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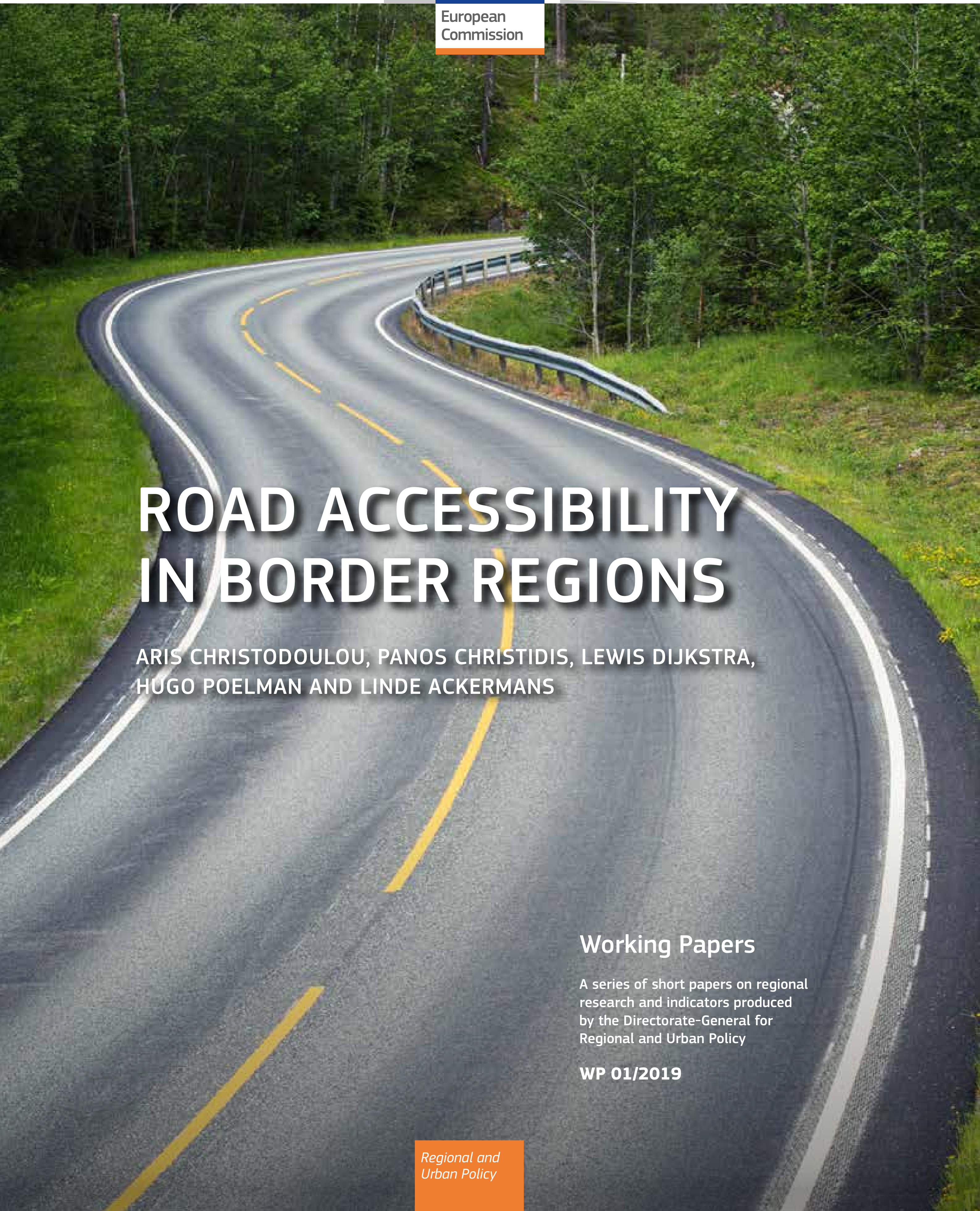

ROAD ACCESSIBILITY IN BORDER REGIONS

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EXECUTIVE SUMMARY

Cross-border interactions within the European Union (EU) still face more obstacles than interactions within national borders. Road accessibility might be only one of these obstacles, but adequate transport infrastructure is necessary to provide access to opportunities. To help improve cross- border cooperation, we assess road transport infrastructure in border regions. We estimate network efficiency, an accessibility measure suitable for focusing on network characteristics, in great spatial detail for all border regions in the EU. As a result, we are able to rank border areas according to the efficiency of their network, spot areas in need of infrastructure and infer the reasons for poor network performance.

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Introduction

The EU has 38 internal land border regions in Europe. For historical and geographic reasons, border regions tend to be relatively isolated. On the one hand, since most EU Member States have developed their infrastructure and regional policy with a centralised state in mind, the periphery of most Member States has not received as much investment as the core, which usually refers to the more central areas of a Member State. In addition, the lack of investment has led to an acceleration of the movements from the periphery to the core. This has created a vicious cycle of further reduced investments in peripheral areas of declining importance in population and economic terms.

On the other hand, border regions face geographic, historical, cultural and linguistic barriers that limit their opportunities for interactions with their cross-border counterparts. In most cases, these areas are also isolated within their own national context. These two trends, internal and cross-border isolation, mean that a significant part of the EU population has limited access to opportunities, even though they may no longer be considered as 'frontier' zones within the EU.

