

TRACC

Transport Accessibility at Regional/Local Scale and Patterns in Europe

Applied Research 2013/1/10

Final Report | Version 06/02/2015

Volume 1

TRACC Executive Summary and Main Report



This report presents the final results of an Applied Research Project conducted within the framework of the ESPON 2013 Programme, partly financed by the European Regional Development Fund.

The partnership behind the ESPON Programme consists of the EU Commission and the Member States of the EU27, plus Iceland, Liechtenstein, Norway and Switzerland. Each partner is represented in the ESPON Monitoring Committee.

This report does not necessarily reflect the opinion of the members of the Monitoring Committee.

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Introduction

The ESPON project TRACC (**TR**ansport **ACC**essibility at regional/local scale and patterns in Europe) aimed at taking up and updating the results of previous studies on accessibility at the European scale, to extend the range of accessibility indicators by further indicators responding to new policy questions, to extend the spatial resolution of accessibility indicators and to explore the likely impacts of policies at the European and national scale to improve global, European and regional accessibility in the light of new challenges, such as globalisation, energy scarcity and climate change.

The Transnational Project Group (TPG) for the ESPON project TRACC consisted of the following seven Project Partners:

- Spiekermann & Wegener, Urban and Regional Research (S&W), Dortmund, Germany (Lead Partner)
- Charles University of Prague, Faculty of Science, Department of Social Geography and Regional Development (PrF UK), Prague, Czech Republic
- RRG Spatial Planning and Geoinformation, Oldenburg i.H., Germany
- MCRIT, Barcelona, Spain
- University of Oulu, Department of Geography (FOGIS), Oulu, Finland
- TRT Trasporti e Territorio, Milan, Italy
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This report is part of the TRACC Final Report. The TRACC Final Report is composed of four volumes.

- Volume 1 contains the Executive Summary and a short version of the Final Report
- Volume 2 contains the TRACC Scientific Report, i.e. a comprehensive overview on state of the art, methodology and concept, and in particular results on the global, Europe-wide and regional accessibility analyses and subsequent conclusions of the TRACC project.
- Volume 3 contains the TRACC Regional Case Study Book. Here, each of the seven case studies conducted within the project is reported in full length.
- Volume 4 contains the TRACC Accessibility Indicator Factsheets, i.e. detailed descriptions of all accessibility indicators used in the project.

TRACC

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Volume 1a

TRACC Executive Summary



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Objectives

Accessibility is the main 'product' of a transport system. It determines the locational advantage of an area (i.e. in ESPON a region, a city or a corridor) relative to all areas (including itself). Indicators of accessibility measure the benefits households and firms in an area enjoy from the existence and use of the transport infrastructure relevant for their area.

The important role of transport infrastructure (i.e. networks and transport services) for spatial development in its most simplified form implies that areas with better access to the locations of input materials and markets will, *ceteris paribus*, be more productive, more competitive and hence more successful than more remote and isolated areas. However, the impact of transport infrastructure on spatial development has been difficult to verify empirically. There seems to be a clear positive correlation between transport infrastructure endowment or the location in interregional networks and the *levels* of economic indicators such as GDP per capita. However, in most countries this correlation may merely reflect historical agglomeration processes rather than causal relationships effective today. Attempts to explain *changes* in economic indicators, i.e. economic growth and decline, by transport investment have been much less successful.

This uncertainty leads to a couple of policy and research questions regarding the accessibility situation, spatial patterns and dynamics at different levels (global, European and regional) for different transport modes (road, rail, water, air and combinations), regarding the impacts of accessibility and its possible policy driven dynamic in the context of changing framework conditions on regional development. From such policy and research questions the main objectives of the project are derived:

- to take up and update the results of existing studies on accessibility at the European scale using most recent available network and socio-economic data,
- to extend the range of accessibility indicators by further indicators responding to new policy questions and further developing the quality and validity of the existing indicators,
- to extend the spatial resolution of accessibility indicators by calculating, besides European accessibility, also global and regional accessibility,
- to explore the likely impacts of available policies at the European and national scale to improve global, European and regional accessibility in the light of new challenges, such as globalisation, energy scarcity and climate change.

Conceptual framework

The TRACC conceptual framework is based on a systematic and comprehensive theoretical consideration of the major dimensions of accessibility, the most frequently used types of accessibility indicators and important extension of these. Accordingly, accessibility indicators may be sensitive to the following dimensions: origins, destinations, impedance, constraints, barriers, type of transport, modes, spatial scale, equity and dynamics. In general terms, accessibility is a construct of two functions, one representing the activities or opportunities to be reached and one representing the effort, time, distance or cost needed to reach them: These functions can be defined and combined in different ways. The most common way of doing this is reflected in three generic accessibility indicators:

- *Travel cost*. If only destinations of a certain kind, e.g. cities beyond a certain size, are considered and the impedance function is travel time or travel cost itself, the accessibility indicator is total or average travel cost to a predefined set of destinations.
- *Cumulated opportunities*. If only destinations within a certain travel time are considered, and the destinations are taken as is, the accessibility indicator measures the number of potential destinations (customers, business contacts, tourist attractions, etc.) reachable in a given time.

- *Potential*. If the impedance function takes travel behaviour into account, i.e. the diminishing inclination to travel long distances, the accessibility indicator is a potential indicator. The activity function may take account of agglomeration effects or economies of scale.

There is a large number of extensions of the above generic accessibility indicators. Four of them are addressed in this project, namely multimodal accessibility, intermodal accessibility, global accessibility and regional accessibility.

TRACC set of accessibility indicators

A comprehensive review of accessibility indicators used in research and practice has shown that there is no single standard accessibility indicator serving all purposes. The conclusion for TRACC has been therefore to develop a systematic and consistent set of accessibility indicators which is derived from the conceptual framework as summarised above and which matches a range of specific requirements.

Table 1 presents the resulting TRACC set of accessibility indicators. The indicator set is differentiated by the three main spatial contexts to be taken into account (global, European, regional), and at each level further differentiated by travel and freight. For the European level, accessibility indicators for travel are further divided into traditional and newer ones. For the regional level, the indicators are differentiated into those regional indicators for both travel and freight that can be calculated for the whole of Europe and those that are calculated in the regional case studies. For the latter, a distinction is made between traditional indicators and indicators looking at the accessibility to services of general interest to reflect current policy debates on the subject of services of general interest. At all levels, each generic indicator type is represented by one indicator.

Illustrative results

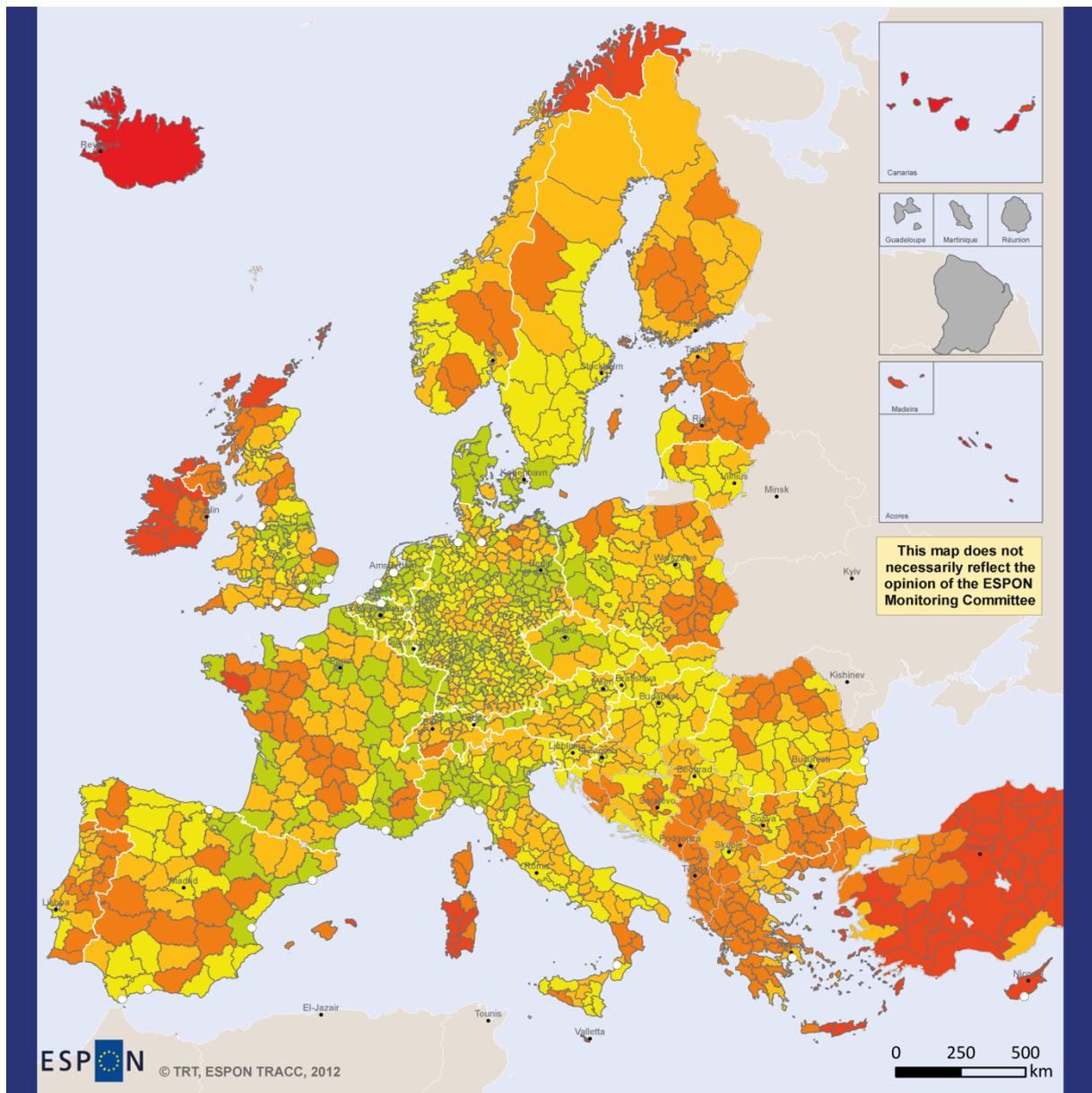
The TRACC project was successful in implementing the full matrix of accessibility indicator as defined in Table 1. By doing this the underlying conceptual framework was followed in which in particular the set of dimensions of accessibility is asking not for a single all-purpose accessibility indicator but for appropriate indicators for different circumstances and demands. The in total 27 accessibility indicators were calculated for different modes or combination of modes; six of them were implemented for road and public transport in seven case studies.

This results in an enormous amount of empirical material presented and analysed with the help of maps and diagrams in the different volumes of the TRACC Final Report. The interested reader might want to visit those other volumes for closer inspection of the results. Volume 4, the TRACC Accessibility Indicator Factsheets, contains detailed technical descriptions of all accessibility indicators used in the project including all maps developed for the ESPON Space. Volume 3, the TRACC Regional Case Study Book, contains the seven case studies conducted within the project in full length and contains all case study maps. Volume 2, the TRACC Scientific Report, contains a comprehensive overview on state of the art, TRACC methodology and concept, and in particular the presentation, analysis and interpretation of results achieved on global, Europe-wide and regional accessibility and subsequent conclusions.

Here, only very selective and illustrative examples for the type of results achieved can be presented in map form. Figure 1 shows an example for global accessibility using rail freight accessibility to sea ports weighted by container throughput. Figure 2 presents an aspect of Europe-wide accessibility by taking multimodal potential accessibility travel. Figure 3 is an illustration for regional accessibility displaying the urban functions available, expressed as number of cities reachable within one hour rail travel time. Figure 4 is a map which combines results of all seven regional case studies by showing access time to the next hospital for LAU-2 regions.

Table 1. TRACC set of accessibility indicators

Spatial context	Basic characteristics	Generic type of accessibility indicator		
		Travel cost	Cumulated opportunities	Potential
Global	Travel	Access to global cities Travel time (intermodal) to global city (New York)	Global travel connectivity Number of flights from European airports to intercontinental destinations reachable within three hours	Global potential accessibility travel Intermodal accessibility to intercontinental flights of European airports weighted by seat capacity as mass
	Freight	Access to global freight hubs Travel time/cost (intermodal) to major intercontinental terminals (New York, Shanghai)	Global freight connectivity Intercontinental container throughput of European sea ports reachable within maximum travel time	Global potential accessibility freight By road and rail to container throughput of European sea ports
Europe	Travel (traditional)	Access to top ten MEGAs Average fastest travel time to top group of MEGAs	European daily accessibility travel Daily accessibility to population by road, rail, fastest mode	European potential accessibility travel To population by road, rail, air, multimodal
	Travel (new)	Travel speed Average travel speed by road and rail	Urban connectivity Urban connectivity by road, rail, air, intermodal	European potential acc. intermodal travel To population intermodal
	Freight	Access to nearest maritime ports Generalised cost to nearest maritime port	European daily accessibility freight GDP accessible within allowed lorry driving time	European potential accessibility freight Accessibility potential to GDP by different modes
Regional	Travel (Europe-wide)	Access to high-level transport infrastructure Weighted access time to motorway exits, rail stations, airports	Availability of urban functions Cities > 50.000 within 60 minutes by road and rail	National potential accessibility travel To national population by road and rail
	Freight (Europe-wide)	Access to freight terminals Weighted access time to freight terminals	Availability of freight terminals Freight terminals within 2 h by lorry	National potential accessibility freight To national GDP by lorry
	Travel (case studies, traditional)	Access to regional centres Travel time to nearest regional centre by road and public transport/rail	Daily accessibility of jobs Jobs accessible within 60 minutes by road and public transport/rail	Regional potential accessibility To population by road and public transport/rail
	Travel (case studies, to services of general interest)	Access to health care facilities Travel time to nearest hospital	Availability of higher secondary schools Number of higher secondary schools within 30 minutes travel time	Potential accessibility to basic health care Potential accessibility to general practice surgeries




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Source: TRUST Accessibility Model (TRT 2012), Road/Rail Network: TransTools (2005),
 Intercontinental container throughput of ports (Eurostat data 2007-2009)
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**Global potential accessibility freight (2011):
 by rail to intercontinental container throughput of European sea ports
 (percentage of average accessibility by rail of all areas)**

