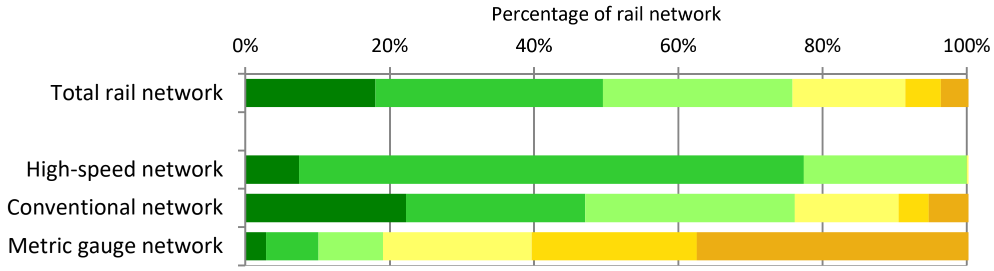
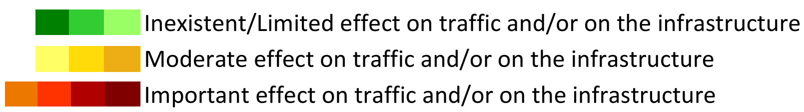


Figure I.18

Impact on the rail service conditions due to very strong wind





ANNEX II – NETWORK VULNERABILITY IN THE FUTURE (MAPS)

Figure II.1

Estimate of the maximum effect of climate change on the sections of the road network in 30 years