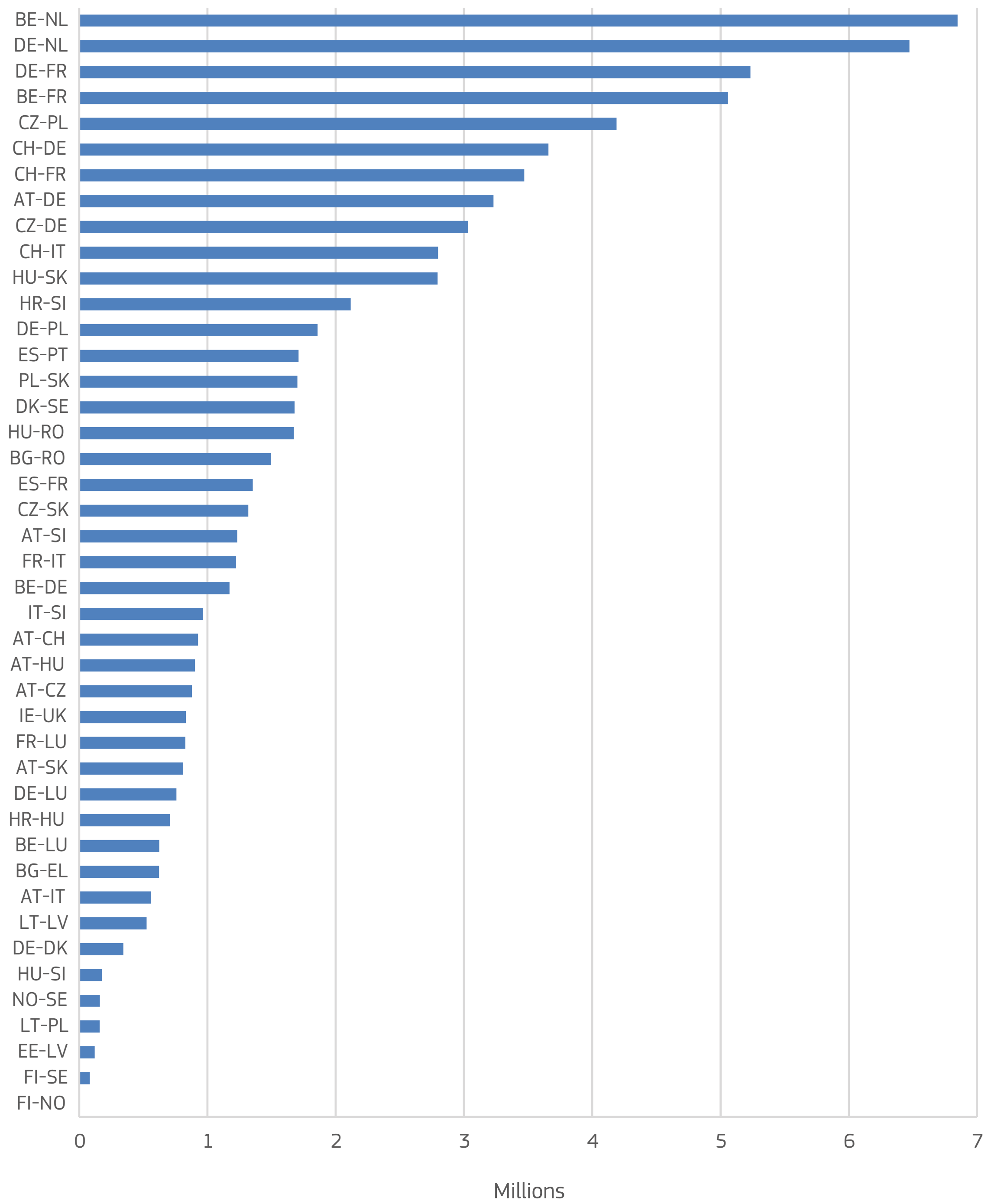
In fact, border regions are literally at the forefront of the geographical cohesion of EU Member States. This increases the significance of appearing to be heterogeneous in terms of transport infrastructure. Improving the connectivity of border regions can strongly influence regional, urban and local development. The Trans-European Network for Transport (TEN-T) is extremely important for the improvement of transport services and cohesion in Europe, although it is not sufficient to cover the border regions' connectivity deficits.

In this study, transport infrastructure in border regions is assessed in terms of accessibility by the network efficiency indicator that measures road network performance in relation to an ideal network. The results on network efficiency can be combined with population data, network data, geomorphology and location of major settlements in order to identify areas in need of transport infrastructure or ways of improving network efficiency. Furthermore, it is possible to focus on specific grids and examine specific routes to identify in detail the parts that can be improved. In addition to the maps presented in this paper, the results at grid level can be found here: https://ec.europa.eu/regional_policy/mapapps/transport/border_regions_nw_efficiency.html. More details can be found in Christodoulou and Christidis (2018).

DEFINING BORDER REGIONS

We define EU border regions as the areas within 25 km from the borders. They are home to almost 13.0 % of the population in the EU, Norway and Switzerland. The distribution of border region populations in each land border is shown in Figure 1. There are 6.8 million inhabitants within 25 km on both sides of the Belgium-Netherlands border and 6.5 million inhabitants along the Germany-Netherlands border. These two borders obviously offer many opportunities for cross-border collaboration, which is also helped by the cultural and linguistic proximity of the local societies. However, it is interesting to note that there are more than 20 other land borders, with a population of over 1 million people within 25 km on either side of those borders.