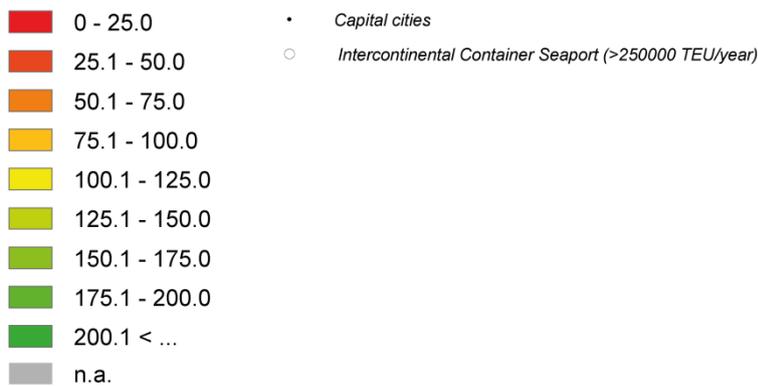
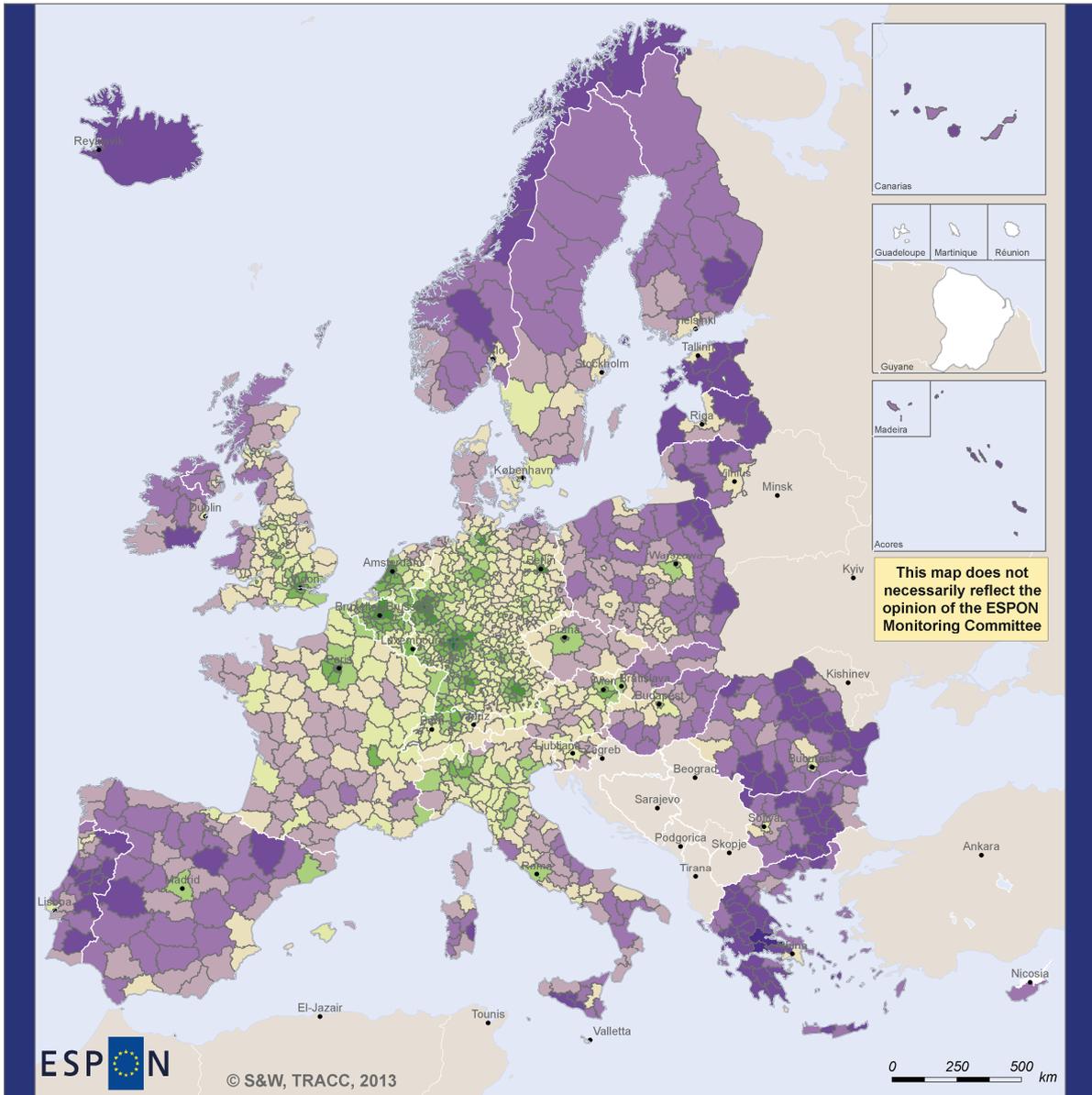


Figure 1. Global freight connectivity – rail



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Regional level: NUTS 3
Source: Spiekermann and Wegener
Urban and Regional Research (S&W), 2013
Origin of data: S&W Accessibility Model, 2013
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Accessibility potential, multimodal (ESPON = 100) 2011

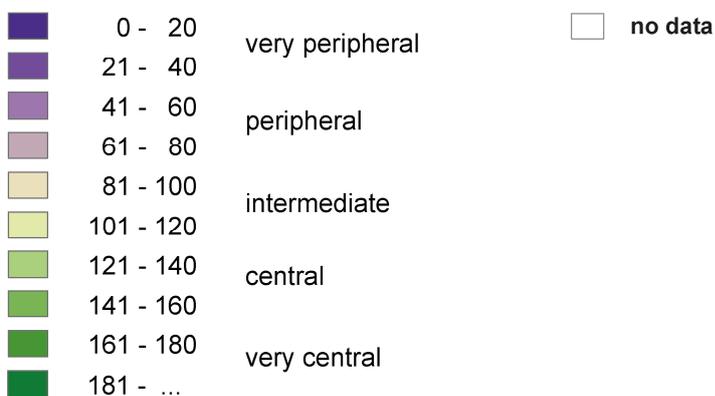
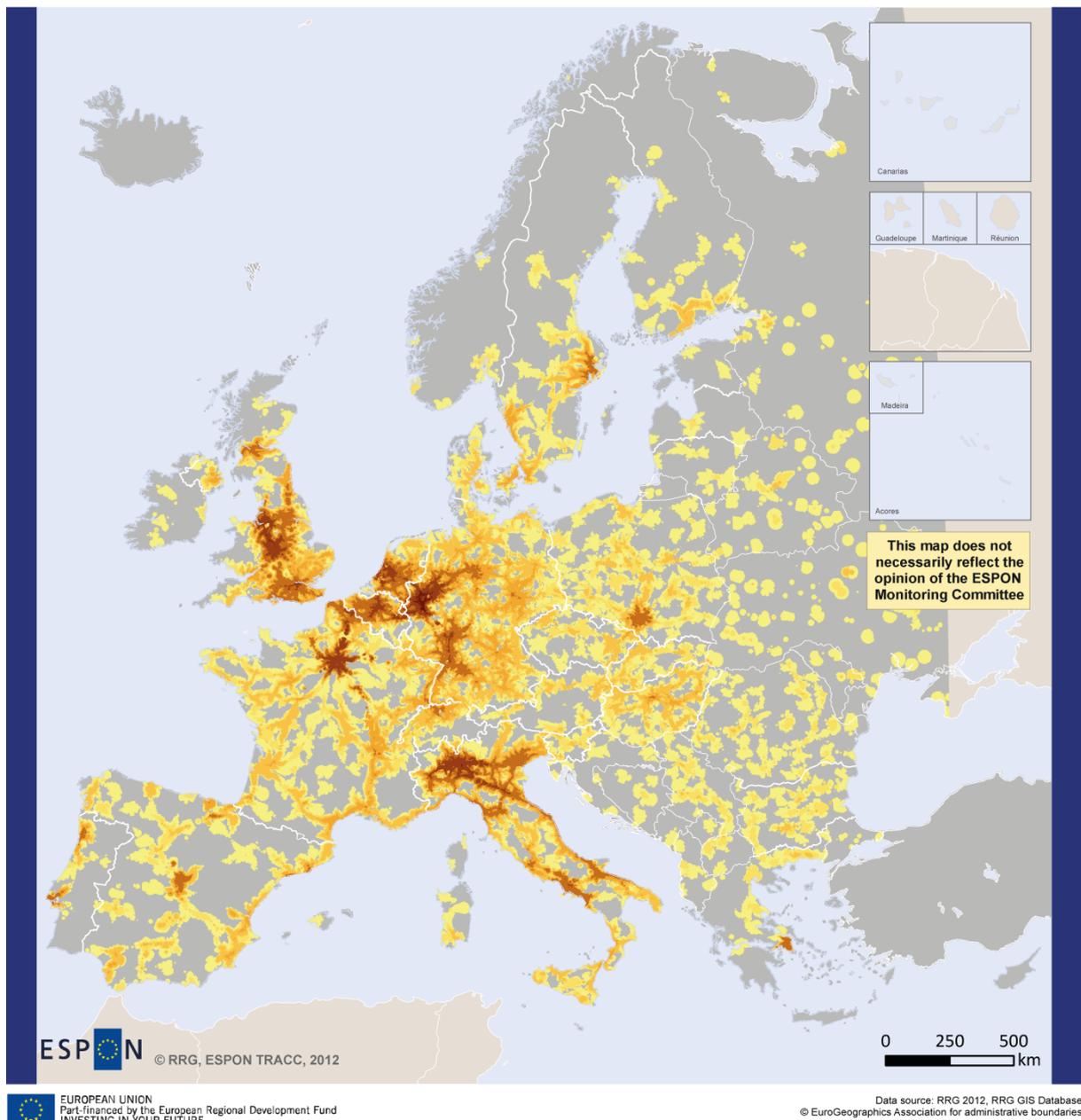


Figure 2. Potential accessibility to population, multimodal



**Availability of urban functions (2011):
Number of cities > 50,000 inhabitants within
60 minutes rail travel time (raster level)**

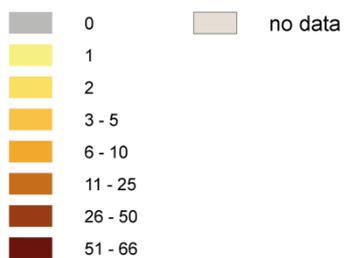


Figure 3. Availability of urban functions, rail

**Travel time to nearest hospital
by public transport (LAU-2, 2012)**

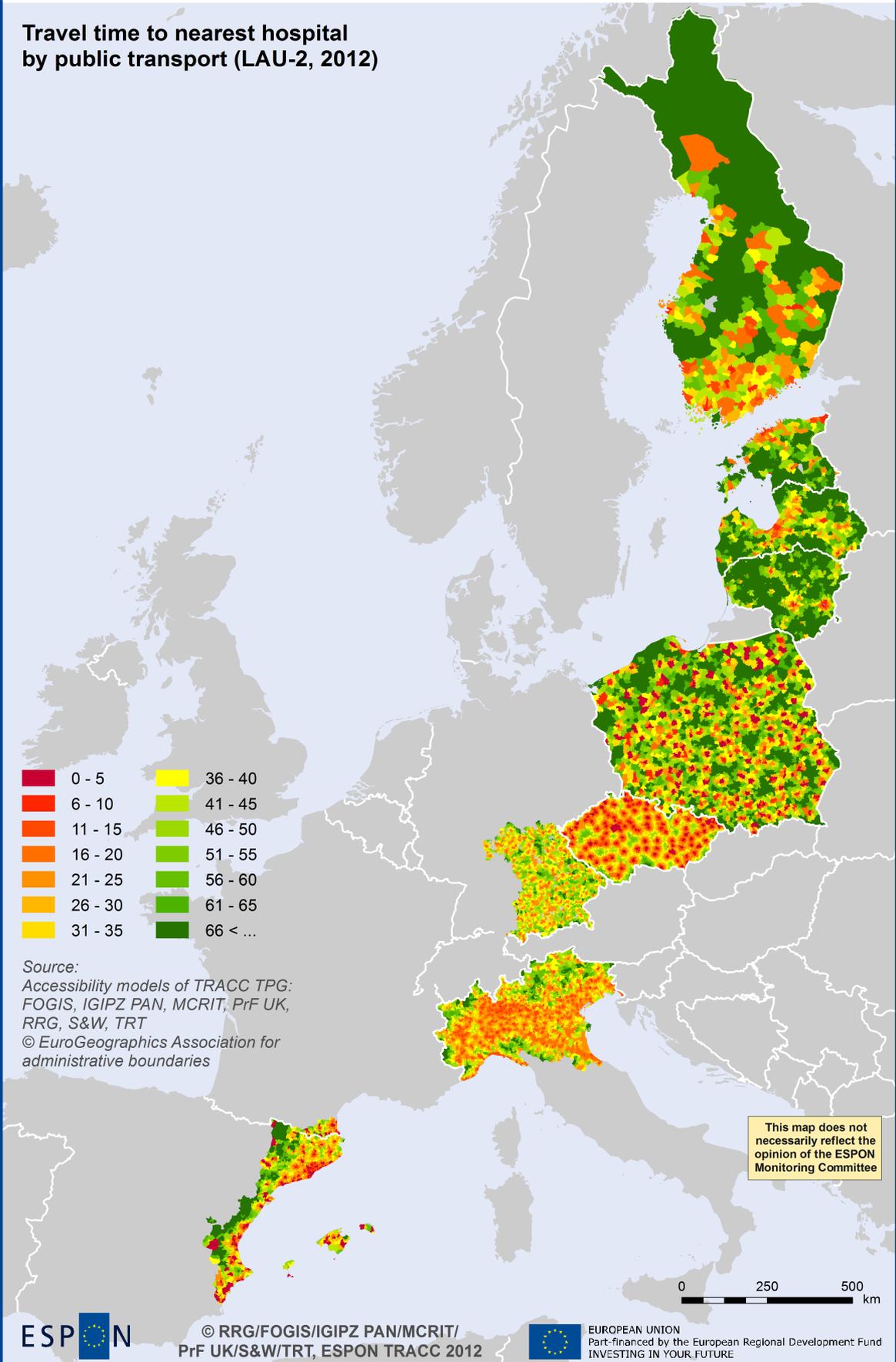


Figure 4. Public transport travel time to next hospital.

Policy implications

What are the main lessons learned from the TRACC project on accessibility for policy making at different territorial levels? In the following bullet points main findings of the project are summarised and some tentative conclusions are drawn.

- **Accessibility is a 2 dimensions driven variable:** Accessibility consists of two components, available activities of interest and transport infrastructure leading to them. Low accessibility values reflect in some cases sparsely populated areas and/or low service endowment, often in the European peripheries; but in others cases low accessibility values are driven by poor transport infrastructure, more often in Eastern Europe than in Western Europe. Accessibility related policy should not only concentrate on the transport infrastructure side as investments in the points of interest might be more efficient. That means that transport and spatial development policies should be more integrated at all territorial levels.
- **Global travel accessibility.** Seen from an accessibility perspective, the integration of European regions in the global economy is very heterogeneous. In particular for passenger travel, huge differences exist between European regions in terms of linkages to global destinations and global accessibility.
- **Global freight accessibility changing.** The progressive rise of Far East as trade partner opens to Mediterranean regions the perspective of exploiting a position advantage. In this respect, efficient multimodal infrastructures (ports, transshipment facilities, intermodal centres, roads, railways) might increase the global accessibility of Southern European regions thus reducing the current differences with respect to the North Sea area.
- **European travel accessibility patterns.** The dominating accessibility pattern in Europe for passenger transport is as follows: highest values in the Core of Europe, in capital city regions in other countries, and in other selected industrial or touristy regions such as Southwestern Scandinavia (Oslo-Gothenburg-Copenhagen), the Western Mediterranean coastal corridor (from southern Spain to northern Italy), the Rhone valley, Southern Italy, Saxony and Upper Silesia. Citizens in core regions are more likely to seamlessly travel in Europe or access global transport gateways (more transport services and point to point connections, shorter local trip legs) as they have denser motorway and rail networks and concentrate a higher number of European and global air hubs.
- **European freight accessibility patterns.** Geographical position, availability of infrastructures and strength of the economy are the three key elements which describe the pattern of European accessibility in relation to freight. Logistic activities tend to follow population and economic concentrations. Best connectivity to freight transport networks is recorded in the North Sea due to the presence of largest container ports in Europe, in addition to denser motorway and freight village networks. The Mediterranean rim has large container ports but less dense motorway and freight village networks in their hinterlands limit to a large extent high performance to coastal fringes. Main inland waterway axes (Rhine, Danube, Elbe) and canal systems in Germany back up good freight accessibility performance.
- **The cost of low EU Integration.** The comparison of potential accessibility patterns restricting origins and destinations within EU Member States against Europe-wide mobility shows that an important number of European regions are likely to lose out when they are restricted to access only national activities, or in other words under lower EU integration conditions. This is especially obvious in border regions like western Poland, north-eastern and southern Germany, eastern and southern France. Low European integration can be due to political issues like border permeability to economic flows but more importantly due to cultural issues like barriers that languages represent to seek jobs or study abroad. Seen it the other way round, border regions are largely benefitting in terms of accessibility of the diminishing importance of those borders and the gain in opportunities available to their citizens.