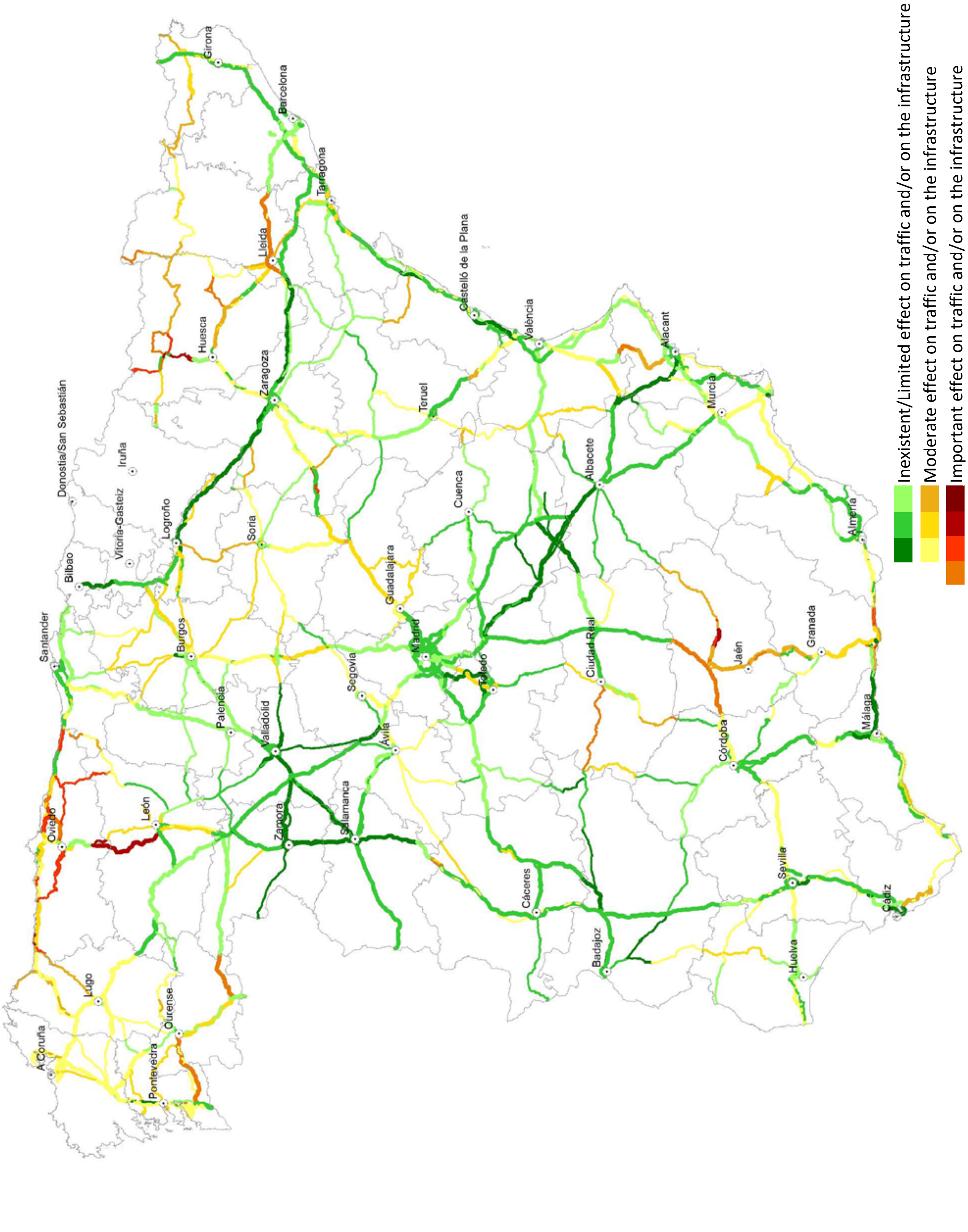
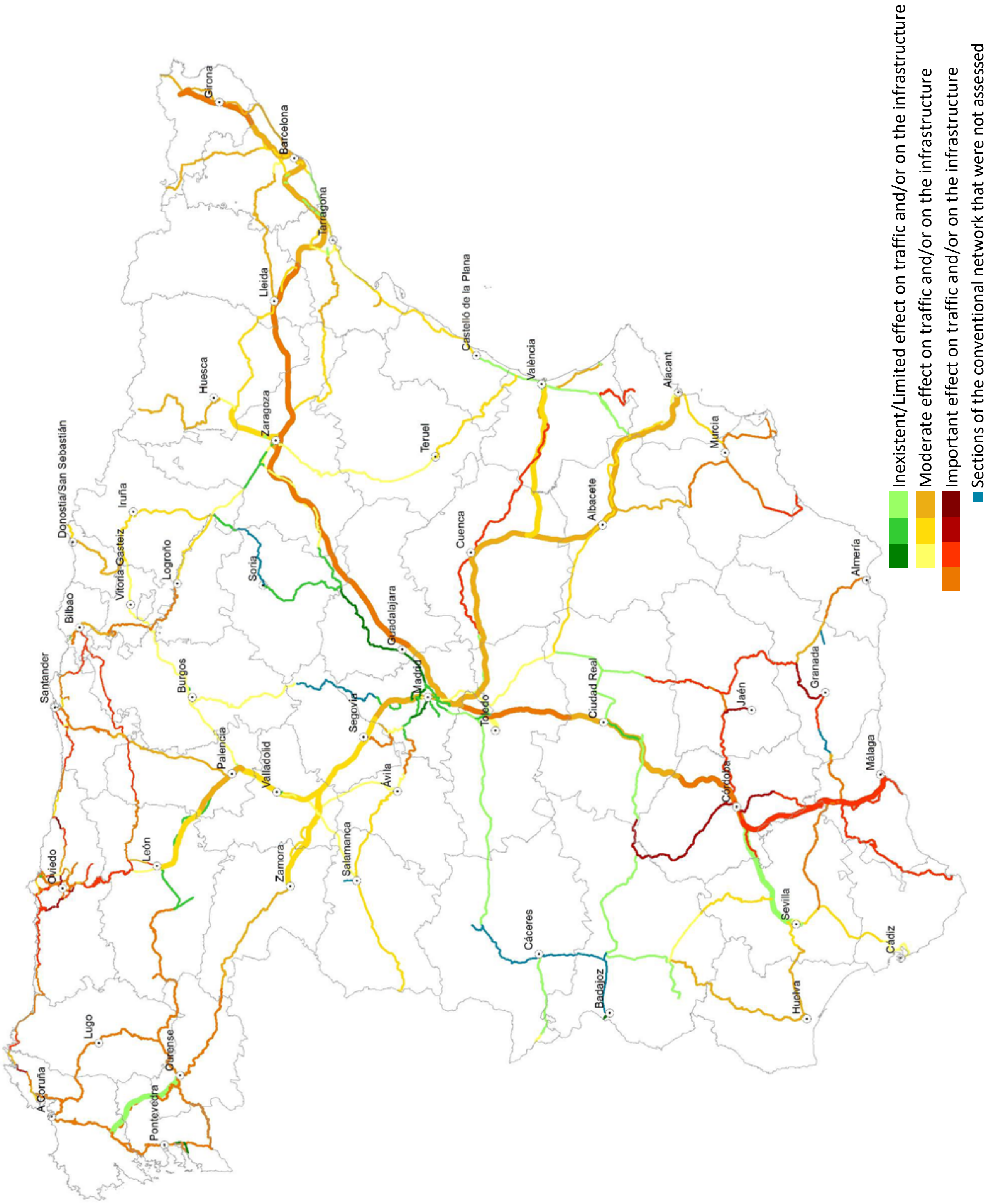


Figure II.2

Estimate of the maximum effect of climate change on the sections of the rail network in 30 year



ANNEX III – CRITICALITY LEVEL OF SECTIONS (MAPS)

Figure III.1

Criticality level of sections of the road network according to the criteria described in chapter 7