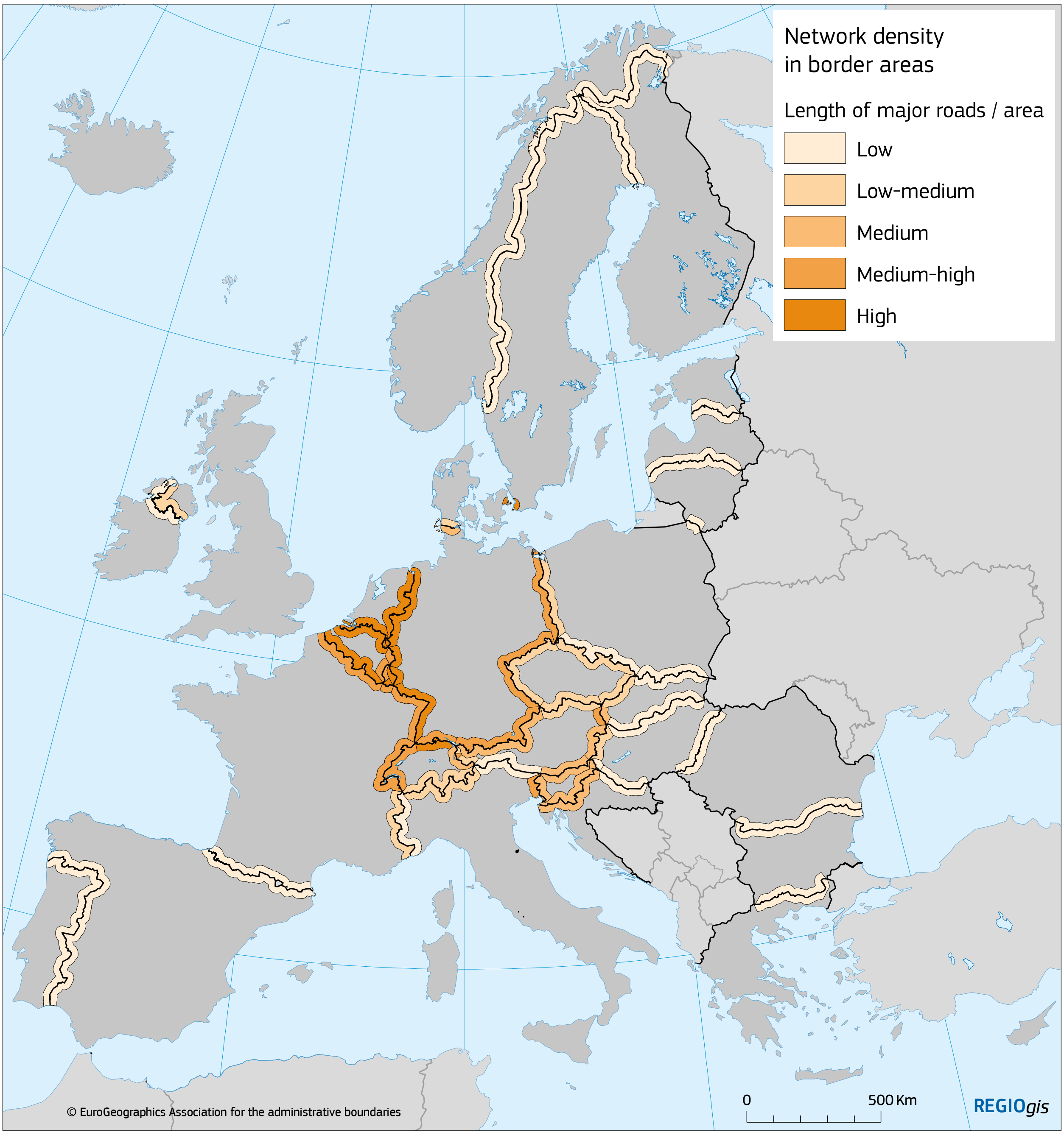
FIGURE 1: Population in border regions, per EU Member State border



(source: own calculation)

The density of major roads in border regions is presented in Figure 2[1]. These estimates refer to length of roads (metres) by border area (square metres). This map shows very clearly the distinction between central and peripheral countries, while the highest densities of major roads can be found in the border regions of Benelux, Germany and France.

FIGURE 2: Density of major roads in EU border regions



1. Where the borders of three countries meet, border areas 25 km wide partially overlap. To simplify the maps, we have represented the border areas as non-overlapping areas by distributing the overlapping zone between the border areas concerned. This has been done purely for the purpose of cartographic simplification. As there are no internal terrestrial borders in any of the outermost regions, these regions are not represented on the maps.

NETWORK EFFICIENCY IN EUROPE'S BORDER REGIONS

Network efficiency indicators were used to control for the effect of the geographic location on accessibility when assessing a region's transport infrastructure needs. The network efficiency indicator considers accessibility on the existing network and accessibility on an ideal network. This indicates the potential for improving the network. In addition to the performance of the network (travel time) and the attractiveness of potential destinations (population), network efficiency includes a parameter that represents the ideal performance of the network in order to reduce the impact of the geographic location.

More specifically, network efficiency takes into account the attributes of the network by including a variable representing ideal travel time. The ideal travel time incorporates issues related to road length and speed as it refers to travel time along a straight-line connection between two points at maximum speed. As a result, speed is linked to the type of road and its length, and road design which may be influenced by several factors, including geomorphology.

Network efficiency is measured for 1 km x 1 km grid cells within 25 km from the borders using the full road network. Potential destinations are selected among settlements with populations that are larger than 5 000, in relative proximity.

National and international network efficiency is calculated separately for each couple of countries sharing borders. For each origin zone (grid cell), national network efficiency is calculated considering the five most populated settlements in the same country within a radius of 75 km and international network efficiency is calculated considering the 5 most populated settlements in the neighbouring country within a radius of 75 km.

Aggregating at the level of specific bilateral borders (Figures 3 and 4) suggests that there is a distinction between older and newer EU Member States, central and peripheral European countries, or Western and Eastern European countries. At country level, the best-performing road network in terms of both national and cross-border network efficiency can be found in the borders of the Netherlands, Belgium and Germany, while the worst performing is in the borders of the Balkan countries.

The network efficiencies of Bulgaria's two border zones (with Greece and with Romania) are in the lowest band. This might be explained by the existence of natural borders: mountains between Bulgaria and Greece, and the River Danube on the border with Romania.

Combining the network efficiency results with Figure 2, which shows the density of major roads, it can be observed that in the borders between Spain and Portugal, and Spain and France network density is relatively low while network efficiency is relatively high. This might indicate that the network effectively serves the needs in these two border areas. Similar observations can be made for the border zones between Latvia and Estonia, and Lithuania and Poland.