- **Local and regional peripheries do not match EU peripheries.** No significant differences can be observed for performance in regional and local accessibility between regions located at the European Periphery and regions located at the European Core. Regional case studies have revealed relatively homogeneous patterns within regions. Regional and local accessibility in case studies is much more dependent on the local conditions of population and economic activity than to their overall European localisation.
- **The East-West divide still persists at regional level.** From most locations in Europe, at least one regional centre can be reached in less than 60 minutes travel time, but only people in Western Europe have options to visit more than five different cities in that time. Infrastructure endowment is still much lower in Eastern Europe, so despite having relatively similar levels of service provision, accessibility to services remains lower than in Western Europe. Accessibility to transport infrastructure is also lower in Eastern Europe.
- **The Urban-Rural divide still persists at regional level.** Accessibilities for capitals regions or for main agglomerations differ significantly from those for rural, peripheral and landlocked regions, as well as for intermediate areas. Minimum services are available with reasonable cost in most areas of Europe, even remote rural or sparsely populated, but the possibility to choose amongst different alternatives is concentrated in highly populated urban areas. Indicators focussing on availability of activities and services (travel cost) provide more balanced patterns on the territory than indicators focussing on the diversity of offer (cumulated opportunities, potential accessibility) which tend to provide more polarised patterns around largest metropolises and well deserved transport corridors.
- **Inner peripheries in all regions.** Inner peripheries with low accessibility values are not only located in the far North or in the Alpine space, as expected, but also in most European countries. The extent of these inner peripheries is substantially larger for rail than for car.
- **Balanced access to services of general interest.** The analysis of case studies show a balanced geographical distribution of public services in Europe, allowing for minimum service availability despite of population figures or economic activity of regions. Many case studies have identified the threat of diminishing accessibility to services of general interest caused by withdrawal of the public sector in the framework of the current financial crisis.
- **Public transport accessibility below car accessibility.** Accessibility patterns for cars and public transport differ to a large degree, both with respect to the level and also with the spatial patterns. Accessibility levels by car are in general higher at regional and local level than those for public transport, but public transport is still able to provide high levels of accessibility within metropolitan areas and in city centres, and along well deserved axes is. Accessibility indicators for cars tend to form different types of plateaus, while for public transport the same indicators form 'stretches' and 'bands' of high accessibilities along transport axis, interrupted by areas of low accessibilities where public transport is missing. Most of the case studies and most of the indicators applied demonstrate that accessibility by car is superior to accessibility by public transport. Only in a few metropolitan areas public transport is providing comparable accessibility to the population.
- **Impact of financial crisis.** Accessibility is a matter of transport infrastructures and of availability of functions. As for transport infrastructures, the impact of the financial crisis is likely to be detrimental in the light of the pro-cyclic approach in public investments dominating the EU architecture. Shortage of financial resources can easily lead to postpone or even cancel planned public investments, whilst private investments are also likely to slow down significantly. The picture could be different if the role of public expenditure as engine of aggregate demand to tackle economic crisis is re-discovered. As for availability of functions, two main linkages with the crisis can be mentioned. First, for some of the TRACC indicators public services (schools, hospitals) are involved. The concentration of services with the

closure of minor local sites has been announced often in the last years. The financial crisis could provide the rationale for put this into practice. In that case, especially accessibility based on travel costs could significantly worsen for many (mostly peripheral) areas. Second, the crisis has been deepening (further than being fuelled by) disparities between European countries. So, current unbalances in accessibility to economic activity are likely to increase.

- **No clear significant overall patterns observed in relation to impacts of TEN-T projects in case studies.** Impacts observed varied largely from one case to another. The diversity of typologies of projects in each case, and the use of particular hypothesis for final performance of envisaged infrastructures (e.g. speeds in new rail links) may be in part responsible for these differences. In a number of case studies, largest metropolitan areas and urban regions tended to win less in relation to intermediate and rural regions (e.g. in the Czech Republic, in the Baltic States, and to some extent in the Western Mediterranean and in Finland). In Poland, road projects benefit to a higher extent the Warsaw – Katowice region, but also important gains can be observed in the far less populated eastern regions bordering with Belarus and Ukraine.
- **Specialised accessibility indicators.** Individual accessibility indicators are to depict different facets and different spatial structures. Accessibility cannot be assessed by just one indicator. Travel cost indicators to next “function” indicate the possibility of regions to have access to certain functions, while cumulated opportunities and potential accessibility indicators also include the variety of functions and therefore reflect the magnitude of alternative choices available. Potential indicators tend to show more laminar patterns (progressive), while availability of functions are more affected by singularities in the territory.
- **Accessibility and regional development.** Based on the empirical and modelling analyses in ESPON TRACC and previous ESPON projects the impacts of changes in accessibility on competitiveness, cohesion and sustainability can be summarised as follows: Good accessibility is a precondition for economic development. Regions with good access to suppliers and markets are ceteris paribus more economically successful than remote and isolated regions. Even large changes in accessibility lead to only small changes in economic development. The magnitude of the effect depends on the existing level of accessibility: Further improvements of the already high accessibility of central regions will have only little effect, improvements of the accessibility of remote regions can have significant effects on their economic development. A reduction of accessibility through higher fuel prices or environmental taxes will reduce the accessibility of central regions more than that of remote regions, but will negatively affect economic development of remote regions more than that of central regions. Transport infrastructure improvements, even if focused on rail, have very little impact on energy consumption and greenhouse gas emissions by transport unless they are accompanied by pricing policies making road and air transport more expensive.

Research implications

The TRACC project has further developed and implemented different methodologies to measure accessibility and to evaluate regional impacts of changing accessibility. The following bullet points summarise some implications for further research into accessibility:

- **Accessibility indicator set.** The accessibility indicator set in TRACC and its implementation is a first attempt to assess accessibility from very different viewpoints and for different purposes. More research should be devoted to develop commonly accepted standard indicators like the European potential accessibility also for other spatial contexts and purposes.
- **Raster approach to increase resolution of accessibility analysis.** A good part of the findings in TRACC is based on grid cell maps, free of administrative divisions. Several

particular areas and spatial patterns can be noticed only on the grid cell basis. TRACC has proven that even at the level of zoom-in regions significant intra-regional disparities exist, which cannot be detected by the traditional, aggregated models. Such intra-regional disparities are often greater than those between regions, thus accessibility studies should acknowledge these disparities and should find ways how to capture them. Raster analysis allows for a more accurate identification of territorial patterns generated by high level and public transport corridors.

- **Public transport modelling approach.** The quantification of public transport accessibility could be improved by modelling different services (road public transport, regional trains, intercity trains etc.) as independent modes, allowing for multimodal trip chains. On the one hand this would allow to better identify the role of each mode (e.g. road public transport for short distances, often when train is not available, regional trains mostly for commuters, etc.), thus providing more precise estimations of times and costs for different demand segments/travel purposes (e.g. accessibility to schools would probably use different input than accessibility to hospitals or potential accessibility to population. On the other hand, modelling multimodal chains (even if in a simplified way) would allow to explore the role of interconnectivity and co-modality, which are increasingly relevant concepts in public transport planning to provide efficient accessibility.
- **Freight transport modelling approach.** Some freight services are based on lines with fixed paths and stops (likewise public transport). Modelling these lines more explicitly would improve the representativeness of the accessibility indicators as the information on the regions pairs actually connected would be more precise. A pre-condition for implementing this approach on an European scale would be however the availability of a reliable and frequently refreshed database of the lines, which are continuously evolving. For rail-road combined transport some information exists, but for maritime container data is much more scattered and difficult to access. Still about freight, road freight accessibility is significantly influenced by assumptions on driving times and costs (e.g. respect or not of the maximum driving limits per day, use of two drivers, accompanied and unaccompanied trucks on ferries). Improvements on modelling of these aspects could be useful.
- **Transport scenario modelling.** The modelling of transport infrastructure and policy scenarios was based on very global assumptions on the scenarios and the development of transport infrastructure. Further research in this direction might concentrate on the impacts of individual projects, of basic infrastructure alternatives and on the integration of transport policies and territorial and regional policies.
- **Case study approach.** The accessibility modelling for the seven case studies in TRACC was done with a rather strict definition of the accessibility indicators and a subsequent research programme. Together with a very identical structure of the case study reports, including the same type of maps, diagrams, even the colour ramps were harmonised, the results are highly comparable across the different regions. However, because the indicators were calculated with seven different accessibility models, some with a detailed representation of public transport networks, some with a more abstract representation, some with raster based approaches, some with centroids of LAU-2 regions, differences in accessibility might also be traced back to differences in spatial resolution, parameters or country-specific definitions of destinations. But notwithstanding this small reservation, the strict case study approach might be used as a model for other territorially oriented case study projects.
- **Transport network data.** The different accessibility models, even at the European level, worked with partly different transport network data which are not easily to obtain and to maintain. In consequence, harmonised databases should be developed based on user needs assessment for accessibility modelling in Europe. In this framework, it has to be assessed how public transport networks can be more easily integrated based on up-to-date sources.

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1 Objectives

Accessibility is the main 'product' of a transport system. It determines the locational advantage of an area (i.e. in ESPON a region, a city or a corridor) relative to all areas (including itself). Indicators of accessibility measure the benefits households and firms in an area enjoy from the existence and use of the transport infrastructure relevant for their area.

The important role of transport infrastructure (i.e. networks and transport services) for spatial development in its most simplified form implies that areas with better access to the locations of input materials and markets will, *ceteris paribus*, be more productive, more competitive and hence more successful than more remote and isolated areas.

However, the impact of transport infrastructure on spatial development has been difficult to verify empirically. There seems to be a clear positive correlation between transport infrastructure endowment or the location in interregional networks and the *levels* of economic indicators such as GDP per capita. However, in most countries this correlation may merely reflect historical agglomeration processes rather than causal relationships effective today.

Attempts to explain *changes* in economic indicators, i.e. economic growth and decline, by transport investment have been much less successful.

The reason for this failure may be that in countries with an already highly developed transport infrastructure further transport network improvements bring only marginal benefits. A different situation can be observed in some regions of the new EU member states where the lack of modern infrastructure (motorways, high-speed trains) is still a major barrier to economic development and where the rapid increase of freight flows by road on the main transport corridors between western and eastern Europe was not followed by new road, rail or multimodal transport investment.

While there is uncertainty about the magnitude of the impact of transport infrastructure on spatial development, there is even less agreement on its direction. It is debated whether transport infrastructure improvements contribute to spatial polarisation or decentralisation. From a theoretical point of view, both effects can occur. A new motorway or high-speed rail connection between a peripheral and a central region makes it easier for producers in the peripheral region to market their products in the large cities, however, it may also expose the region to the competition of more advanced products from the centre and so endanger formerly secure regional monopolies.

These developments have to be seen in the light of changes in the field of transport and communications which will fundamentally change the way transport infrastructure influences spatial development. Several trends combine to reinforce the tendency to diminish the importance of transport infrastructure for regional development:

- An increased proportion of international freight comprises high-value goods for which transport cost is much less than for low-value bulk products. For modern industries the *quality* of transport services has replaced transport *cost* as the most important factor.
- Transport infrastructure improvements which reduce the variability of travel times, increase travel speeds or allow flexibility in scheduling are becoming more important for improving the competitiveness of service and manufacturing industries and are therefore valued more highly in locational decisions than changes resulting only in cost reductions.
- Telecommunications have reduced the need for some freight transports and person trips but they also increase the demand for transport by their ability to create new markets.
- With the shift from heavy-industry manufacturing to high-tech industries and services other less tangible location factors have come to the fore and have at least partly displaced traditional ones. These new location factors include factors related to leisure, culture, image and environ-

ment, i.e. quality of life, and factors related to access to information and specialised high-level services and the institutional and political environment.

On the other hand, there are also tendencies that increase the importance of transport infrastructure:

- The introduction of totally new, superior levels of transport such as the high-speed rail system create new locational advantages, but also disadvantages for regions not served by the new networks.
- Another factor adding to the importance of transport is the general increase in the volume of goods movements (due to changes in logistics such as just-in-time delivery) and travel (due to growing affluence and leisure time).
- In the future rising energy prices and the need to reduce greenhouse gas emission of transport may increase the importance of transport cost for regional development.

Both above tendencies are being accelerated by the increasing integration of national economies within the European Union and by the continuing globalisation of the world economy.

Key policy questions

In this situation the TRACC project has addressed the following key policy question from a European point of view:

- What are the differences between accessibility at three different levels (global, European and regional) considering the four modes road, rail, water and air?
- What is the link between accessibility at the different levels and for different modes of European regions and their economic development? How has this link changed over time? Does the strength of this link differ across the EU?
- What could be the territorial impact of rising energy prices on the future developments of road, rail, water and air transport?
- What could be the impact of various transport scenarios on climate change, access patterns and economic development?

In addition the project has looked into the regional dimension of accessibility often neglected in previous studies of accessibility:

- How does accessibility/connectivity look like at the regional level? For example, how many jobs/people can be reached in 45 minutes travel time (by road or by train), how many city centres can be reached by flying out in the morning and returning in the evening?
- In which type of regions is the level of European accessibility very different from their regional accessibility?

From a research point of view, the following key research questions have been addressed:

- What is the accessibility of European regions for travel by different modes (road, rail, air) at the European level?
- What is the accessibility of European regions for air travel at the global level?
- What is the potential of intermodal travel, in particular the combination of high-speed rail and air?
- What would be the impacts of different policies to make rail more competitive on the modal share of travel and travel accessibility?

- What would be the impacts of different policies to make rail and water more competitive on the modal share of freight transport and freight accessibility?
- What are the most favoured urban centres and most disadvantaged regions with respect to travel accessibility (island, mountain areas)?

Project objectives

From these key policy and research questions the main objectives of the project have been derived:

- to take up and update the results of existing studies on accessibility at the European scale using most recent available network and socio-economic data,
- to extend the range of accessibility indicators by further indicators responding to new policy questions and further developing the quality and validity of the existing indicators,
- to extend the spatial resolution of accessibility indicators by calculating, besides European accessibility, also global and regional accessibility,
- to explore the likely impacts of available policies at the European and national scale to improve global, European and regional accessibility in the light of new challenges, such as globalisation, energy scarcity and climate change.

Geographical coverage of all analyses is according to the project specification NUTS-3 or equivalent regions in all countries participating in the ESPON 2013 Programme plus ideally the EU candidate countries Croatia, FYR Macedonia and Turkey and the other countries of the Western Balkans Bosnia and Herzegovina, Serbia, Montenegro, Albania and Kosovo.

When calculating accessibility indicators transport connections to destinations outside the study area have been usually included. When calculating European accessibility, also links to destinations in neighbouring countries, such as Belarus, Moldova, Russia and Ukraine, have been considered, and when calculating global accessibility, links to destinations in all world regions.

2 Political context

The European transport system serves key roles in the transportation of people and goods in a local, regional, national, European and international context. At the same time, it is essential to Europe's prosperity and closely linked to economic growth and quality of life. The grand challenge for transport is to make growth and sustainability compatible, by decoupling environmental impacts from economic growth, while assuring the competitiveness and innovative character of the European transport industry. Economic crisis, increasing scarcity of non-renewable energy sources, aging, migration and internal mobility, urbanisation, and globalisation of the economy are among the other challenges to be faced by Transport policy.

The Common Transport Policy

The Common Transport Policy (CTP) is an essential component of the EU policy since the Maastricht Treaty of 1992, when the concept of Trans-European transport Networks (TEN) was introduced for the first time, with a special emphasis on interconnection and interoperability of the diverse national networks. The main policy instruments of the CTP are the White Paper on Transport and the TEN-T programme. The TEN-T programme is intended to increase the co-ordination in the planning of infrastructure projects by the member states. Progress in the TEN-T implementation has been relatively slow due to the scale, complexity and cost of the proposed projects in the past. A new proposal of TEN-T guidelines was presented in October 2011 and agreed upon in December 2013, intended to focus the efforts of the program on key network elements of European relevance. The White Paper on Transport is the document of strategic reflection providing the conceptual framework for the CTP, having had substantial influence on EU, national and regional policies since 1992 (e.g. liberalisation of transport markets and modal change from road to rail). The 2009 EC Communication on the Future of Transport triggered the debate for the 2011 White Book revision, proposing that focus should now turn on improving efficiency of the transport system through co-modality, technology development, and prioritise infrastructure investment on links with highest returns. The new transport White Paper was presented in late March 2011.

According to the 2011 Transport White Paper, one of the major challenges in the field of transport is to break the system's dependence on oil without sacrificing its efficiency and compromising mobility, in line with the flagship initiative "Resource efficient Europe" set up in the EU2020 Strategy and the new Energy Efficiency Plan 2011. Curbing mobility is not an option. The EU and Governments need to provide clarity on the future policy frameworks (relying to the greatest extent possible on market based mechanisms) for manufacturers and industry so that they are able to plan investments.

The concept of co-modality introduced by the White Paper back in 2006 implies that greater numbers of travellers are carried jointly to their destination by the most efficient (combination of) modes. Individual transport is preferably used for the final miles of the journey and performed with clean vehicles. In the intermediate distances, new technologies are less mature and modal choices are fewer than in the city. However, this is where EU action can have the most immediate impact. Better modal choices will result from greater integration of the modal networks: airports, ports, railway, metro and bus stations, should increasingly be linked and transformed into multi-modal connection platforms for passengers.

The EU-wide multi-modal TEN-T 'core network' defined by the new TEN-T guidelines of December 2013 should be fully functional by 2030. The core network must ensure efficient multi-modal links between the EU capitals and other main cities, ports, airports and key land border crossing, as well as other main economic centres. It should focus on the completion of missing links – mainly cross-border sections and bottlenecks/bypasses – on the upgrading of existing infrastructure. Better rail/airport connections must be devised for long distance travel. By 2030, the length of the existing high-speed rail network should be tripled, and a dense railway network in all Mem-

ber States should be maintained. By 2050, a European high-speed rail network should be completed. By 2050, the majority of medium-distance passenger transport should go by rail and all core network airports should become connected to the rail network, preferably high-speed. The quality, accessibility and reliability of transport services is increasingly important, requiring attractive frequencies, comfort, easy access, reliability of services, and inter-modal integration.