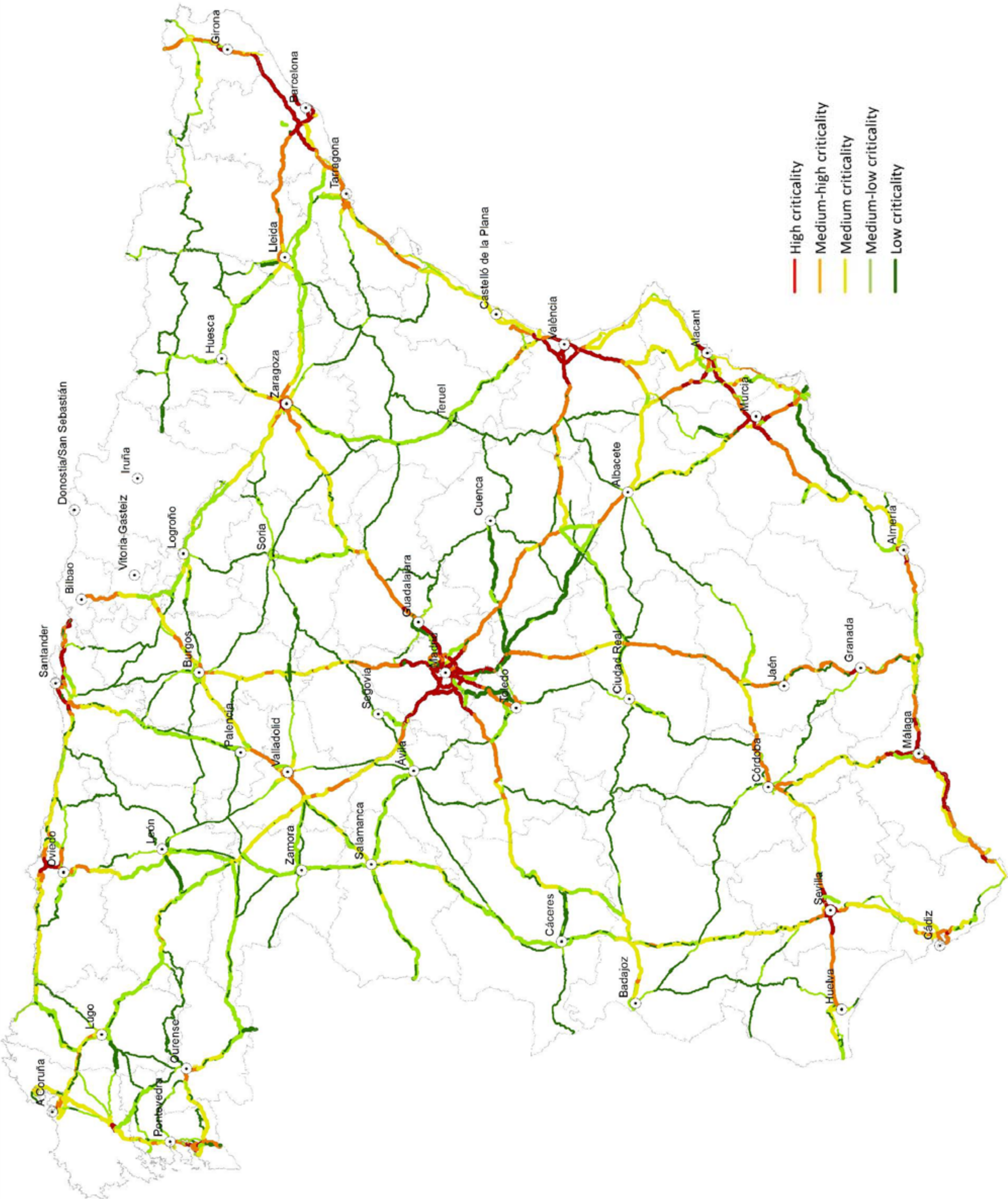
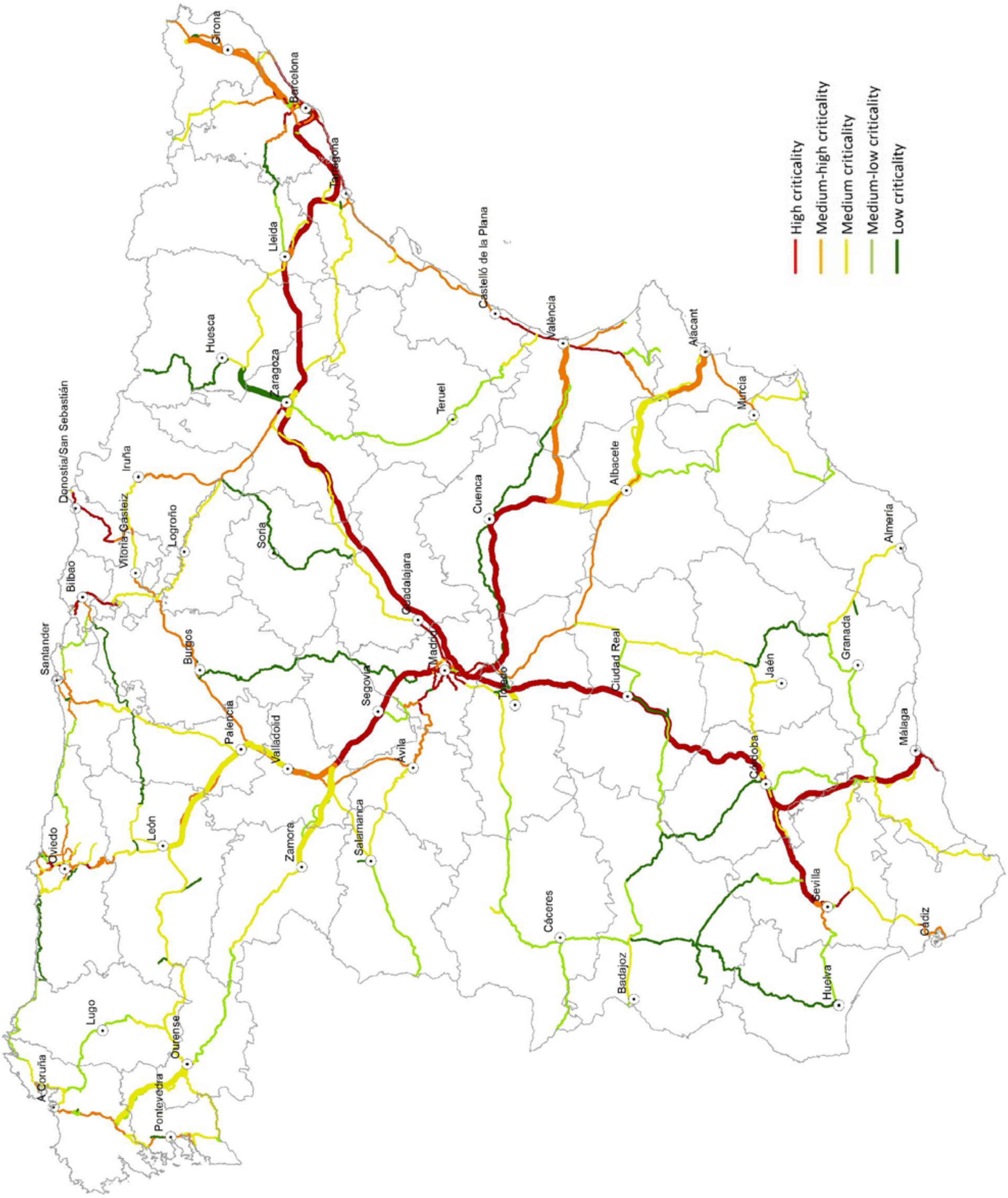