FIGURE 3: Network efficiency (national) of border regions

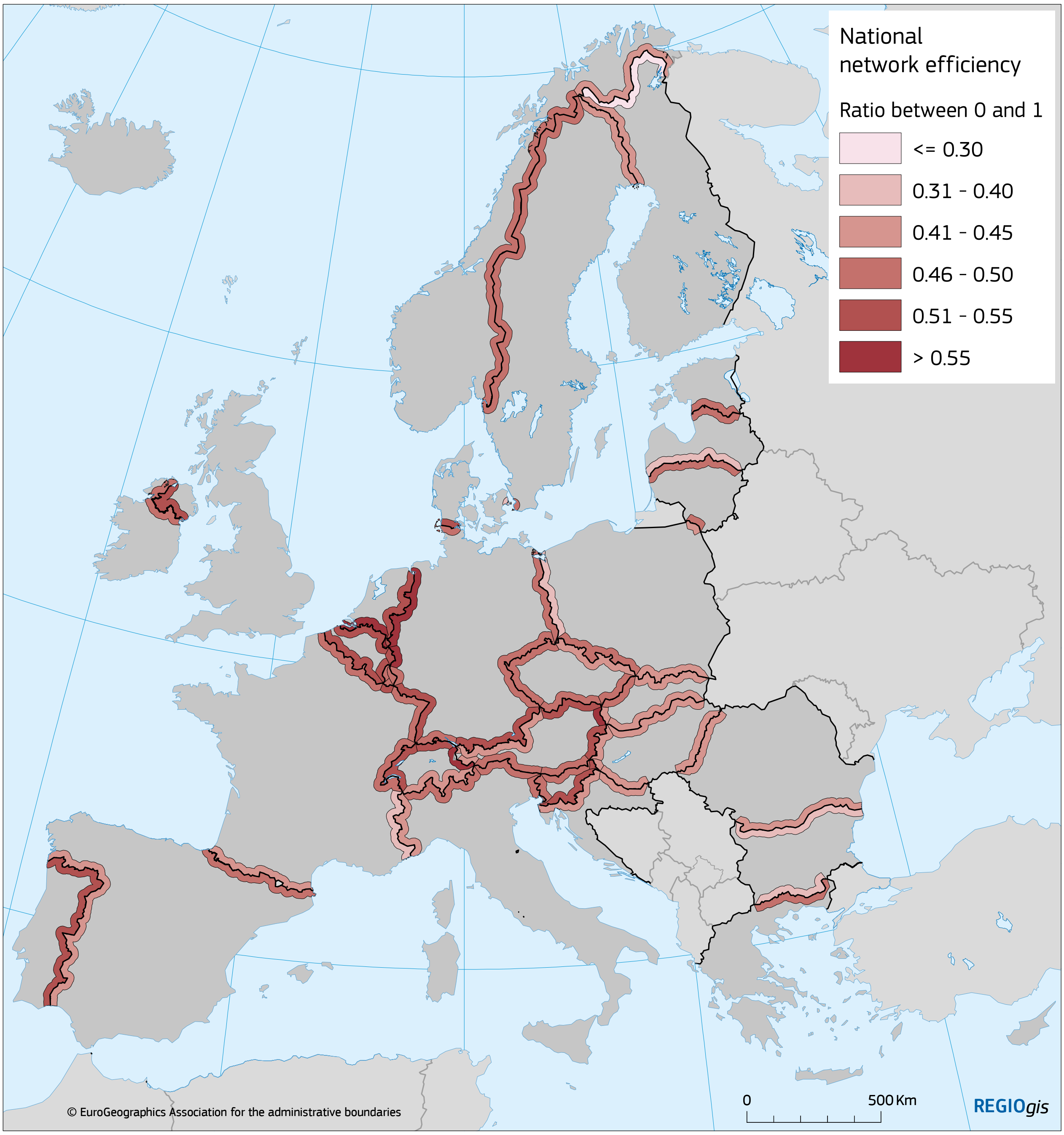
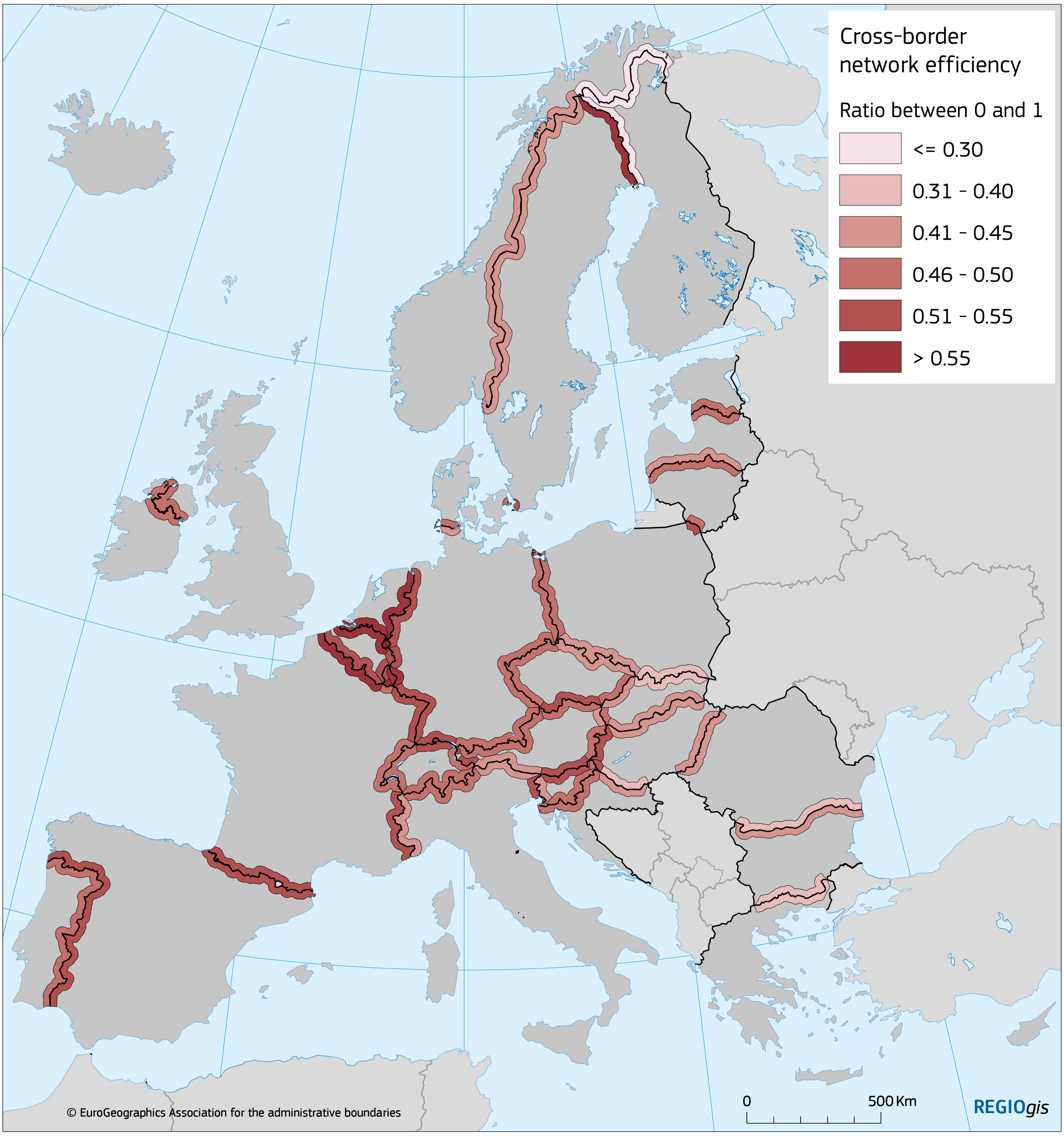