The cost of EU infrastructure development to match the demand for transport has been estimated € 1.5 trillion for 2010-2030. The completion of the TEN-T network requires about € 550 billion until 2020 out of which some € 215 billion can be referred to the removal of the main bottlenecks. This does not include investment in vehicles as well as guidance and information systems.

Other key elements in relation to passenger transport are according to the transport White Paper improved energy efficiency performance of vehicles across all modes and more efficient use of transport and infrastructure through improved traffic management and information systems. The gradual phasing out of 'conventionally-fuelled' vehicles is a major contribution to significant reduction of oil dependence, greenhouse gas emissions and local air and noise pollution. The use of smaller, lighter and more specialised road passenger vehicles must be encouraged. By 2030, the use of 'conventionally-fuelled' cars in urban transport should be halved, and by almost eliminated in cities by 2050. Low-carbon sustainable fuels in aviation would have to reach 40% by 2050; at the same time it should be reduced EU CO₂ emissions from maritime bunker fuels by 40% (if feasible 50%). Road pricing and the removal of distortions in taxation can also assist in encouraging the use of public transport and the gradual introduction of alternative propulsion.

According to the CTP Evaluation report (EC 2009), substantial progress has been made in the last 20 years towards meeting the objectives of the CTP of creation of a competitive internal market for transport services by liberalising the transport market. Market opening has been very successful in the air sector and there would be signs that market opening in the rail sector is starting to bring success. In all sectors, further reforms are required in order to fully implement liberalisation. Whilst there has been progress towards the objective of introducing a system of transport infrastructure pricing and taxation which better reflects marginal costs, and most of the specific measures proposed in the 2001 White Paper have been implemented, overall progress towards meeting this objective has been limited, largely because most decisions about pricing and taxation are still taken by Member States, and in some cases face strong public opposition.

In order to ensure that the limited TEN-T funds are used most efficiently to address infrastructure bottlenecks, decision-making about the allocation of funding should tend to be, according to the same source, increasingly based on cost benefit analysis of different schemes, using consistent criteria and parameters, not favouring specific modes of transport. The different environmental and other social costs of different modes should be taken into account in this cost benefit analysis. In fact, the EC provides unified criteria for project appraisals, as embodied in the regulations of the Structural Funds, the Cohesion Fund, and Instrument for Pre-Accession Assistance, through its Cost-Benefit guidelines . However many methodological issues remain unsolved (e.g. appraisal of the so called intangible effects, both positive and negative) and even worse, the very paradigms of e.g. time savings in cost-benefit analysis are still being debated intensely.

But emphases on different type of policy aims and instruments may change over time, also in the CTP. The Commission has identified seven transport policy areas in which specific policy measures could have a key role in stimulating the expected shift of the transport system to another paradigm. These policy areas are: pricing, taxation, research and innovation, efficiency standards and flanking measures, internal market, infrastructure and transport planning. Only a long-term and overarching strategy established for all identified policy areas has a reasonable chance of achieving the EU objectives. It should combine policy initiatives targeted at enhancing the efficiency of the system through better organisation, infrastructure and pricing with those that are more focused on technology development and deployment. It should also provide a framework for action at all levels of government.

Transport investment in Europe over time and over space

The total investment in infrastructure in Europe between 1995 and 2010 has been on average between 0.9% and 1.2% of total European GDP. The level of investment in Western European Countries has been substantially lower than in the Eastern European countries, but overall level are well above mean values in other regions of the World such as North America.

About 1/3 of all invested funds in transport were merely spent on infrastructure maintenance, and only about 60% were specifically dedicated to providing new infrastructure. The funding of new infrastructure proceeded mostly from National budgets of Member States (almost 90%), and only 5% of total expenditure was assumed by European funds (Cohesion Fund and ERDF) despite the fact that 50% of total investment was devoted to new infrastructure in TEN-T networks.

The analysis per mode reveals that around 60% of total investment has been devoted to Road mode, 20% to Rail and 10% equally split between Air and Water modes (including maintenance). However, almost half of the investment on TEN-T was devoted over the last 10 years to rail, and around 35% to road. This was especially important in Western European countries, where the development of High Speed Rail networks required large investments (around € 20 million per kilometre of HSR, against € 5 million per kilometre for motorways, on average). In Eastern European countries, investment on roads was still dominant.

Transport and Territorial Cohesion

A central element of the Community Strategic Guidelines on Cohesion 2007-2013 (2005) is the assumption that transport infrastructure and accessibility are necessary conditions for economic growth in the Union, having a direct impact on the attractiveness of regions for businesses and people. This is supported by the Reports on economic and social cohesion (2007, 2010), which reiterate how improved accessibility tends to create new job opportunities for rural and urban areas, but warns that potentialities from improving accessibility depend on the previous competitiveness of the regions concerned, being some regions liable to lose out as they become more open to competition from elsewhere. The reports claim the importance of combining investment in transport infrastructure with support for businesses and human capital development to achieve sustainable economic and social development. The Territorial Agenda of the EU (2007) claims the need to support to the extension of the TEN-T for economic development in all regions of the EU, especially in the EU12 countries, while the Green Paper on Territorial Cohesion (2008) later puts the accent on regional and local accessibility as key elements for granting balanced access to services and European transport terminals and networks.

The two dominant themes of spatial planning in Europe, as reflected already in the Europe 2000 study programme, are the urban and regional dichotomy, and the centre and periphery dichotomy. The “integration” between urban-rural, as well as between centre-periphery has always been the European narrative to overcome territorial unbalances. The necessary links to integrated urban and rural zones were included into the wider concept of “partnership”, later on by the ESDP. On the other hand, solving “missing links” in the networks of transport and communication was an important issue in the definition of the Trans-European Transport Networks, and the creation of “integration zones”, “polycentric and cross-border development areas”, between central and more peripheral regions.

The European Spatial Development Perspective (ESDP) of 1999 (European Commission, 1999) lists the trans-European transport networks as major policy field of importance for European spatial development, only second to EU economic policy, because of their effect on both the functioning of the Single Market and economic and social cohesion. In line with its spatial vision of polycentric and balanced system of metropolitan regions, city clusters and city networks, the ESDP called for improvement of the links between international/national and regional/local networks and strengthening secondary transport networks and their links with TENs, including efficient regional

public transport systems, improvement of transport links of peripheral and ultra-peripheral regions, both within the EU and with their neighbouring third countries and promoting the interconnection of inter-modal junctions for freight transport, in particular on the European corridors.

Following the European Spatial Development Programme (ESDP), the Study Program on European Spatial Planning (SPESP), carried out a number of specific researches territorial structures and typologies, and the opposition between urban and rural areas. Urban-rural partnerships as defined by the ESDP required among others, a balanced settlement structure and improvement of accessibility (concerning land use and development of public transportation networks). Improved infrastructure and accessibility bring new kinds of rural-urban linkages.

The first Territorial Agenda of the European Union: Towards a More Competitive and Sustainable Europe of Diverse Regions of 2007 (European Commission, 2007) took up the vision of polycentric territorial development of the EU of the ESDP, highlighted the territorial dimension of cohesion and emphasised the importance of integrated and sustainable multi-modal transport systems but failed to set priorities.

The new Territorial Agenda of the European Union 2020: Towards an Inclusive, Smart and Sustainable Europe of Diverse Regions of 2011 (European Commission, 2011d) puts spatial development into the framework of the Europe 2020 Strategy and the 5th Cohesion Report and takes up the proposals of the ESDP for inter-modal transport solutions, further development of the trans-European networks between main European centres and improvement of linkages between primary and secondary systems and accessibility of urban centres in peripheries.

The Europe 2020, the growth strategy of the EU for the coming decade, aims at five targets in the fields of employment, research and development, greenhouse gases, renewable energy, energy efficiency, education and social inclusion. European Commission, 2010). The Commission emphasises that essential elements of the transport policy are better integration of transport networks, promoting clean technologies, and upgrading infrastructure. Among the obstacles to be overcome, insufficiently interconnected networks are listed. Transport is listed among the policy tools to be applied only in very general terms as "smart transport and energy infrastructure".

A further example of the current debate on cohesion aspects is the changes in the understanding of the "urban-rural narrative" as put forward through the Spanish Presidency (2010) Its contribution highlights the need for a thorough investigation of urban-rural relationships and spatial trends in conceptualizing the new pattern of spatial relations, becoming visible through increased flows and implying analysis beyond core and periphery paradigms. New territorial paradigms emerge today thanks to ICTs and to faster and cheaper transport, increased accessibility and connectivity. These changes result on severe reductions of distance or cost to reach core areas of Europe from the peripheries ("cost of being peripheral") and making remote places more accessible when well connected to the networks. Even when distance still matters, impacts on spatial development become today more complex, ubiquitous centres and peripheries can suddenly emerge almost anywhere, even in remote rural areas, and the challenge is to face increasing development opportunities but also to manage exposure to threats.

3 Conceptual framework

The TRACC conceptual framework is based on a systematic and comprehensive theoretical consideration of the major dimensions of accessibility, the most frequently types of accessibility indicators and important extension of these.

Accessibility dimensions

Accessibility indicators may be sensitive to the following dimensions: origins, destinations, impedance, constraints, barriers, type of transport, modes, spatial scale, equity and dynamics. These dimensions are summarised in Table 3.1.

Table 3.1. Dimensions of accessibility

Dimension	Comments
Origins	Accessibility indicators may be calculated from the point of view of different population groups such as social or age groups, different occupations such as business travellers or tourists or different economic actors such as industries or firms.
Destinations	Accessibility indicators may measure the location of an area with respect to opportunities, activities and assets such as population, economic activities, universities or tourist attractions. The activity function may be rectangular (all activities beyond a certain size), linear (of size) or non-linear (to express agglomeration effects).
Impedance	The spatial impedance term may be a function of one or more attributes of the links between areas such as distance (Euclidean or network distance), travel time, travel cost, convenience, reliability or safety. The impedance function applied may be linear (mean impedance), rectangular (all destinations within a given impedance) or non-linear (e.g. negative exponential).
Constraints	The use of the links between areas may be constrained by regulations (speed limits, access restrictions for certain vehicle types or maximum driving hours) or by capacity constraints (road gradients or congestion).
Barriers	In addition to spatial impedance also non-spatial, e.g. political, economic, legal, cultural or linguistic barriers between areas may be considered. In addition, non-spatial linkages between areas such as complementary industrial composition may be considered.
Types of transport	Only travel or only freight transport, or both, may be considered in the analysis.
Modes	Accessibility indicators may be calculated for road, rail, inland waterways or air. Multimodal accessibility indicators combine several modal accessibility indicators. Intermodal accessibility indicators include trips by more than one mode.
Spatial scale	Accessibility indicators at the continental, transnational or regional scale may require data of different spatial resolution both with respect to area size and network representation, intra-area access and intra-node terminal and transfer time.
Equity	Accessibility indicators may be calculated for specific groups of areas in order to identify inequalities in accessibility between rich and poor, central and peripheral, urban and rural, nodal and interstitial areas.
Dynamics	Accessibility indicators may be calculated for different points in time in order to show changes in accessibility induced by TEN projects or other transport policies, including their impacts on convergence or divergence in accessibility between areas.

Generic accessibility indicators

In this section a classification of accessibility indicators is proposed that encompasses a great variety of possible indicators in three generic types.

In general terms, accessibility is a construct of two functions, one representing the activities or opportunities to be reached and one representing the effort, time, distance or cost needed to reach them:

$$A_i = \sum_j g(W_j) f(c_{ij})$$

where A_i is the accessibility of area i , W_j is the activity W to be reached in area j , and c_{ij} is the generalised cost of reaching area j from area i . The functions $g(W_j)$ and $f(c_{ij})$ are called *activity functions* and *impedance functions*, respectively. They are associated multiplicatively, i.e. are weights to each other. That is, both are necessary elements of accessibility. A_i is the total of the activities reachable in areas j weighted by the ease of getting from i to j . It is easily seen that this is a general form of potential, a concept dating back to Newton's Law of Gravitation. According to the Law of Gravitation, the attraction of a distant body is equal to its mass divided by its squared distance. The gravity model of regional science is somewhat more general, it states that the attraction of a distant location is proportional to its size (e.g. population) weighted by a decreasing function of its distance.

In the context of accessibility, the 'size' are the activities or opportunities in areas j (including area i itself), and the 'distance' is the spatial impedance c_{ij} . The interpretation here is that the greater the number of attractive destinations in areas j is and the more accessible areas j are from area i , the greater is the accessibility of area i . This definition of accessibility is referred to as destination-oriented accessibility. In a similar way an origin-oriented accessibility can be defined: The more people live in areas j and the easier they can visit area i , the greater is the accessibility of area i . Because of the symmetry of most transport connections, destination-oriented and origin-oriented accessibility tend to be highly correlated.

However, the generic equation of accessibility above is more general than the gravity model. Different types of accessibility indicators can be generated by specifying different forms of functions $g(W_j)$ and $f(c_{ij})$. Table 3.2 shows the most frequent specifications of $g(W_j)$ and $f(c_{ij})$ for the three most frequent types of accessibility indicator, where W_{\min} and c_{\max} are constants and α and β parameters:

Table 3.2. Accessibility indicators

Type of accessibility	Activity function $g(W_j)$	Impedance function $f(c_{ij})$
<i>Travel cost</i> Travel cost to a set of activities	$W_j \mid 1$ if $W_j \geq W_{\min}$ 0 if $W_j < W_{\min}$	c_{ij}
<i>Cumulated opportunities</i> Activities in a given travel time	W_j	1 if $c_{ij} \leq c_{\max}$ 0 if $c_{ij} > c_{\max}$
<i>Potential</i> Activities weighted by a function of travel cost	W_j^α	$\exp(-\beta c_{ij})$

- *Travel cost*. If only destinations of a certain kind, e.g. cities beyond a certain size, are considered (the activity function is rectangular), and the impedance function is travel time or travel cost itself (i.e. the impedance function is linear), the accessibility indicator is total or average travel cost to a predefined set of destinations.
- *Cumulated opportunities*. If only destinations within a certain travel time are considered (the impedance function is rectangular), and the destinations are taken as is (the activity function is linear), the accessibility indicator measures the number of potential destinations (customers, business contacts, tourist attractions, etc.) that can be reached in a given time, e.g. a day.
- *Potential*. If the impedance function takes travel behaviour into account, i.e. the diminishing inclination to travel long distances (the impedance function is nonlinear, e.g. exponential), the accessibility indicator is a potential indicator. The activity function may take account of agglomeration effects or economies of scale (i.e. may be nonlinear, e.g. a power function).

There is a large number of extensions of the above generic accessibility indicators. Four of them have been addressed in this project:

- *Multimodal accessibility*. All three generic types of accessibility indicator can be calculated for any mode. At a European scale, accessibility indicators for road, rail and air are most frequently calculated. Modal accessibility indicators may be integrated into one indicator expressing the combined effect of alternative modes for a location. There are essentially two ways of integration. One is to select the fastest mode to each destination and to ignore the remaining slower modes. Another way is to calculate an aggregate accessibility measure combining the information contained in the modal accessibility indicators by replacing the generalised cost c_{ij} by the 'composite' generalised cost

$$\bar{c}_{ij} = -\frac{1}{\lambda} \ln \sum_m \exp(-\lambda c_{ijm})$$

where c_{ijm} is the generalised cost of travel by mode m between i and j and λ is a parameter indicating the sensitivity of travellers to travel cost. This formulation of composite travel cost is superior to average travel cost because it makes sure that the removal of a mode with higher cost (i.e. closure of a rail line) does not result in a – false – reduction in aggregate travel cost. This way of aggregating travel costs across modes is theoretically consistent only for potential accessibility. No consistent ways of calculating multimodal accessibility indicators for travel cost and cumulated opportunities exist.