Figure III.2

Criticality level of sections of the rail network according to the criteria described in chapter 7



ANNEX IV – SECTIONS THAT MERIT PRIORITY ATTENTION (MAPS)

Figure IV.1
Priority of the attention to be paid to sections of the road network
because of climate variability and change

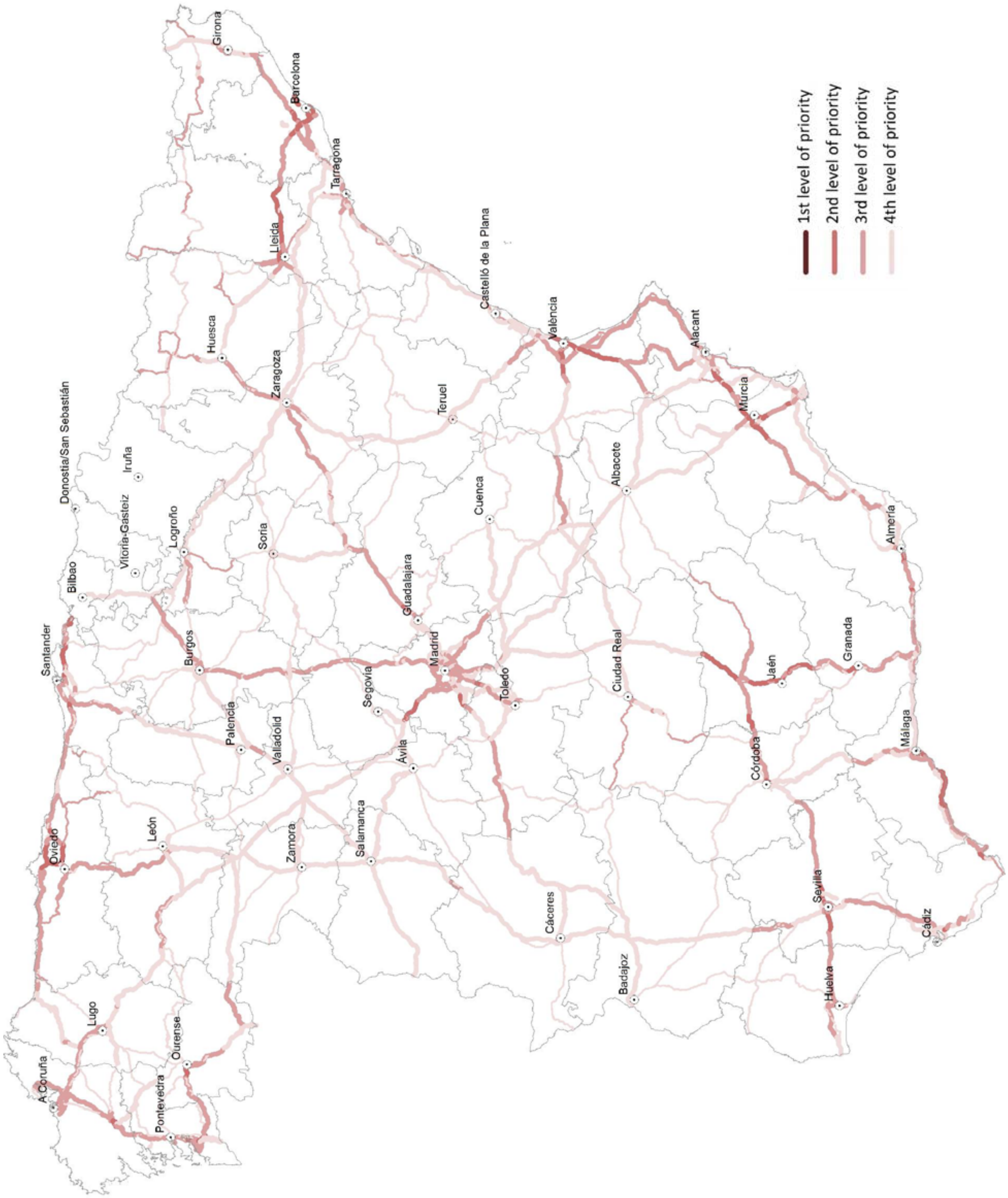
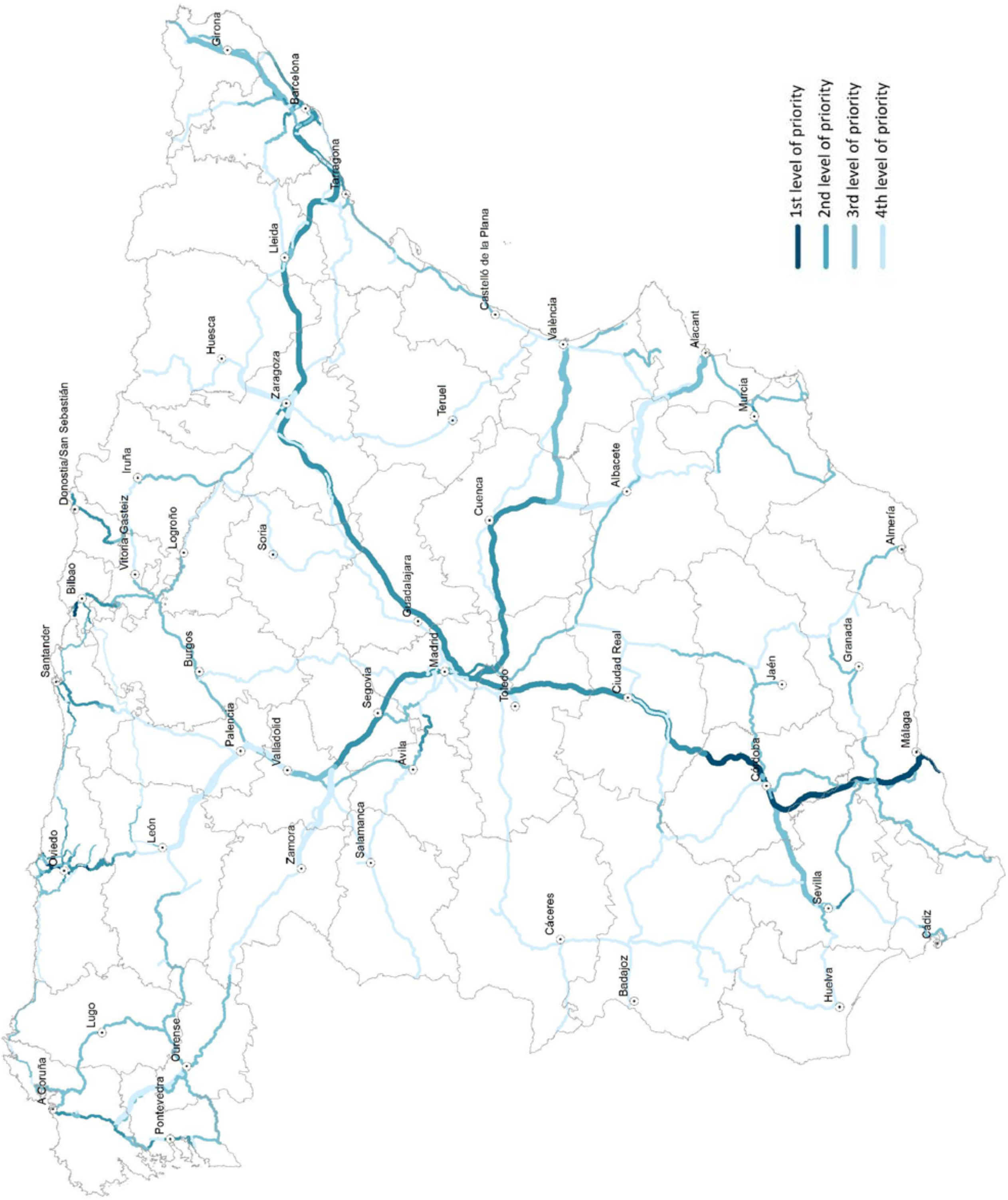