FIGURE 4: Network efficiency (cross-border) of border regions

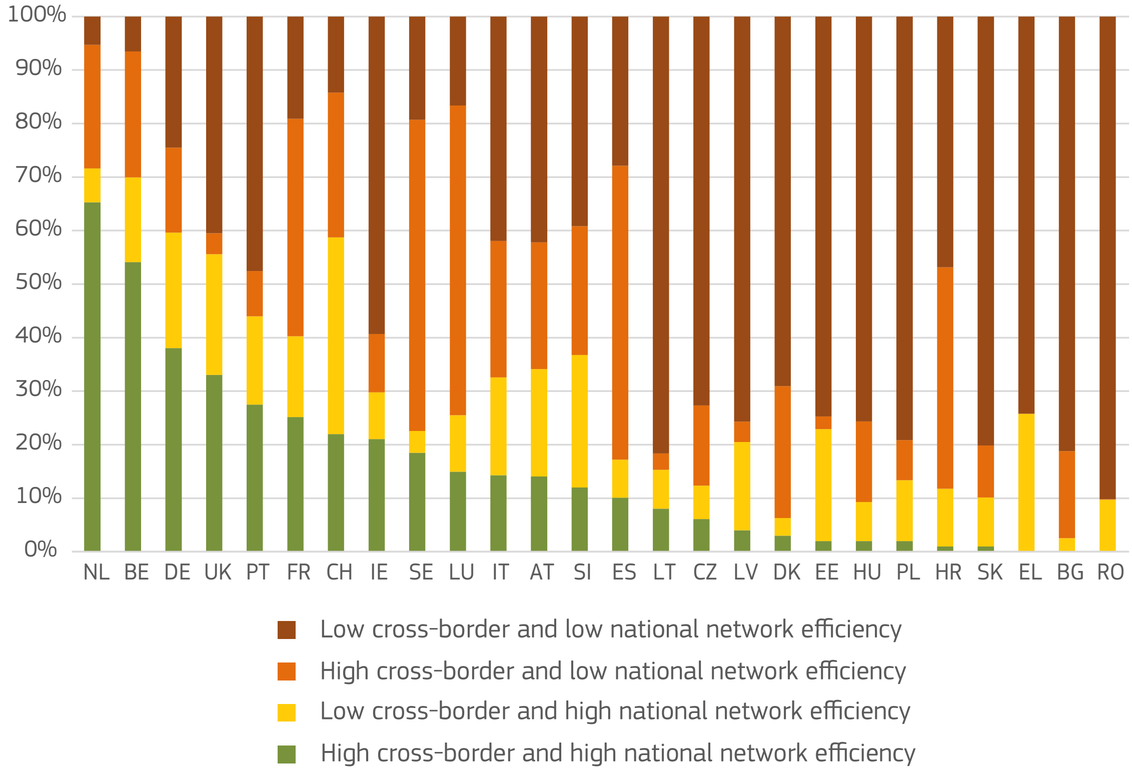


National and cross-border network efficiency are combined to rank countries in terms of the proportion of the population affected by the quality of the network in border zones (Figure 5). As the network efficiency ratio (NER) takes values between 0 and 1, each grid cell can belong to one of the following four categories:

1. National NER < 0.5 and cross-border NER < 0.5
2. National NER < 0.5 and cross-border NER ≥ 0.5
3. National NER ≥ 0.5 and cross-border NER < 0.5
4. National NER ≥ 0.5 and cross-border NER ≥ 0.5

Category 1 refers to the worst-performing grid cells, while grid cells in category 4 are performing well in terms of both cross-border and national network efficiency. Having classified border grid cells in one of the four categories, the population of each grid is used to find the distribution of the border region population in relation to the network efficiency level of their residential location. The results are aggregated at country level. Figure 5 ranks the countries in terms of the network efficiency in relation to the population living in border regions. For countries with more than one neighbour, cross-border efficiency with all neighbours is considered.

FIGURE 5: Distribution of border population in relation to the level of network efficiency



The Netherlands is the country with the highest proportion of border population (more than 60%) with access to well performing national and cross-border networks, followed by Belgium (more than 50%) and Germany (almost 40%).