- *Intermodal accessibility*. A further refinement is to calculate *intermodal* accessibility. Intermodal accessibility indicators take account of trips involving two or more modes. Intermodal accessibility indicators are most relevant for logistic chains in freight traffic such as rail freight with feeder transport by lorry at either end. Intermodal accessibility indicators in passenger travel involve mode combinations such as Rail-and-Fly or car rentals at railway stations and airports.
- *Regional accessibility*. Most accessibility studies concentrated on the accessibility of cities, i.e. network nodes which are assumed to represent the whole area or even a larger region. This presents two problems: (i) Accessibility indicators calculated for network nodes ignore that accessibility is continuous in space. The decline of accessibility from the central node (centroid) of a region to smaller towns and less urbanised parts of the region is not considered. (ii) The quality of the interconnections between the high-speed interregional and the low-speed local transport networks cannot be taken into account. Yet the ease of getting from home or office to the nearest station of the high-speed rail network or the nearest airport may be more important for the accessibility of a location than the speed of the long-distance connection from there.
- *Global accessibility*. Only a few accessibility studies have so far addressed issues of global accessibility. It has been part of the research of the TRACC project to propose and calculate meaningful accessibility indicators for global accessibility.

Research concept

The TRACC project is based on and extends the state of the art of accessibility analysis presented in the previous sections:

- It takes up and updates the results of existing studies on accessibility at the European scale using most recent available network and socio-economic data.
- It extends the range of accessibility indicators by further indicators responding to new policy questions and further developing the quality and validity of the existing indicators.
- It extends the spatial resolution of accessibility indicators by calculating accessibility indicators for both the global and the regional scale.
- It explores the likely impacts of available policies at the European and national scale to improve global, European and regional accessibility in the light of new challenges, such as globalisation, energy scarcity and climate change.

To achieve this, the research in the project was divided into seven Tasks.

- *Task 1: Methodology/indicators.* The objective of the first Task is to review the existing methods and indicators for different types of transport, transport modes and spatial scales, to improve the methods to measure European accessibility by calculating other indicators than potential accessibility and to extend them by calculating not only European travel accessibility as done so far in ESPON but also freight accessibility and global and regional accessibility. Based on this review, this Task is to define the methodology of the project, in particular to define a set of accessibility indicators for the ESPON Programme for all spatial levels considered, which has been implemented in the subsequent Tasks.
- *Task 2: Network and socio-economic data.* The objective of this Task is to provide an assessment of network and socio-economic data including an assessment of data availability in the EU candidate countries and Western Balkan and to provide network and socio-economic datasets customised for all accessibility and impact modelling in the project at all scales addressed based on a comprehensive overview and assessment of available network and socio-economic databases.
- *Task 3: European accessibility: travel.* The objective of Task 3 is to calculate a unique set of standard and new travel accessibility indicators. Those indicators are to address European as well as global accessibility for the regions of the ESPON space and the Western Balkan. Some basic accessibility travel indicators are to show the development of accessibility patterns in Europe for the last decade and for possible future situations. The accessibility patterns are to be transformed into European and global accessibility typologies. The results are to be presented in maps of the ESPON territory and the Western Balkan showing the spatial distribution of the different travel accessibility indicators by road, rail, air and combinations of these modes at the global and European level.
- *Task 4: European accessibility: freight transport.* The objective of this Task is to calculate a set of freight accessibility indicators for European as well as global accessibility for the regions of the ESPON space and the Western Balkan. The accessibility patterns are to be transformed into European and global accessibility typologies. The results are presented in maps of the ESPON territory showing the spatial distribution of the different freight accessibility indicators computed for various modes and with reference to the different types of accessibility.
- *Task 5: Regional accessibility.* The objective of this Task is to measure and analyse accessibility at the regional scale in Europe. This is to be done by two different approaches. On the one hand, a set of regional case studies encompassing different types of regions in Europe are to provide in-depth insight into regional accessibility indicators with as much as possible harmonised approaches across the different case studies. On the other hand, accessibility indicators

are to be calculated that show accessibility to regional destinations, but are covering the whole ESPON space and the Western Balkan on a raster base. Finally, regional accessibility results and European accessibility results are to be compared to gain insight into the relationship of regional and European accessibility.

- *Task 6: Impacts of accessibility.* The objectives of this task are to analyse the relationship between different types of accessibility and regional economic development and the environment (energy consumption and greenhouse gas emissions) and to forecast the development of accessibility and GDP per capita, employment and population and energy consumption and greenhouse gas emissions of transport subject to a set of long-term scenarios of European transport policies and assumptions about future developments in vehicle technology and alternative fuels and fuel price increases. In addition the results are to be analysed by different cohesion indicators expressing the impacts of the policies modelled on the convergence (or divergence) of accessibility and socio-economic development in the regions of the ESPON space and the Western Balkan.
- *Task 7: Policy implications.* This Task is to summarise the findings of the project in relation to the goals of the European Union competitiveness, territorial cohesion and environmental sustainability for different types of regions and to evaluate the policy instruments available to the European Union and its member states to maintain and improve the different types of regional accessibility in order to draw as much benefit for regional development from accessibility with the smallest possible negative implications for territorial cohesion and the environment and to formulate policy conclusions which can stimulate and enlighten the ongoing political discourse on transport and accessibility policy for decision makers, experts and the wider public.

With this research concept the project started from the standard accessibility indicators developed in ESPON 1.2.1, 1.1.1, 2.1.1 and 1.1.3 and the recent Accessibility Updates and extended these to first freight accessibility and global accessibility and then to the regional/local level of intraregional accessibility in regional case studies and eventually looked at impacts of accessibility changes. By exploring several alternative ways of calculating regional/local accessibility indicators and comparing them with European accessibility indicators, the added value of more detailed accessibility indicators have been assessed.

The results of the project presented in the different volumes of the TRACC Final Report are:

- a consistent set of European network and regional socio-economic data,
- an analysis and a database of various European and global accessibility indicators at NUTS-3 level for travel and freight accessibility by different modes,
- case studies of regional accessibility in different types of regions and exploratory research on Europe-wide regional accessibility,
- evidence on the relationship between accessibility and regional development (GDP per capita, energy consumption and greenhouse gas emissions by transport),
- policy-relevant findings, policy conclusions and suggestions for further research.

4 Review of accessibility studies

This chapter contains a summary of a comprehensive review of accessibility studies done in Europe (see TRACC Final Report Volume 2, Chapter 4, for the detailed review). The review was done in the first phases of the TRACC project. A focus of the review was on studies published during the last decade. The review has been organised in three main parts which address different spatial contexts of accessibility, i.e. global, European and regional followed by a fourth part on accessibility impacts.

Global accessibility studies

The understanding of global accessibility studies in this report is that studies are included that analyse the accessibility of Europe and its regions to the world. Only a few accessibility studies are addressing global accessibility. However, all generic types of accessibility indicators were represented. The indicators, however, were in most cases calculated for an airport or an airport city, consequently, air transport was the only transport mode. Only one study calculated global accessibility for a set of regions by incorporating the access time from the regions to the airports into an overall intermodal travel time. Most studies considered travel, but air freight was addressed in one study. In the freight study, not only travel time, but also other criteria such as quality of service and tariffs were included in the accessibility indicator.

With respect to accessibility patterns, spatial disparities and its changing patterns over time, the studies looking at global accessibility by using airports as origins and either indicators of the travel cost or cumulated opportunities type came to the result of a strong hierarchy of airport cities in Europe. The study looking at global accessibility for a set of regions by using a potential accessibility indicator stated much less disparities in Europe. This might be traced back to the fact that the different access times from the regions to the airports play a much lower role for the accessibility value, because the higher proportion of the total travel times consists of airport terminal times and the travel times of long-distance flights.

In conclusion, there are only a few global accessibility models available, which are mostly concerned with the different intercontinental accessibility provided by airports, i.e. points in space, and not by the way how this translates into the global accessibility of regions. This is considered by one study only, however, its regional system is mainly confined to one European macro region. A systematic evaluation of the global accessibility of European regions is lacking so far.

European accessibility studies

Over the last decades a vast number of accessibility studies addressing Europe-wide accessibility have been published. The European accessibility models reviewed yield a wide range of approaches with respect to various dimensions of accessibility. They differ in many respect, but there are also some commonalities:

- More than half of the models use potential type indicators, the remaining models use travel costs or cumulated opportunities indicators. A few models calculate several types of indicator.
- The origins for which accessibility indicators are calculated are usually NUTS-2 or NUTS-3 centroids, very few studies have a more detailed representation of space.
- The destination activities are usually population or GDP for potential type accessibility indicators and a pre-defined set of agglomerations for the travel cost indicators. For daily accessibility indicators both population and public facilities, such as airports, high-speed train stations, universities or hospitals are used as destinations.
- Nearly all models use travel time as impedance term, only few models apply travel costs or a combinations of both as generalised cost.

- Only few models consider constraints on the impedance term. Models that consider freight transport use statutory drivers' rest breaks as constraints.
- Only few accessibility models consider barriers, such as waiting times at national borders. Only one model uses trade barriers, such as tolls.
- Nearly all accessibility models are based on passenger travel, only few models consider freight.
- Half of the models consider one mode only, in most cases road. The other models have networks for different modes, however, only two use intermodal travel times.

With respect to spatial disparity and its changing patterns over time, all European accessibility studies expose the existing core-periphery pattern of accessibility in Europe and all indicate that over time the gap in accessibility between core and peripheral regions has increased. A distinction can be made between potential and cumulated opportunities types of indicators. Whereas potential accessibility has improved in the former cohesion countries in southern Europe and increasingly also in the new member states in central and eastern Europe, cumulated opportunities, in particular where business trips are concerned, have increased mainly in central regions with good air connections. Another important distinction can be made between whether changes in accessibility are measured in relative or in absolute terms. Whereas in relative terms (e.g. in percent) accessibility has improved more in the peripheral regions, in absolute terms accessibility in the core regions in western Europe has continued to grow more.

An overall assessment of European accessibility models is difficult. The general tendency is that none of the models is really able to serve all purposes:

- Most models focus on person travel and ignore freight transport although freight transport might be more relevant for peripheral regions. However, empirical work has shown that road accessibility by using car and trucks are highly correlated and that car accessibility can be used as a proxy for truck accessibility.
- Most models do only have an implicit relation to certain sectors of the economy, i.e. by concentrating on person travel the models are closely related to the service sector and neglect that transport has different relations with different sectors.
- Following that, the reality of the business environment in peripheral rural areas is hardly represented in the European accessibility models.
- Some models, those working with travel cost indicators, support the case for public investment in infrastructure by demonstrating increased cohesion. Other models, mainly of the potential type, are much more cautious or even forecast increased regional disparities as outcome of transport infrastructure investments.

To conclude, despite the vast range of models, there is currently no model presented in the literature that would match all requirements for the different dimensions. Models that are superior in a certain dimension are behind in others. There is no model available that would be able to calculate accessibility for a spatially detailed representation of pan-Europe for person travel and freight transport for all transport modes including multi- and intermodal trips for different indicator types and destination activities and that has a database that allows assessments for different points in time, i.e. past, current and future accessibility patterns.

Regional accessibility studies

The number and diversity of accessibility studies at the regional level in Europe is much larger than those of Europe-wide studies. Consequently, only a part of these studies can be included in this review. The focus of the subsequent presentation of regional accessibility studies in Europe is on studies from the last decade. First, studies will be presented in which the study area covers

more than one country, i.e. trans-national accessibility studies. The second subchapter presents studies which are either for whole countries, i.e. national accessibility studies, or are dealing with only parts of a country.

Trans-national accessibility studies

For several trans-national areas in Europe, accessibility studies evaluated the situation from a viewpoint that is below the Europe-wide, but above the national scale. The trans-national accessibility models reviewed yield a wide range of approaches to the various dimensions of accessibility. They differ in many respects, but there are also some commonalities:

- About half of the models use potential type indicators, the remaining models use travel costs or cumulated opportunity indicators. A few models are able to calculate more than one type of indicator.
- The origins for which accessibility indicators are calculated differ very much. The range is from NUTS-3 regions through municipalities down to a detailed representation of space in form of small raster cells.
- The destination activities are usually population for accessibility indicators of the potential type and a pre-defined set of agglomerations, cities or certain facilities, such as airports or hospitals, for the travel cost indicators. For cumulated opportunity indicators, population, cities or public facilities are used as destinations.
- Nearly all models use travel time as impedance term, only one model applies travel costs. Some models use airline or road distance.
- Only few models consider constraints on the impedance term in form of timetable restrictions for public transport.
- None of the trans-national accessibility models considers political, cultural or language barriers in the impedance term.
- Nearly all accessibility models are based on passenger travel, only few models consider freight.
- Half of the models consider one mode only, in most cases road. The other models have networks for different modes, however, only one model uses intermodal travel times.

With respect to the spatial pattern of accessibility observed, nearly all trans-national accessibility studies show large differences in accessibility for different parts of their study area. Regardless the type of indicator, spatial disparities are very much pronounced in those studies. However, it is also stated that the question of disparities in accessibility is a question of the destinations considered. That means that some trans-national areas show large disparities if Europe-wide accessibility is considered, but are much less polarised when destinations of regional interest are considered. In addition, when evaluating the access to public facilities, such as hospitals or regional centres, some of the studies conclude that the travel times are reasonable for most of the population and better than expected.

An overall assessment of trans-national accessibility models is difficult. The general tendency is similar to that of the European accessibility models in so far that none of the models is really able to serve all purposes. In addition, it is difficult to compare the results of the different trans-national accessibility models in more detail. The different ways of incorporating the dimensions of accessibility in the models, in particular the different destination activities considered, the different ways the impedance terms are calculated and the very large variety of spatial detail with respect to origins, destinations and network representation, do not allow to draw more detailed conclusions concerning spatial patterns in different types of regions than those stated above.

National and regional accessibility studies

The national and regional accessibility models reviewed yield also a wide range of approaches with respect to various dimensions of accessibility. They differ in many respect, but there are also some commonalities:

- Only one third of the national models and only every sixth of the regional model use potential type indicators, very few are calculating cumulative opportunities. The majority of the models use travel cost indicators mainly in the form of travel time to pre-selected destinations. A few models calculate more than one type of indicator.
- The origins for which accessibility indicators are calculated are in most accessibility models the centroids of municipalities. A few studies, mainly at the national scale, are less detailed in space. However, the main tendency of the last decade was a movement towards spatially more disaggregate accessibility models. This is done by using raster representations of space in which the cell size ranges from a few kilometres down to 100 m only in some regional applications.
- The destination activities are much more diverse than in the European or trans-national accessibility models. The potential type models work usually with population as destination activity, however, also accessibility to jobs is the subject of several studies. Many studies, in particular those working with travel cost type indicators, use urban and regional centres, network nodes and services of general interest as destination activities.
- With a few exceptions, all models use travel time as impedance term, the remaining models work with travel distance. None of the models at these scales use travel costs.
- Some of the models consider constraints on the impedance term. This is usually done when public transport is considered and represented with real timetable based travel times..
- None of the accessibility models considers barriers.
- Nearly all accessibility models are based on passenger travel, only two models at the national scale and none at the regional scale consider freight transport.
- Many of the models consider road transport only, in particular models at the national scale. Other models have networks for rail or for all means of public transport, a few include also walking and cycling. The use of intermodal travel times is a rare exception of the accessibility models at these scales.

Regarding spatial patterns it can be seen that most of the national and regional accessibility studies point to the existence of large disparities of accessibility in the areas considered. This is regardless the type of indicator used. On the other hand, when evaluating the access to public facilities such as hospitals or regional centres, some of the studies conclude that the travel times are reasonable for most of the population and better than expected.

An overall assessment of national and regional accessibility models is difficult. The general tendency is that none of the models is really able to serve all purposes. In national and regional studies of accessibility other origins and destinations become relevant than in European studies. If a balanced polycentric urban system is a goal of national spatial planning, accessibility of cities at the second or third level of the urban systems is of interest. Accessibility on the labour market is important from both viewpoints, i.e. from the firms' and from the workers'. More and more, the provision of minimum standards of services of general interest in urban, periurban or rural areas is becoming a problem of high political importance. This makes the analysis of accessibility of public facilities such as schools, food shops, doctors and pharmacies, important.

Nearly all national and regional studies have highlighted the sometimes large differences in accessibility in their study areas. However, the review has also shown that due to the great variety of the dimensions of accessibility, more detailed statements on overall regional patterns of acces-

sibility by type of regions cannot be derived from the literature. The conclusion is to develop a systematic and consistent set of accessibility indicators at the regional scale to be applied in TRACC to elaborate an accessibility typology for different types of regions.

Accessibility impacts

Accessibility is not a goal by itself but a derived demand. Accessibility is important because it provides access to opportunities at distant locations or makes it possible to receive goods and services or visitors from distant locations. For policy making, the maximisation of accessibility is therefore an objective only as far as it helps to improve the quality of life by facilitating access to opportunities, goods and services and so participation in social and cultural life.