Figure IV.2
Priority of the attention to be paid to sections of the rail network
because of climate variability and change



ANNEX V – PEOPLE WHO HAVE COLLABORATED IN THIS EXERCISE

This document - prepared by **Centro de Estudios y Experimentación de Obras Públicas, CEDEX** - could be done thanks to the collaboration of the following people, on behalf of their corresponding organisations:

- Ministerio de Fomento's **Dirección General de Carreteras**: Antonio J. Alonso Burgos / Agustín Sánchez Rey (*Subdirector General de Explotación y Gestión de Red*) and Manuel de Lucas Téllez de Meneses (*Jefe de Área de Planeamiento y Seguimiento de Planes*).
- **Administrador de Infraestructuras Ferroviarias, ADIF**: Pedro Pérez del Campo (*Gerente de Área de Medio Ambiente, Dirección de Actuaciones Técnicas, Dirección General de Explotación y Construcción*).
- **Agencia Estatal de Meteorología, AEMET**: Ernesto Rodríguez Camino and Mª Jesús Casado Calle (*Área de Modelización y Evaluación del Clima*).

The exercise has also been supported by Ministerio de Fomento's **Subdirección General de Planificación de Infraestructuras y Transporte** and by **Ministerio para la Transición Energética** through the Fundación Biodiversidad.

Regional services of the Ministerio de Fomento's Directorate General of Roads

The vulnerability of the road sections has been characterised with the support of the following technical staff of the regional services of the Directorate General of Roads:

- **Demarcación de Carreteras del Estado en Andalucía Occidental**: Rodrigo Vázquez Orellana (*Jefe de Demarcación*), Emilio Asensio García (*Jefe de Área de Conservación y Explotación en Sevilla*), José María Padilla Jiménez (*Jefe de Área de Conservación y Explotación en Cádiz*), Tomás González Villa (*Jefe de Área de Conservación y Explotación en Córdoba*) and Joaquín Solís Gómez (*Jefe de Sección Técnica en Huelva*).
- **Demarcación de Carreteras del Estado en Andalucía Oriental**: José del Cerro Grau (*Jefe de Demarcación*), Darío Rodríguez Pedrosa (*Jefe de Servicio de Conservación y Explotación en Granada*), Juan A. de Oña Esteban (*Jefe de Área de Conservación y Explotación en Almería*), Antonio Enrique Ortega Montoro (*Jefe de Área de Conservación y Explotación en Jaén*) and José Antonio Domingo Atencia (*Jefe de Área de Conservación y Explotación en Málaga*).
- **Demarcación de Carreteras del Estado en Aragón**: Rafael López Guarga (*Jefe de Demarcación*), Ignacio Rivera Blasco (*Jefe de Área de Planeamiento, Proyectos y Obras en Zaragoza*), Albano Arnés García (*Jefe de Servicio de Planeamiento, Proyectos y Obras en Zaragoza*), Sandra de Francisco Méndez (*Jefa de Servicio de Planeamiento, Proyectos y Obras en Zaragoza*), Javier Andrés Pelegrina (*Jefe de Sección Técnica en Zaragoza*), Ignacio García Cavero (*Jefe de Área de Conservación y Explotación en Huesca*) and Carlos Casas Nagore (*Jefe de Área de Conservación y Explotación en Teruel*).
- **Demarcación de Carreteras del Estado en Asturias**: César Fernández-Nespral Pérez (*Jefe de Demarcación*) and Javier Uriarte Pombo (*Jefe de Área de Conservación y Explotación*).
- **Demarcación de Carreteras del Estado en Cantabria**: Fernando Hernández Alastuey (*Jefe de Demarcación*), Juan Carlos Mas Bahillo (*Jefe de Área de Conservación y Explotación*), José

Francisco Sánchez Cimiano (*Jefe de Servicio de Planeamiento, Proyectos y Obras*) and Juan Antonio Ruiz De Villa (*Técnico Superior de Actividades Técnicas y Profesionales*).