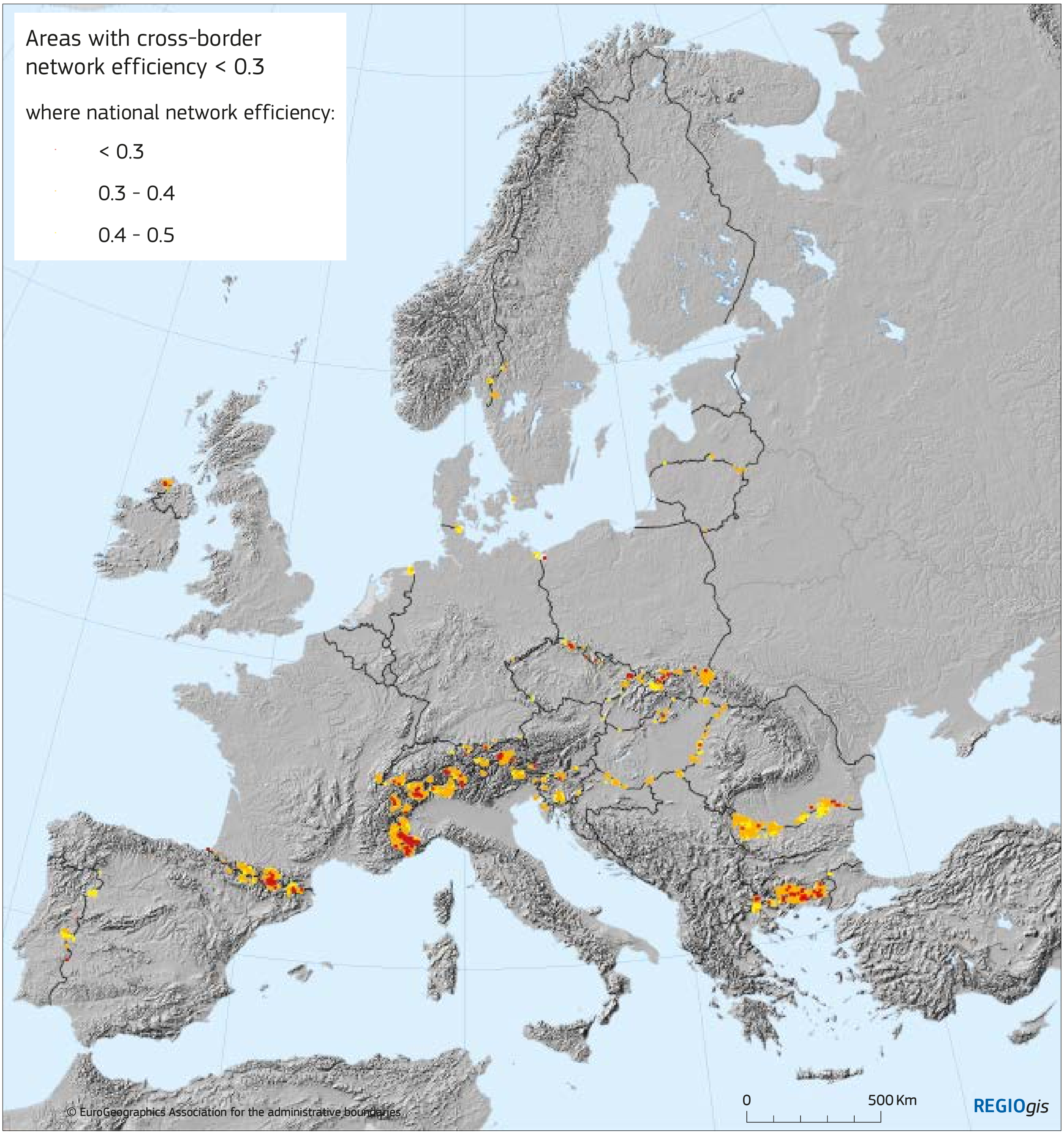
The values of the network efficiency indicator vary significantly depending on the local conditions. The median values of the national and cross-border sides are relatively close, 0.47 and 0.45, respectively, but the variance of the international part is higher. The higher values for international network efficiency correspond to areas very close to border crossings served by highways, while the lowest values correspond to zones that are located close to natural obstacles. In the first case, the geomorphology and the road design permit a travel time close to the theoretical travel time at maximum speed in a straight line. In the second case, however, multiple factors affect the low value of the indicator: long distance to border crossing, inefficient road design due to difficult geomorphology and low operational speed.

The concentration of zones with low values for network efficiency on both sides of the border is evident in Figure 6. Virtually all the cells with a low value (<0.3) on the international side also have a value lower than 0.5 on the national side. The combination of the location of those zones with the elevation map of Europe confirms the hypothesis of a high concentration of zones with low network efficiency on specific borders. Moreover, most of the zones with values lower than 0.3 on both sides of the border (red point on the map in Figure 6) are located in mountainous areas.

A key advantage of this study is that the analysis is conducted at a spatial level of high resolution with respect to the full road network. The maps of national and cross-border network efficiency at grid level for Europe, where each area can be examined in detail, can be found here: https://ec.europa.eu/regional_policy/mapapps/transport/border_regions_nw_efficiency.html.

Each border area can be analysed separately to identify the main factors that affect network efficiency and possibly indicate infrastructure needs. The results at grid level can be combined with other factors to indicate with precision the areas that suffer from poor accessibility, and play a significant role in recommending measures.

FIGURE 6: Correlation of national and international level network efficiency indicator per cell



NETWORK EFFICIENCY IN SOUTH-EASTERN EUROPE

Easy-to-spot poorly performing areas include the borders between Greece and Bulgaria (central part), as well as Bulgaria and Romania (western part). These will be further discussed as an example of the detail this analysis delivers. The results of network efficiency for the borders between Greece, Bulgaria and Romania are presented in Figure 7.

In general, national network efficiency is greater than cross-border network efficiency, especially in Greece. This has partly to do with the fact that the vast majority of major settlements in Bulgaria are far from the borders, especially in the southern part of the country. The poor road network connection with Greece is obvious from the map of the major roads. There are only two main points to cross the border between Greece and Bulgaria, and very few other major roads within a range significantly larger than the 25 km buffer that determines the border area.