A further section of the reviews (see TRACC Final Report Volume 2, Chapter 4.4) addresses the state of the art of measuring, explaining and forecasting the impacts of accessibility. It first identifies the types of impacts of interest of accessibility of political interest. It then summarises the theoretical concepts explaining the relationships between accessibility and the impacts of interest. Guided by this theoretical background it reviews available empirical evidence about these relationships and existing mathematical models to forecast them. The section closes by proposing hypotheses about the likely effects of transport policies on the most relevant accessibility impacts.

Types of impacts

The impacts of accessibility of political interest are scale-dependent. At the European or national level, the relevant impacts are *economic*, i.e. impacts on regional economic development and territorial cohesion. At the intraregional level, the most important impacts are *social*, i.e. effects on social inclusion or exclusion by access to services of general interest and participation in social and cultural life. *Environmental* impacts of accessibility are relevant at all levels, but they are indirect and inversely related to accessibility, as good accessibility gives rise to more movements of goods and persons over longer distances, and these movements generate negative environmental impacts, such as more energy consumption and greenhouse gas emissions.

Economic, social and environmental impacts of accessibility differ in how they are measured and forecast. Social impacts can be measured and forecast directly by appropriate accessibility indicators, such as travel time to the nearest urban centre, education facilities or health services. Economic impacts of accessibility can be measured directly, e.g. in terms of GDP per capita, but to forecast the economic impacts of accessibility requires a theory or model about the way changes in accessibility affect regional economic development. The calculation of environmental impacts of changes in accessibility requires a transport model forecasting the flows of trains, cars and lorries likely to result from transport infrastructure investments.

Regional economic models

There are three types of regional economic development models available: regional production function models, multiregional input-output models and spatial computable general equilibrium models.

The three types of model, regional production function models, multiregional input-output models and spatial computable general equilibrium models, have much in common with respect to underlying theory. All three are aggregate models at the meso scale of regions. All consider transport a production factor of great importance for regional economic development. There are no neoclassical models assuming perfect factor mobility in the set of models discussed here, as all of them model spatial impedance in the form of transport costs and other forms of barriers, though with different detail. Markets with imperfect competition, increasing returns to scale and bounded rationality under uncertainty by economic agents are addressed in models of all three groups, either

by the nonlinear specification of production factors in the extended production functions or by logit type utility functions in the multiregional input-output models or by the Dixit-Stiglitz model of monopolistic competition in the SCGE models.

However, there are also major differences.

- Multiregional input-output models and SCGE models explicitly model trade flows between regions based on product prices and transport costs and determine regional growth of industrial sectors from these flows. Production function models aggregate trade and travel flows into one complex variable, accessibility. Needless to say that the explicit modelling of purchases of firms from other regions based on comparison of product price, diversity and transport cost is superior to the econometric estimation of the aggregate impact of accessibility on regional economic development, in particular if not only trade volumes but also prices are endogenous as in SCGE and some multiregional input-output models.
- More problematic are obvious omissions in some of the models. If accessibility is expressed only as freight transport time for distance bands or only by interregional distance or km of roads in a region, such models are likely to underestimate the impact of network improvements, in particular of rail investments. Another model assumes that regional labour is constant and immobile and so fails to take account of the impacts of demographic change and interregional migration on regional labour markets. One model presently treats regional sector productivity as exogenous instead of modelling improvement in productivity through better accessibility. However, all these deficiencies can be easily overcome by relatively minor model modifications.
- Another relevant difference between the models is their treatment of dynamics. Multiregional input-output models and SCGE models assume that markets are in equilibrium, at the start and target year, at the end of each period or after a number of periods. The production function models, however, are all recursively dynamic with different types of adjustment delays. This seems also to affect the sensitivity of the models to transport cost changes.

Hypotheses

The combined results of empirical and modelling studies suggest that the present European transport policy may widen rather than narrow differences in accessibility between central and peripheral regions. Although the biggest absolute changes in accessibility are gained in some peripheral regions which start with very poor levels of provision, the relative gap between the best and the worst of the main centres increases.

This does not imply that the relative gains in accessibility of peripheral regions may not be beneficial to their economic development, however it must be pointed out that these gains will always be overshadowed by the much larger gains in accessibility of the regions in the European core. It is therefore not possible to refer to transport network improvements unambiguously as instruments to promote the cohesion between the regions in Europe and the reduction of interregional economic and social disparities. A European transport policy truly committed to that goal would have to shift significantly the focus of the trans-European networks investment programme to transport links within and between the peripheral regions, not in addition to, but at the expense of, transport investment in the European core.

Similarly, the results of the empirical and modelling studies suggest that transport policies that aim at improving accessibility do not automatically also improve sustainability. Even transport policies explicitly aimed at shifting transport to environmentally more sustainable models are not certain to achieve that goal due to the inherent nonlinear dynamics of transport and location.

5 TRACC accessibility and impact indicators

Based on the review of accessibility and impact indicators in the previous chapter, this chapter presents the TRACC set of accessibility and impact indicators implemented in the project.

Accessibility indicators

The review of accessibility studies ranging from a few studies addressing global accessibility down to a vast number of studies dealing with regional accessibility has shown the variety of indicators and approaches. Most frequently used are accessibility indicators of the basic type travel cost, particularly in studies at the regional or national scale. However, also the two other generic types of accessibility indicators, cumulated opportunities and potential accessibility, are used in several studies, the latter in particular in studies at the European scale and only rarely at the regional scale. The activities of interest at the destination are very often population, but also GDP, jobs, labour force, cities of different functions, different public and private services or institutions or freight terminals are used. The spatial resolution differs much. Whereas some European studies consider only a few points in space or are working at the NUTS-2 level, many studies work at the NUTS-3 level or are even based on a raster representation of Europe. Most studies at the regional scale work at the LAU-2 level, however, with the availability of high-resolution grid data, there is a tendency towards calculating accessibility at the regional scale for small raster cells. The level of network detail differs accordingly. Whereas a few studies use no network at all but airline distances, the other end of the spectrum is marked by studies working with full road networks and public transport timetables including real transfer times. Most accessibility studies deal with passenger travel, only very few are concerned with freight transport.

The review has shown that there is no single standard accessibility indicator serving all purposes. The conclusion for TRACC has been therefore to develop a systematic and consistent set of accessibility indicators which is derived from the conceptual framework as laid down in Chapter 3 and which matches the following requirements:

- As different types of accessibility indicators provide answers to different questions, the three generic types of accessibility indicators, i.e. travel cost, cumulated opportunities (daily accessibility) and potential accessibility should be used at all levels considered.
- The TRACC project is expected to analyse accessibility at very different spatial levels ranging from the global through the European to the regional level.
- The spatial coverage should be at least the ESPON space. Candidate countries and other countries of the Western Balkan should be included if possible. Regional case studies should cover different types of the regional typologies developed by ESPON.
- The spatial resolution should be appropriate. This is NUTS-3 for the Europe-wide indicators and LAU-2 for the regional case studies. In addition, raster representations of space should be explored to analyse to what extent a finer spatial resolution influences results.
- All relevant transport modes should be addressed, i.e. road, rail and public transport, air and water as well as combinations of modes as multimodal aggregation and intermodal trip chains.
- Traditional accessibility indicators should be amended by newer forms of accessibility. The traditional indicators should guarantee continuity with previous ESPON studies; in particular the potential accessibility indicator should be updated to a recent year.
- There should be accessibility indicators dealing with passenger travel and indicators dealing with freight transport.

Table 5.1 presents the resulting TRACC set of accessibility indicators. The indicator set is differentiated by the three main spatial contexts to be taken into account (global, European, regional),

and at each level further differentiated by travel and freight. For the European level, accessibility indicators for travel are further divided into traditional and newer ones. For the regional level, the indicators are differentiated into those regional indicators for both travel and freight that are calculated for the whole of Europe and those that are calculated in the regional case studies only. For the latter, a distinction is made between traditional indicators and indicators looking at the accessibility to selected services of general interest to reflect current policy debates on the subject of services of general interest. For all levels, each generic indicator type is represented by one indicator.

Global accessibility

The task of the global accessibility indicators is to describe the linkages of the regions to the world. As demonstrated previous analyses of global accessibility were in most cases restricted to travel time indicators for selected points in Europe, usually airports. The TRACC set of global accessibility indicators provides progress in three directions: (i) Besides travel also freight accessibility is included. (ii) Not only travel cost indicators are included but also accessibility indicators of the types cumulated opportunity and potential: (iii) The indicators are not restricted to preselected rare points in Europe, but are calculated for all NUTS-3 regions of the ESPON space.

There are three global accessibility indicators defined for travel, i.e. each generic type of accessibility indicators is represented:

- *Access to global cities.* What are the travel times from the European regions to selected global cities? New York serves as example for a non-European global city. For each NUTS-3 region the shortest total travel time is calculated including intermodal trips by road, rail and/or air to airports with intercontinental flights plus the flight time to this city.
- *Global travel connectivity.* How many intercontinental flights can be reached from the European regions within a maximum travel time of three hours? For each NUTS-3 region the shortest total intermodal travel times by road, rail and/or air to airports with intercontinental flight services is calculated. If an airport is within the maximum travel time, the intercontinental destinations served from that airport is added to the regional global connectivity value.
- *Global potential accessibility travel.* What is the relative position of the European regions towards global destinations? For each NUTS-3 region the shortest total intermodal travel times by road, rail and/or air to airports with intercontinental flight services is calculated. The intercontinental flights weighted by seat capacity are used as attraction, i.e. the mass term in the calculation of the potential accessibility.

Accordingly, there are three global accessibility indicators for freight transport following a similar approach as the indicators for travel:

- *Access to global freight hubs.* What are generalised travel costs for specific commodity groups from the European regions to selected global freight hubs? New York and Shanghai serve as examples for non-European global freight hubs. For each NUTS-3 region the lowest total generalised costs is calculated including intermodal trips by road, rail, water and/or air to seaports and airports with intercontinental services plus the generalised costs from there to the two freight hubs.
- *Global freight connectivity.* What amount of intercontinental container throughput of ports can be reached from the European regions within a mode-specific maximum freight transport time? For each NUTS-3 region the shortest total travel times by road, rail, water and/or air to seaports with intercontinental container services are calculated. If a seaport is within the maximum travel time, the intercontinental container throughput of that port is added to the regional global connectivity value for freight.

Table 5.1. TRACC set of accessibility indicators

Spatial context	Basic characteristics	Generic type of accessibility indicator		
		Travel cost	Cumulated opportunities	Potential
Global	Travel	Access to global cities Travel time (intermodal) to global city (New York)	Global travel connectivity Number of flights from European airports to intercontinental destinations reachable within three hours	Global potential accessibility travel Intermodal accessibility to intercontinental flights of European airports weighted by seat capacity as mass
	Freight	Access to global freight hubs Travel time/cost (intermodal) to major intercontinental terminals (New York, Shanghai)	Global freight connectivity Intercontinental container throughput of European sea ports reachable within maximum travel time	Global potential accessibility freight By road and rail to container throughput of European sea ports
Europe	Travel (traditional)	Access to top ten MEGAs Average fastest travel time to top group of MEGAs	European daily accessibility travel Daily accessibility to population by road, rail, fastest mode	European potential accessibility travel To population by road, rail, air, multimodal
	Travel (new)	Travel speed Average travel speed by road and rail	Urban connectivity Urban connectivity by road, rail, air, intermodal	European potential acc. intermodal travel To population intermodal
	Freight	Access to nearest maritime ports Generalised cost to nearest maritime port	European daily accessibility freight GDP accessible within allowed lorry driving time	European potential accessibility freight Accessibility potential to GDP by different modes
Regional	Travel (Europe-wide)	Access to high-level transport infrastructure Weighted access time to motorway exits, rail stations, airports	Availability of urban functions Cities > 50.000 within 60 minutes by road and rail	National potential accessibility travel To national population by road and rail
	Freight (Europe-wide)	Access to freight terminals Weighted access time to freight terminals	Availability of freight terminals Freight terminals within 2 h by lorry	National potential accessibility freight To national GDP by lorry
	Travel (case studies, traditional)	Access to regional centres Travel time to nearest regional centre by road and public transport/rail	Daily accessibility of jobs Jobs accessible within 60 minutes by road and public transport/rail	Regional potential accessibility To population by road and public transport/rail
	Travel (case studies, to services of general interest)	Access to health care facilities Travel time to nearest hospital	Availability of higher secondary schools Number of higher secondary schools within 30 minutes travel time	Potential accessibility to basic health care Potential accessibility to general practice surgeries

- *Global potential accessibility freight.* What is the relative position of the European regions towards global destinations with respect to freight transport? For each NUTS-3 region the shortest total travel cost by road, rail, water and/or air to ports with intercontinental container services are calculated. The intercontinental container throughput of the ports is used as attraction, i.e. the mass term in the calculation of the global freight potential accessibility.

European accessibility

The task of the European accessibility indicators is to provide assessments of the attractiveness and competitiveness of European regions in the European context based on their location and their integration in the transport networks. As shown in Chapter 3.2, there is already a wide collection of previous studies including ESPON work on European accessibility available. The TRACC set of European accessibility brings value-added in three directions: (i) Traditional accessibility indicators such as the accessibility potential are updated to a current point in time thus allowing an up-to-date assessment and also the analysis of trends over time. (ii) The additional inclusion of new types of accessibility indicators and in particular of indicators addressing freight transport enables new insights into European accessibility conditions. (iii) The explorative analysis of raster-based indicators enables methodological conclusions on the appropriate spatial resolutions of accessibility indicators.

For each of the three generic types of accessibility indicators, first a traditional indicator for accessibility travel is defined:

- *Access to top group of MEGAs.* What is the average travel time from the regions to the upper level subset of the European MEGAs? For each NUTS-3 region the fastest travel time of road, rail and air transport to reach the top group of MEGAs is calculated, and an average value is determined.
- *European daily accessibility travel.* How many people can I reach within a day's round trip? How many people can visit my region within a day's round trip? For each NUTS-3 region the number of persons that can be reached within a one way travel time of five hours by road, rail and fastest mode is summed up. Five hours per way is used to allow for at least five hours of activities at the destination.
- *European potential accessibility travel.* What is the relative competitive position of European regions towards European destinations? For each NUTS-3 region the population in destination regions is weighted by the travel time to go there. The weighted population is summed up to give the value of the accessibility potential for the origin region. The potential accessibility indicator is calculated for road, rail, air and as an multimodal aggregate. The indicator is calculated with the same specification and network detail for the year 2011 as the potential accessibility indicators of ESPON 2006 and the Accessibility Updates. That means that the development of potential accessibility by road, rail, air and multimodal is also analysed over a time period of ten years in total.

There is a second set of European accessibility travel indicators that goes somewhat beyond the traditional indicators described before. These indicators include relatively new aspects and are more complex in terms of data requirements and calculation methods:

- *Travel speed.* What is the average travel speed to serve regional transport demand? The rationale of this indicator is based on the assumption that transport policy cannot provide the same degree of accessibility everywhere in Europe, but might provide the same quality of the infrastructure by delivering comparable speeds to the regional transport demand. First, regional transport demand is calculated by a negative exponential model in which the number of trips from the region to all other regions is estimated. Then, the travel time to the destination regions

is converted to airline speeds. Finally, the average travel speed of a region is calculated as the trip-weighted average speed to all other regions.

- *Urban connectivity.* What opportunities or restrictions for urban connectivity does transport infrastructure provide? For each city of more than 50,000 inhabitants the travel time to other cities of that minimum size is calculated for road, rail, air and intermodal travel. Urban connectivity is there if two cities are less than three or alternatively five hours of centre-to-centre travel time apart from each other. The indicator is mainly presented in map form, but could also be numerically defined by using concepts of graph theory.
- *European potential accessibility intermodal travel.* What is the relative competitive position of European regions towards European destinations by using the best combination of all transport modes in intermodal trip chains? For each NUTS-3 region the population in destination regions is weighted by the intermodal travel time to go there. The weighted population is summed up to give the value of the accessibility potential for the origin region. The potential accessibility indicator is calculated by using shortest intermodal travel times between regions.