- **Demarcación de Carreteras del Estado en Castilla – La Mancha**: Francisco Javier González Cabezas (*Jefe de Demarcación*), Isidoro Picazo Varela (*Jefe de Área de Conservación y Explotación en Albacete*), Juan Antonio Mesones López (*Jefe de Área de Conservación y Explotación en Ciudad Real*), Carlos Celaya Escribano (*Jefe de Área de Conservación y Explotación en Cuenca*) and Rafael Moreno Ramírez (*Jefe de Área de Conservación y Explotación en Guadalajara*).
- **Demarcación de Carreteras del Estado en Castilla y León Occidental**: José Vidal Corrales Díaz (*Jefe de Demarcación*), Javier Payán de Tejada González (*Jefe de Área de Conservación y Explotación en Valladolid*), Rosendo Martínez Fernández (*Jefe de Área de Conservación y Explotación en León*), Javier Largo Maeso (*Jefe de Área de Conservación y Explotación en Palencia*), Alberto Buitrago Pérez (*Jefe de Área de Conservación y Explotación en Salamanca*) and Alejandro Ortegón Salas (*Jefe de Área de Conservación y Explotación en Zamora*).
- **Demarcación de Carreteras del Estado en Castilla y León Oriental**: Ignacio Ormazábal Barriuso (*Jefe de Demarcación*), Javier Fernández Armiño (*Jefe de Área de Planeamiento, Proyectos y Obras en Burgos*), Alberto Cidad Murillo (*Jefe de Sección Técnica en Burgos*), Alberto del Río Alonso (*Jefe de Sección Técnica en Segovia*) and Ignacio Gil Jiménez (*Técnico en Ávila*).
- **Demarcación de Carreteras del Estado en Cataluña**: Luis Bonet Linuesa (*Jefe de Demarcación*), José María Riu Grávalos (*Jefe de Servicio de Planeamiento, Proyectos y Obras en Barcelona*), Jorge Verdú Vázquez (*Jefe de Área de Conservación y Explotación en Gerona*) and Alberto Hernández Moreno (*Jefe de Área de Conservación y Explotación en Tarragona*).
- **Demarcación de Carreteras del Estado en Comunidad Valenciana**: Ismael Ferrer Domingo (*Jefe de Demarcación*), Javier Soler Ribes (*Jefe de Servicio de Conservación y Explotación en Valencia*), Juan Carlos Yuste Cotanda (*Jefe de Área de Planeamiento, Proyectos y Obras en Valencia*), Vicente Ferrer Pérez (*Jefe de Área de Planeamiento, Proyectos y Obras Valencia Circunvalación*), Juan Antonio Moreno Soriano (*Jefe de Sección Técnica en Valencia*), Guillermo Llopis Serrano (*Técnico Superior en Valencia*) and Emilio Peiró Miret (*Jefe de Área de Conservación y Explotación en Alicante*).
- **Demarcación de Carreteras del Estado en Extremadura**: José Manuel Blanco Segarra (*Jefe de Demarcación*), Antonio Ruiz-Roso Gómez (*Jefe de Servicio de Conservación y Explotación en Badajoz*), Juana Isabel González Rodríguez (*Jefa de Servicio de Planeamiento, Proyectos y Obras en Cáceres*), Esmeralda Samaniego de Peroy (*Jefa de Sección Técnica en Badajoz*) and Regino Díaz Cortés (*Jefe de Sección Técnica en Badajoz*).
- **Demarcación de Carreteras del Estado en Galicia**: Ángel González del Río (*Jefe de Demarcación*), Marta Latas López (*Jefa de Área de Planeamiento, Proyectos y Obras en A Coruña)*, Eduardo Toba Blanco (*Jefe de Área de Conservación y Explotación en A Coruña)*, Álvaro Rodríguez Aguiar (*Jefe de Área de Conservación y Explotación en Ourense*), Pablo Domínguez Gómez (*Jefe de Área de Conservación y Explotación en Pontevedra*) and Francisco Prego Gómez (*Técnico Superior Facultativo Proyectos y Obras en Lugo*).
- **Demarcación de Carreteras del Estado en Madrid**: Juan José Jorquera Moya (*Jefe de Demarcación*) and José Ignacio Cuñado Arroyo (*Jefe de Área de Conservación y Explotación*).
- **Demarcación de Carreteras del Estado en Murcia**: Ángel García Garay (*Jefe de Demarcación*), Antonio M. Martínez Menchón (*Jefe de Servicio de Conservación y Explotación*) and José F. Oña Navarrete (*Ineco*).