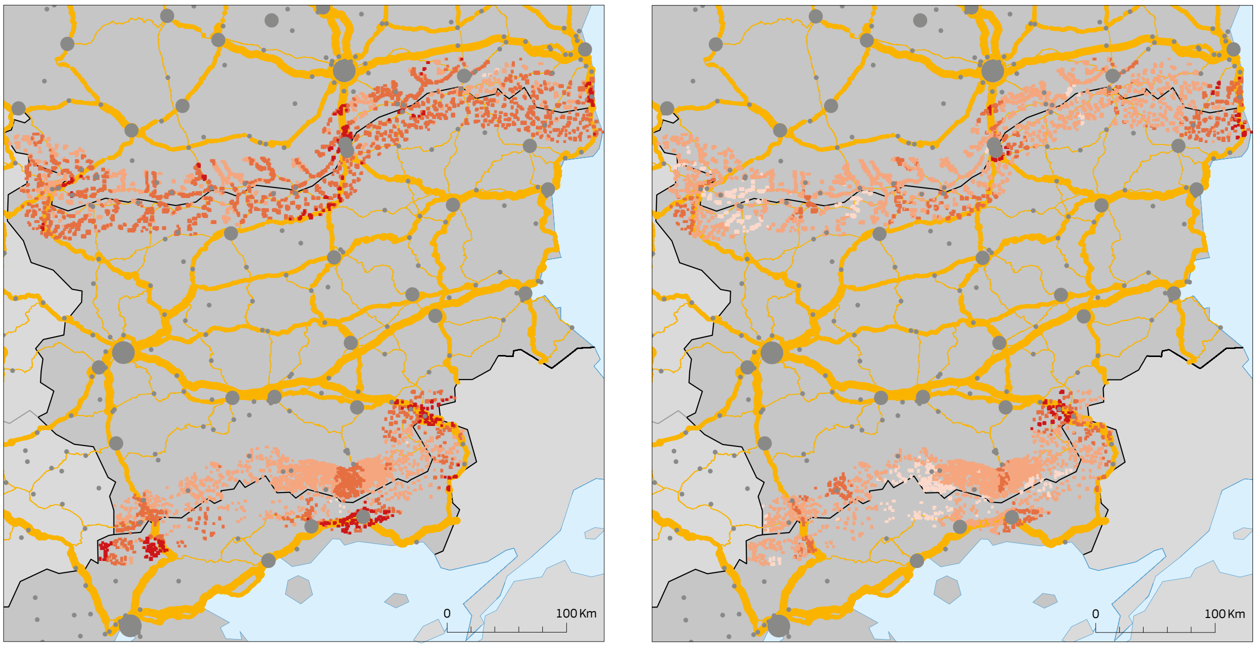
In the two border zones Bulgaria shares with Greece and Romania, there are very few grids with network efficiency greater than 0.5 in Bulgaria. These are concentrated around the road connecting the eastern part of Greece with Sofia, and the northern part of Bulgaria with Bucharest or Burgas.

The borders of Bulgaria with Romania and Greece have quite specific geomorphology, which definitely affects accessibility. The borders between Greece and Bulgaria are in a mountainous region that is relatively undeveloped, while the natural border between Bulgaria and Romania is the River Danube.

As regards cross-border network efficiency, there is a high concentration of grids with particularly low network efficiency (below 0.25) in the central part of the Greece-Bulgaria border zone and in the western part of the Romania-Bulgaria border zone. In addition, Bulgaria's border regions with its EU neighbours are quite sparsely populated.

The existence of the River Danube as a natural border determines the network efficiency measurements of the border zone between Bulgaria and Romania (Figure 8). The three selected grid cells have a little more than 6 000 people in total, but the case highlights the effects of the scarcity of bridges in the area. Water navigation is not considered in the analysis. For the selected points in Bulgaria, it is necessary to make a 135 km trip by road to reach a relatively large settlement (with more than 5 000 people) in Romania that is less than 5 km away in distance in a straight line.

FIGURE 7: National (left) and cross-border (right) network efficiency in the borders of Bulgaria, Greece and Romania



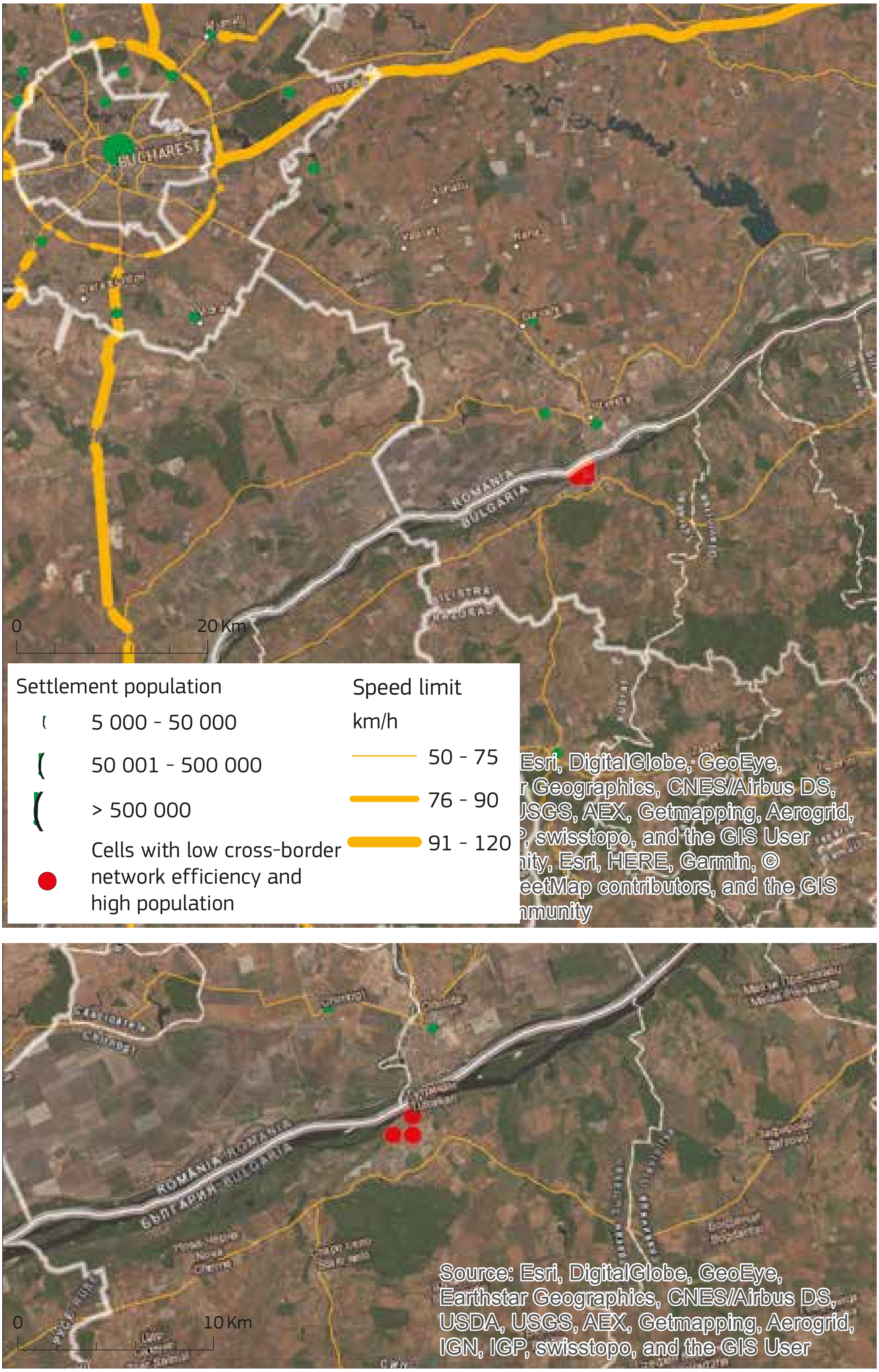
National road network efficiency

Settlements Population	Speed limit km/h	National network efficiency Ratio between 0 and 1
5000 - 50000	50 - 75	<= 0.25
50001 - 500000	76 - 90	0.26 - 0.40
> 500000	91 - 120	0.41 - 0.50
		> 0.50