A third group of European accessibility indicators is concerned with freight transport. The indicators developed follow the logic of the more traditional accessibility indicators for travel:

- *Access to nearest maritime ports.* What are the costs to reach the nearest maritime ports? For each NUTS-3 region the average generalised travel cost for different commodities to reach the nearest three maritime ports are estimated. Modes considered are road, road and rail and road and inland waterway.
- *European daily accessibility freight.* What market area can be served by lorries from a region? For each NUTS-3 region the amount of GDP that can be reached within the maximum allowed driving time of a lorry driver is calculated.
- *European potential accessibility freight.* What is the relative competitive position of European regions towards European destinations with respect to freight transport? For each NUTS-3 region the GDP in destination regions is weighted by the generalised travel time to go there. The weighted GDP is summed up to give the value of the potential accessibility freight for the origin region. Freight handling categories considered are unitised goods and non-unitised goods (bulk and general cargo) thus reflecting different conditions with respect to impedance, e.g. different times and costs for loading and unloading. Modes included are road, rail, inland waterways, short sea shipping and air. For those modes that are generally used in combination with other modes, e.g. short-sea shipping needs feeder service by an inland mode to connect non-coastal regions, travel times and costs are calculated based on intermodal trip chains.

Regional accessibility

The task of the regional accessibility indicators is to provide the base for an analysis of the restrictions and opportunities for daily life provided by the transport infrastructure in the regions to the population and economic actors. The review of regional accessibility studies has shown that there is a huge variety of approaches at this scale. In most of them travel cost type indicators in the form of travel time to a few selected destinations and the trend towards high spatial resolution dominate. The TRACC set of regional accessibility indicators provides progress in three directions: (i) A Europe-wide modelling of accessibility to regional destinations allows a comparison of regional accessibility for all NUTS-3 regions. (ii) The systematic integration of freight accessibility provides insights in the local restrictions and opportunities for economic actors. (iii) A harmonised set of accessibility indicators implemented in different regional case studies allows a unique Europe-wide comparison of local and regional conditions of daily life in very different types of European regions.

There are two basic groups of regional accessibility indicators. In the first group accessibility for travel and freight to destinations of regional importance are calculated for the whole ESPON space and the Western Balkan. The indicators of the second group have been calculated in the seven TRACC case studies only.

The regional accessibility travel indicators calculated for the whole of Europe cover again all three generic types of accessibility indicators:

- *Access to high-level transport infrastructure.* What is the access time to reach the nearest entrance nodes of higher-level transport infrastructure? Access time to the nearest transport nodes (motorway exits, main rail stations and airport) is calculated for raster cells for road and rail. Access times are aggregated by including the relative importance and utility of the different networks for the regional population (so called ICON approach, see Vol. 4, Chapter 4.1). Aggregation from raster cells to NUTS-3 allows comparison with other accessibility indicators.
- *Availability of urban functions.* What amount of urban functions can be reached in reasonable travel time? By looking at road and rail transport, it is assessed which cities with more than 50,000 inhabitants can be reached within a travel time of 60 minutes maximum. Calculation are for raster cells and are aggregated to NUTS-3 regions.
- *National potential accessibility travel.* What is the relative competitive position of regions towards national destinations? This indicator is similar to the potential accessibility at the European level. For each NUTS-3 region the population in destination regions are weighted by the travel time to go there. and the weighted population is summed up to give the value of the accessibility potential for the origin region. However, the destinations are restricted to regions in the same country as the origin region. That means that in practice national accessibility calculations is done separately for each country of the ESPON space and the Western Balkan. The potential accessibility indicator is calculated for road and rail.

The regional accessibility indicators for freight transport to be calculated Europe-wide follow a similar logic as those for travel:

- *Access to freight terminals.* What is the access time to reach the nearest freight terminals? Access time to nearest transport nodes (cargo transport centres, seaports, inland ports, airports with cargo handling) is calculated for raster cells for road and rail. Access times are aggregated by including the relative importance and utility of the different networks for the regional economic actors (so called ICON approach, see Vol. 4, Chapter 4.4). Aggregation from raster cells to NUTS-3 allows comparison with other accessibility indicators.
- *Availability of freight terminals.* What amount of options do regions have with respect to freight logistic centres? By looking at road transport, it is assessed which number of freight terminals can be reached within a lorry travel time of two hours maximum. The indicators are for raster cells and then aggregated to NUTS-3 regions.
- *National potential accessibility freight.* What is the relative competitive position of regions towards national destinations with respect to freight transport? This indicator is similar to the potential accessibility for freight at the European level. For each NUTS-3 region the GDP in destination regions is weighted by the generalised travel time to go there and the weighted GDP is summed up to give the value of the accessibility potential for the origin region. However, the destinations are restricted to regions in the same country as the origin region. That means that in practice national accessibility calculations for freight is done separately for each country of the ESPON space and the Western Balkan. The potential accessibility indicator is calculated for road and rail.

In the regional case studies, the first set of indicators follows the traditional set of accessibility indicators calculated at the European level. All indicators have been calculated for municipalities, i.e. at the LAU-2 level. However, in some case studies the calculation has been done first for

smaller raster cells and has then been aggregated to LAU-2:

- *Access to regional centres.* How distant or how far is the nearest regional centre? Proximity to an urban centre has often been used as a proxy for accessibility to jobs and different services such as higher education, health care, commerce etc. For each municipality or raster cell of the case study region, the minimum travel times by road and public transport to the nearest urban centre are calculated.
- *Daily accessibility of jobs.* How many jobs can I reach from my place of residence? This indicator approaches the opportunities of the regional labour market from the point of view of the population. For each municipality or raster cell the amount of jobs reachable within a maximum commuting distance of 60 minutes by car and by public transport is estimated.
- *Regional potential accessibility.* What is the regional population potential of a municipality? In order to evaluate the different locations within a region from the viewpoint of economic actors, e.g. firms assessing the regional labour market, or retail industries assessing the market area, the population potential of each municipality or raster cell within the case study region is calculated. As for the other spatial levels the population potential is calculated as the sum of people in destination areas weighted by the travel times to go there. Modes considered are road and public transport.

The second set of indicators of the regional case studies is also for travel and considers destinations of specific relevance for daily life, i.e. services of general interest:

- *Access to health care facilities.* What is my travel time to go to the nearest hospital? Travel times for each municipality or raster cells by road and by public transport show the spatial diversity in access to important health care facilities.
- *Availability of higher secondary schools.* Do I have access to higher secondary schools in reasonable travel time and do I have a freedom of choice to select between different options? For each municipality or raster cells travel time contours of 30 minutes travel time by road and by public transport are calculated, and it is checked how many higher secondary schools are reachable within this travel time.
- *Potential accessibility to basic health care.* What is my locational quality with respect to basic health care? Using general practice surgeries as destination activity in a potential accessibility indicator allows to assess the relative distribution of health care provision of different areas within the case study region. For each municipality or raster cell, the potential value is calculated as sum of general practice surgeries located in the case study region weighted by travel times by road and public transport.

Implementation

There are two different spatial reference systems for which accessibility indicators is calculated. All global and all European accessibility indicators as well as Europe-wide regional travel and freight indicators are calculated for NUTS-3 regions or partly for raster cells of the ESPON space and the Western Balkan. Turkey is not included as internal zone in the accessibility models nor in the SASI model because this would raise some fundamental methodological and data issues.: If Turkey would be an internal zone, countries in the Caucasus, countries in the Arab world (Near East and Middle East), and also Russian regions in central Asia would have to become 'external zones', as they have direct boundaries with Turkey or because important transport routes are directly linked to Turkey. In consequence, this would require to include these countries as external zones into the models, and to collect all required network and socio-economic data for them as well. As this is not feasible in the TRACC framework the Turkish regions are included as external zones only with higher spatial detail than done so far.

It has to be noted that the destinations in the accessibility models are not confined to the ESPON space and the Western Balkan. In particular for the indicators of the type cumulated opportunities and potential it is important to include destinations in Eastern Europe and North Africa to avoid edge effects. The second spatial reference system is that of the case study region for which the last two groups of accessibility indicators are calculated.

The results of the different accessibility indicators are presented in map form and analysed with respect to their spatial pattern. In addition, a post-processing of the indicators is done to compare different accessibility indicators with each other. This includes a comparative analysis of European and regional accessibility. In addition, the aggregation of indicators to relate it to the ESPON regional typologies, and the provision of indices for territorial cohesion with respect to accessibility has been done

The TRACC set of accessibility indicators yields a major innovation compared to other accessibility studies, because it addresses different aspects of accessibility of municipalities and regions in Europe in a systematic way, something that has not been done by any previous accessibility study. Each place in Europe can be classified according to different accessibility aspects ranging from its relative location in the global competition or within Europe down to the daily accessibility requirements of the local population.

Accessibility impact indicators

As indicated in Chapter 4, the relevant impacts of accessibility at the European or national level are *economic* and *environmental* impacts. At the intraregional level, the most important impacts are *social* impacts.

The indicators of *economic* impacts of accessibility have been produced by the SASI model: impacts on regional economic development expressed as gross domestic product (GDP) per capita and impacts on territorial cohesion expressed by several cohesion indicators. Cohesion indicators are either relative or absolute. Relative cohesion indicators measure relative convergence or divergence in terms of percent of GDP per capita. Absolute cohesion indicators measure absolute convergence or divergence in terms of GDP per capita in Euro. The difference between relative and absolute cohesion is important because relative convergence can be associated with absolute divergence. For instance, regions in the new EU member states may benefit from a certain transport infrastructure investment more than regions in the old member states in relative terms (in percent), but in absolute terms (in Euro) the regions in the old member states may benefit more. Relative cohesion indicators are the Gini coefficient, the coefficient of variation and the correlation between GDP per capita and the relative change in GDP per capita. Absolute cohesion indicators are the correlation between GDP per capita and the absolute change in GDP per capita.

Social impacts of accessibility, i.e. effects on social inclusion or exclusion by differences in access to services of general interest, are measured by a number of accessibility indicators, such as travel time to the nearest urban centre, travel time to education facilities and travel time to health services.

Environmental impacts of accessibility are measured as energy consumption and greenhouse gas emissions by transport calculated with a travel and goods transport model attached to the SASI model.

6 Accessibility to global destinations

What are the linkages of European regions to the world? How are the regions embedded in the global economy seen from an accessibility point of view? What are their linkages to global hotspots outside Europe or to European gateways to the world, what is the necessary transport effort to such destinations? To address such questions, TRACC has developed a set of global accessibility indicators that go beyond the few examples in the literature that usually provide restricted travel time indicators from airports only. The TRACC set of global accessibility indicators provides progress as it includes also freight accessibility indicators of the types cumulated opportunity and potential and as the indicators are not restricted to preselected rare points in Europe, but are calculated for all NUTS-3 regions of the ESPON space. This section can only provide a few illustrative examples; more is given in Volume 2 and Volume 4 of the TRACC Final Report.

A first illustrative approach to consider the global integration of European regions is to analyse the total travel effort people have to take into account when travelling to global destinations. As an illustrative example for that TRACC has calculated travel times from the European regions to selected global cities. Figure 6.1 presents the travel time from Europe to New York which serves as one proxy for such global hotspots. For each NUTS-3 region the shortest total travel time to New York City (Downtown Manhattan) was calculated. The travel time reflects intermodal trips from the centres of the regions. It is based on road, rail and/or air travel times to airports in Europe with intercontinental flights plus the flight time from there to New York, plus the travel time from one of the city's airports to Manhattan and includes necessary terminal times as well.

The travel times to New York differ very much across European regions (Figure 6.1). There are regions in Europe from which the total travel time is clearly below 15 hours. Not surprisingly, these regions are located in western parts of Europe with close access to airports with intercontinental flights. Countries in which most of the regions belong to this favourable group are the UK, Ireland, Iceland, Portugal and the Benelux. In addition, there are larger areas around Paris, Frankfurt, Madrid; Milano and Zürich and some smaller areas in Spain or France benefitting from relatively low travel times which can also be experienced when travelling from Copenhagen, Vienna or Rome. However, travel times clearly increase up to 18 hours in other regions of western Europe that have a longer access to intercontinental flight services; similar travel times have to be expected when travelling from capital city regions in eastern or northern Europe. Longest travel times exist from non-metropolitan regions in northern and eastern Europe; for few regions it might take almost a full day to travel to New York. This very unbalanced pattern of global accessibility is also reflected in the two other types of indicators describing global travel accessibility.

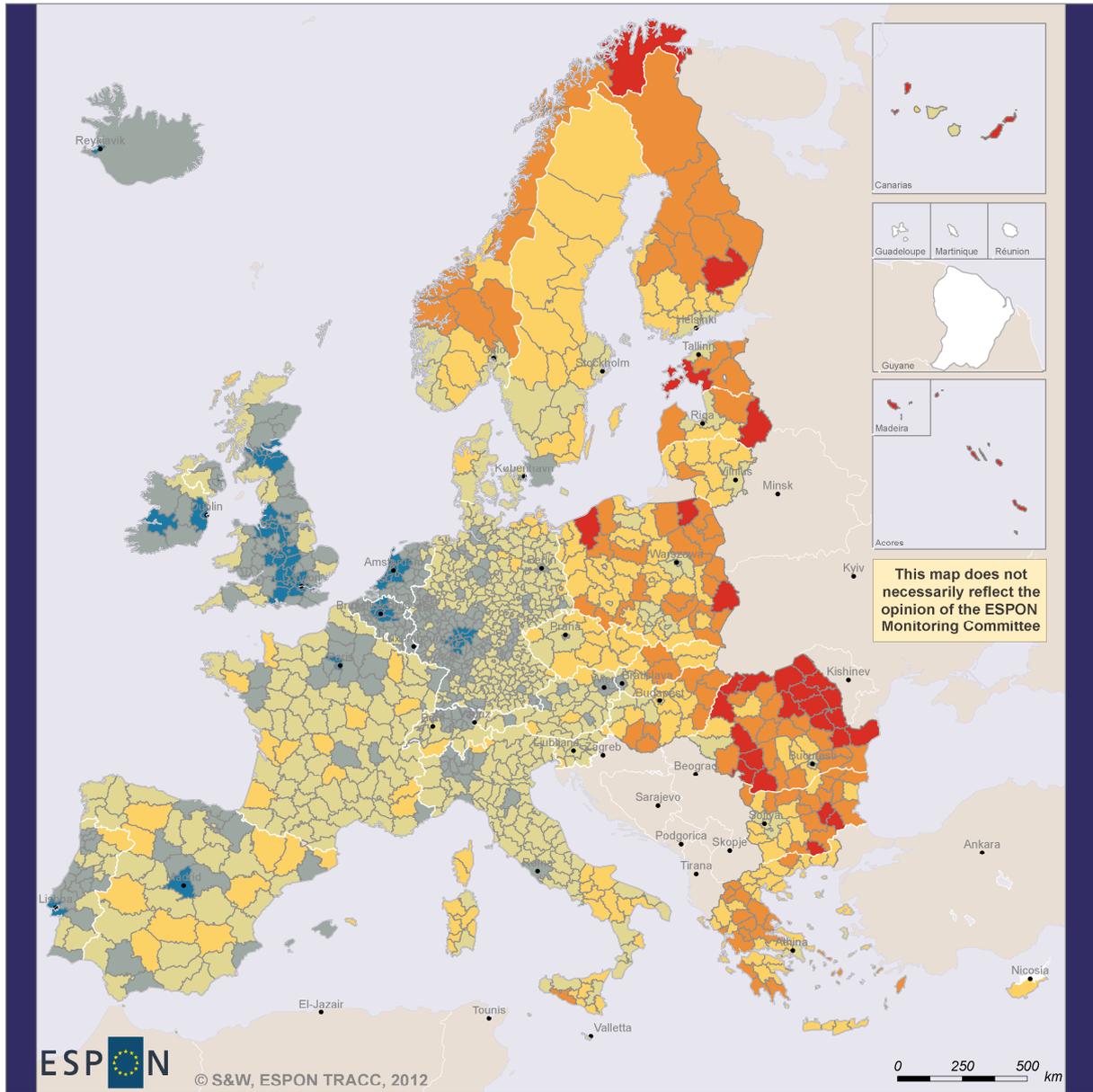
Global freight accessibility is described by three different indicators making reference to different dimensions. It is considered how far representative intercontinental global hubs are (travel cost type accessibility) as well as how much intercontinental traffic can be reached in a relatively short time (cumulated opportunities type accessibility) and, finally, the potential accessibility to intercontinental traffic. In order to get a comprehensive picture of the level of global accessibility of European regions the contribution of all three indicators should be taken into account.

The accessibility to intercontinental global hubs is significantly affected by the geographical position of regions. In general, western European zones are more accessible to the New York hub, while the South-eastern European zones are more accessible to the Shanghai hub. However, in most of the cases, for a European forwarder, the accessibility to European intercontinental ports is more critical than the connection from the European port to the overseas port. In other words, the navigation time for deep sea shipping is usually far less important than the time and cost of the European leg of the shipment. For instance, despite reaching Shanghai is faster from Genoa than from Le Havre, for the Paris region the latter is a much more convenient port than the former.