- **Demarcación de Carreteras del Estado en La Rioja**: Jesús Enrique García Garrido (*Jefe de Demarcación*), Miguel Ángel García Rodríguez (*Jefe de Área de Conservación y Explotación*) and Eva García-Casarrubios Berrocal (*Jefa de Área de Planeamiento, Proyectos y Obras*).

Maintenance Directorates of ADIF and ADIF Alta Velocidad

The vulnerability of the rail sections has been characterised with the support of the following technical staff of the Maintenance Directorates of ADIF and ADIF Alta Velocidad:

- **Subdirección de Operaciones Alta Velocidad**: Javier Movilla Sánchez (*Jefe de Área de Infraestructura AV*), Juan Cabello Álvarez (*Jefe de Área de Energía AV*), Angel Ladrón Martínez (*Jefe de Área de Vía AV*), Alicia Ortega Sánchez (*Técnico Especialista Eje AV Sur*), Yolanda Ruiz González (*Técnico Eje AV Este*) and Daniel Mulero Krambs (*Técnico Eje AV Norte*).
- **Subdirección de Operaciones Red Convencional Centro**: Mª del Carmen Gómez Rodríguez (*Jefe de Coordinación, Seguimiento y Calidad*), Pedro Soto Ceballos (*Gerente de Área de Infraestructuras*), Abel Rajo Soto (*Jefatura de Área de Mantenimiento de Madrid Sur*) and Enrique Fernández Mourelo (*Jefatura de Área de Mantenimiento de Madrid Norte*).
- **Subdirección de Operaciones Red Convencional Noroeste**: Ignacio García Menéndez (*Jefe de Coordinación y Seguimiento*), Avelino González Álvarez (*Jefatura de Área de Mantenimiento de León*), José Manuel Serrano Teso (*Jefatura de Distrito de Salamanca*) and Álvaro Pérez Mansilla (*Técnico de Apoyo Gerencia Noroeste*).
- **Subdirección de Operaciones Red Convencional Sur**: Miguel Ángel Fuentes Romero (*Jefe de Coordinación y Seguimiento*), Francisco Javier Penco Ramos (*Facilitador de Calidad y Medio Ambiente*), José Guijarro Mata (*Jefatura de Área de Mantenimiento de Sevilla*), Rafael Domínguez Prat (*Jefatura de Área de Mantenimiento de Córdoba*), Antonio Rodríguez Vaquero (*Jefatura de Área de Mantenimiento de Córdoba*), Juan Casado Filgueira (*Jefatura de Mantenimiento de Linares Baeza*), Juan Garrido Urbano (*Jefatura de Mantenimiento de Linares Baeza*), Antonio Duarte Jiménez (*Jefatura de Mantenimiento de Mérida*) and Francisco Gijón López (*Jefatura de Mantenimiento de Mérida*).
- **Subdirección de Operaciones Red Convencional Este**: Fernando Ugena Carrasco (*Subdirector de Operaciones Este*), Javier Peiró Bolós (*Jefe de Coordinación, Seguimiento y Calidad*), Ángel Contreras (*Gerente de Área de Infraestructuras Este*), Sebastián Ávila Medina (*Jefatura de Área de Mantenimiento de Valencia*) and José Delicado Moreno (*Jefatura de Área de Mantenimiento de Albacete*).
- **Subdirección de Operaciones Red Convencional Noreste**: Carlos Quingles Grange (*Subdirector de Operaciones Noreste*), Salvador Angosto Gavilán (*Gerente de Área de Infraestructuras Noreste*), Carlos Sarabia Vives (*Jefatura de Área de Mantenimiento de Barcelona*), Juan Miguel Mata Morales (*Jefatura de Área de Mantenimiento de Tarragona*) and Jacobo Villacampa Dourdil (*Jefatura de Área de Mantenimiento de Zaragoza*).
- **Subdirección de Operaciones Red Convencional Norte**: Daniel A. González Fernández (*Técnico de Coordinación y Seguimiento*), Juan Manuel Estradé Panadés (*Gerente de Área de Infraestructuras Norte*), Carlos Manzano Baró (*Jefatura de Coordinación, Seguimiento y Calidad*) and Jesús María Puente Guerra (*Jefatura de Coordinación, Seguimiento y Calidad*).
- **Subdirección de Operaciones Red de Ancho Métrico**: Juan Antonio González Peláez (*Jefatura de Coordinación, Seguimiento y Calidad*).