Cross-border road network efficiency

Settlements Population	Speed limit km/h	Cross-border network efficiency Ratio between 0 and 1
5000 - 50000	50 - 75	<= 0.25
50001 - 500000	76 - 90	0.26 - 0.40
> 500000	91 - 120	0.41 - 0.50

FIGURE 8: Selected grid cells close to the border of Bulgaria with Romania (zoom-in view in lower map)



CONCLUSIONS

Physical distance and – by extension – travel time on the road network can be one of the reasons why interaction is impeded across those EU areas close to a land border. In various cases, border regions have been neglected at both national and international level. Priorities for transport infrastructure tended to favour more central zones or a few border crossings necessary for international trade. As a result, a large part of the internal EU land borders face the double burden of a difficult geographic situation and a lack of transport infrastructure investment to help reduce isolation. It should be noted, however, that the size of the population to benefit from an investment (i.e. in infrastructure) must be taken into account during the decision-making on the investment, especially when the investment is expected to be particularly high because of natural obstacles in sparsely populated areas.

Increasing cross-border cooperation is a policy objective at the EU level that aims to improve the situation for border regions and exploit the untapped potential of connecting neighbouring regions. A wide range of measures can be implemented to reduce the non-physical obstacles (such as linguistic, cultural or administrative barriers), but tangible physical infrastructure may still play a role in facilitating cooperation. The methodological appendix presented in this report concentrated on this aspect of connectivity, in particular on exploring ways to measure the quality of border road networks.

The population living in border regions is considerable, equal to 13% of the total EU population. In most cases, there is a marked difference in the level of cross-border connectivity and accessibility that these zones enjoy compared to the respective levels on the national side. Even when taking the influence of local geographic barriers into account, cross-border links are significantly slower and longer than links within the same country.

The road accessibility of all border regions in EU-28 (plus Norway and Switzerland) was assessed at grid level using network efficiency. Aggregating the results at the level of specific bilateral borders suggests that there is a distinction between older and newer EU Member States. At country level, the best performing road network in terms of both national and cross-border network efficiency can be found in the borders of the Netherlands, Belgium and Germany, while the worst performing road network can be found in the borders of the Balkan countries.

The results of the calculation of network efficiency at grid level, which can be used for further analysis, can be found here: https://ec.europa.eu/regional_policy/mapapps/transport/border_regions_nw_efficiency.html. In particular, the combination of the results on network efficiency with the road network and population distribution can help to indicate the reasons for low or high network efficiency while highlighting the role of the road network.

METHODOLOGICAL APPENDIX

Network efficiency indicators were initially proposed by Gutiérrez and Monzón (1998) as an elaboration of the route factor used to measure the sinuosity of individual links. The rationale is to reduce reliance on geographic location – or to 'neutralise the impact of the geographic location' – and to assess a region's transport infrastructure needs or potential.

The network efficiency indicator (NER) reported in the results of this study is the reverse of network efficiency (NE). NE is represented by the following formula:

$$NE_i = \frac{\sum_{j=1}^{n} \frac{t_{ij}}{t'_{ij}} P_j}{\sum_{j=1}^{n} P_j}$$

NER is represented by the following formula:

$$NER_i = \frac{1}{NE_i}$$

where,

t_{ij} is the travel time on the network from origin zone i to destination zone j

t'_{ij} is the time needed to cover the straight-line distance between origin zone i and destination zone j when travelling at a constant speed of 120 km/h

P_j is the population of destination zone j

n is the total number of destination zones to be considered, in the specific case n=5

As t_{ij} is the ideal travel time, NEi will tend towards 1 as accessibility improves and will increase as accessibility declines. By reversing network efficiency, the NERi indicator obtains values between 0 and 1, so that values reaching 1 indicate high network efficiency, while values reaching 0 indicate low network efficiency.

For the analysis, three sources of data have been combined:

- Population distribution map at 1 km^2 grid for the areas defined as border zones. It is based on the following sources: Eurostat, Joint Research Centre and Directorate-General for Regional and Urban Policy (DG REGIO).
- Map of settlements with a population of more than 5 000 inhabitants (based on the following sources from the European Commission: Eurostat, Joint Research Centre and DG REGIO).
- Detailed transport network at European level (TomTom, 2015).

The points of departure are the centroids of the inhabited 1 km^2 grid cells within a 25 km buffer of national terrestrial borders, and the points of arrival are the centroids of settlements with a population larger than 5 000 inhabitants. More specifically, travel times are calculated between the nodes of the road network that are closest to the origin and destination points. Travel times are based on the calculation of the shortest path using the A* algorithm and the speed information included in the TomTom data for each link that is part of the shortest path. The full TomTom road network is used.

Only populated grid cells are considered, while in a few cases of sparsely populated areas no settlements could be found within the determined 25 km buffer. These cases are not considered when reporting the total results of network efficiency. A map of grid cells without settlements – either in the country where the grid cell is located or in the neighbouring one – within the determined radius (75 km) is presented in Figure 9. The majority of cases of grid cells without settlements in the buffer can be found in the Swedish-Finnish, Norwegian-Finnish and Norwegian-Swedish borders, all in very sparsely populated areas. Other areas with a high concentration of grid cells without settlements within the determined buffer are in the borders between Switzerland and Italy, Italy and Austria, Austria and Czechia, France and Spain, Spain and Portugal, and Estonia and Latvia, all in sparsely populated areas.

FIGURE 9: Grid cells with no settlements in a 75 km buffer

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