That's why it is important to consider the access to European intercontinental ports, described by the other indicators. The picture these two indicators provide is somewhat different as the relevance of the geographical position changes and the role of infrastructures rises, with particular reference to rail and water accessibility (Figures 6.2 and 6.3). As far as rail (and road) is concerned, a clear separation is visible between central western Europe and peripheral Europe in terms of global freight connectivity: peripheral regions are connected to a much lower amount of intercontinental container throughput (Figure 6.3). The geographical position matters as the most important intercontinental ports are at the North Sea, but also to the poorer inland infrastructures in some regions (e.g. the Balkan area or the extreme north of Norway) or the distribution of rail intermodal centres has an effect. Infrastructures – i.e. ports and inland waterways – are of course of particular relevance for water accessibility (Figure 6.2). From this point of view it should be considered that the picture of accessibility shown in the maps can change if some ports are subject of large improvements which attract new traffic (as the case of Gdansk, for instance, where the opening of direct services with China has increased the port throughput at the extent that it might become one of the major intercontinental hub ports in Europe). Another significant change might occur if future melting of North Pole ice because of global warming makes the Northern Sea route an available alternative towards East.

The analysis of global accessibility of different parts of Europe crosses with the considerations on global accessibility by different transport modes. Modes should not be considered as pure competitors. In some terms they are at least partially complementary. Water (especially maritime) is a convenient transport alternative especially for larger volumes of freight on longer distances. Its role in the logistic chain is closer to the production than to the consumption end. Conversely, road transport is more efficient for small or even individual shipment and to reach the final distribution. Rail is in an intermediate position. Therefore different levels of accessibility depending on the transport mode considered can also suggest that different functions can be located in one region. For instance, southern Europe, which is better ranked in terms of global accessibility by water, performs better as European transshipment platform to handle large volumes to and from overseas. At the same time, despite maritime transport is dominant for the freight transport between Europe and Asia, land routes (mainly by rail but also by truck) exist and might develop in the future. Considering inland connections, the global accessibility of eastern European regions would be higher.

In summary, there are differences in terms of global freight accessibility between European regions which partly depend on their geographical position and part on availability of infrastructures. However these two aspects are not independent. While it is difficult to conceive that Scandinavian countries or Finland can fully remove the gap of accessibility due to their position, the advantage of the North Sea area is the result of the location of European major ports which however are not there only by chance but also because they can benefit of the geographical centrality. Nevertheless, the progressive rise of Far East as trade partner opens to Mediterranean regions the perspective of exploiting a position advantage. In this respect, efficient multimodal infrastructures (ports, transshipment facilities, intermodal centres, roads, railways) might increase the global accessibility of Southern Europe regions thus reducing the current differences with respect to the North Sea area.



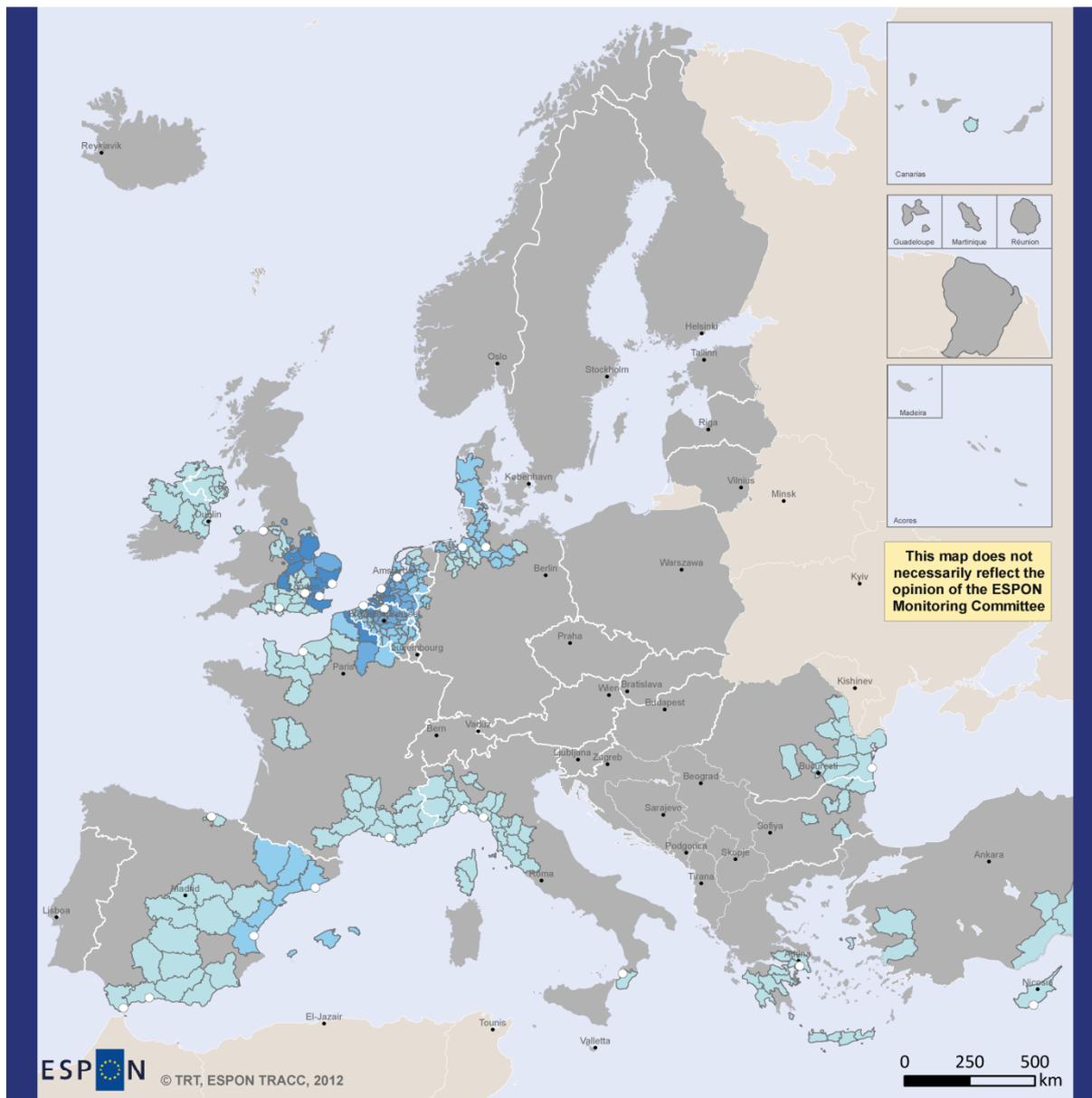

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Regional level: NUTS-3
 Source: RRG GIS Database
 S&W Flight Network
 Origin of data: S&W Accessibility model, 2012
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Travel Time to New York, intermodal (minutes)

-  702 - 800
-  801 - 900
-  901 - 1000
-  1001 - 1100
-  1101 - 1200
-  1201 - 3256
-  no data

Figure 6.1: Accessibility to global hubs: travel time to New York City




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Source: TRUST Accessibility Model (TRT 2012), Maritime Network: TRUST Model,
 Road/Rail Network: TransTools (2005), IWW Network: RRG GIS Database,
 Intercontinental container throughput of ports (Eurostat data 2007-2009)
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Global freight connectivity (2011):
Intercontinental container throughput (Ths. TEU) of European sea ports
reachable within 72h Sea Shipping/Inland Waterway travel time (3 days)

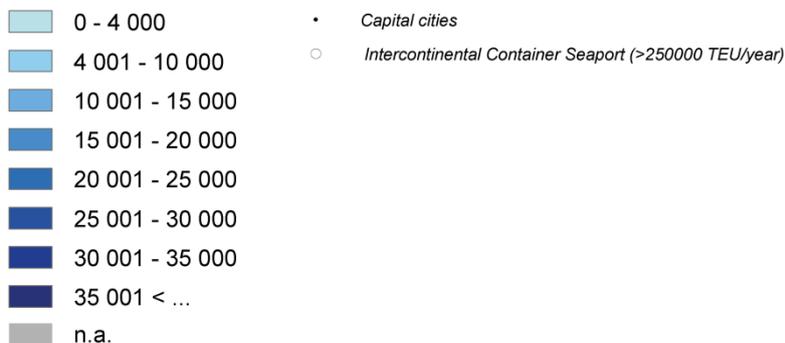
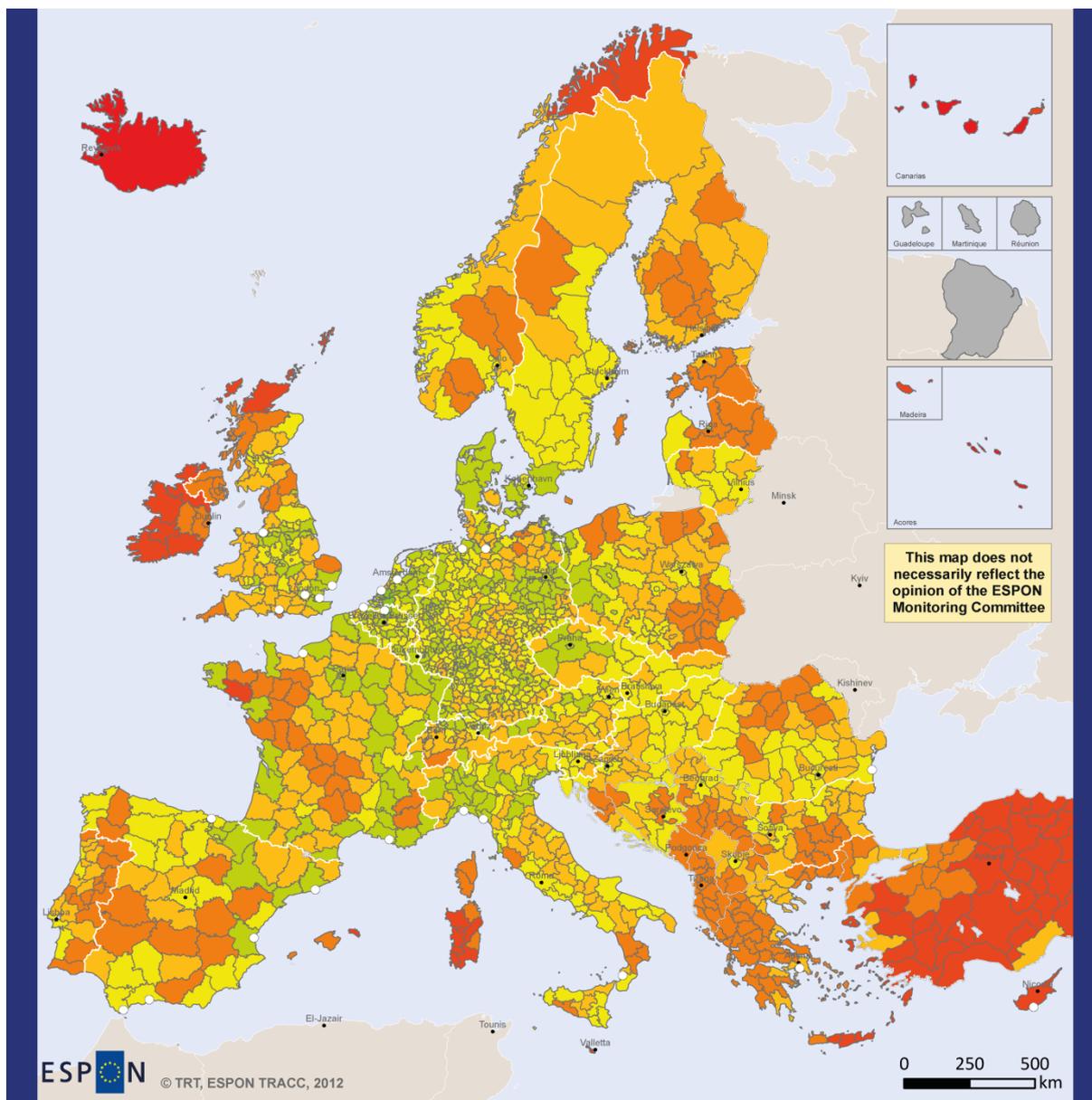


Figure 6.2. Global freight connectivity – water



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Source: TRUST Accessibility Model (TRT 2012), Road/Rail Network: TransTools (2005),
Intercontinental container throughput of ports (Eurostat data 2007-2009)
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**Global potential accessibility freight (2011):
by rail to intercontinental container throughput of European sea ports
(percentage of average accessibility by rail of all areas)**

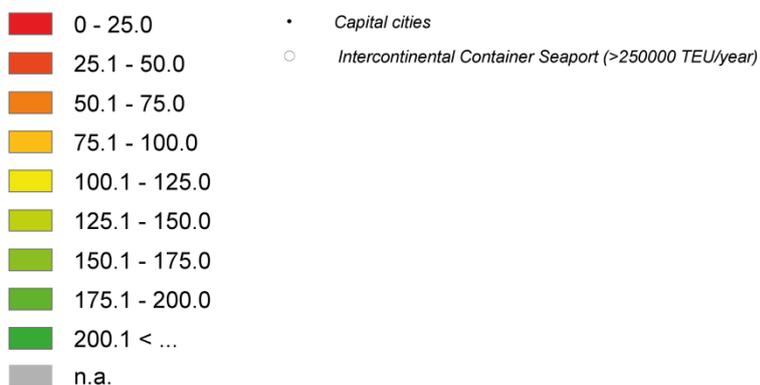


Figure 6.3. Global potential accessibility freight – rail

7 Accessibility to European destinations

European accessibility indicators are expected to provide assessments of the attractiveness and competitiveness of European regions in the European context based on their location and their integration in the transport networks. Compared to existing indicators, the TRACC set of European accessibility brings value-added as traditional accessibility indicators such as the accessibility potential have been updated to a current point in time, as additional new types of accessibility indicators and in particular of indicators addressing freight transport enables new insights into European accessibility conditions.

Most of the accessibility indicators for passenger travel display huge disparities across the European regions. The huge disparities in European accessibility are in particular visible in the potential type of accessibility indicator. Accessibility potential to population is presented for three modes of transport, road, rail and air, as well as the combined working of these modes as multimodal accessibility. The accessibility indicators are standardised to the ESPON average which is set to 100. By doing so, the potential accessibility indicators allow to identify regions that have different degrees of peripherality or centrality or are intermediate regions around the European accessibility average. Thus, the accessibility pattern presented can also be considered as accessibility typologies of European regions.

Accessibility potential by road and rail show the traditional core-periphery pattern in Europe with highest accessibility in Belgium and neighbouring regions of Germany. Because high-level road infrastructure serves all regions there, highest accessibility forms a plateau. High-speed rail serves hubs and corridors, so, highest accessibility is visible along major corridors (Figure 7.1). In addition, high-speed rail is able to extend the areas of high accessibility to the outside. This is in particular visible in France with the corridors of high accessibility towards the Atlantic and the Mediterranean Sea. For both transport modes, accessibility goes gradually down when coming to regions more apart from those high-accessibility areas.

Accessibility potential by air shows a distinct picture. The major airport regions and their close surroundings have highest accessibility. This is also true in countries that have lower accessibility for other modes. Disparities in accessibility are now visible between but also within countries. Multimodal accessibility as a combination of the three modal accessibilities shows a somewhat intermediate spatial pattern (Figure 7.2). It can be seen that regions that are not served by good air connection might be compensated by other good transport links for road and in particular rail. However, this is true for regions in France, Germany etc., but not for regions in Eastern Europe.

The second example for European travel accessibility is devoted to a somewhat different approach on analysing the opportunities or restrictions that transport infrastructure provide to city citizens. The urban connectivity indicator displays from cities to other cities reachable within certain travel time bands. The higher the number of possible travel connections to other cities the greater are the opportunities for business activities, city networking or for social interaction. Figure 7.3 shows for road travel the international connectivity of cities, i.e. national destinations are excluded to display the opportunities for international interaction of urban actors.

International urban connectivity for road is mainly restricted to neighbouring countries: Relations within the Benelux countries and towards Northern France and Western Germany are those with highest accessibilities, so as relations between Portugal and Spain, Spain and France, France and Switzerland and Italy. There are also many fast city-to-city relations along the former Iron Curtain between East Germany and Poland and the Czech Republic, between Austria and Slovakia and Hungary, as well as between Italy and Slovenia and Croatia. In general, taken all modes and intermodal urban connectivity together, the picture looks quite promising but there are still some interesting observations:

- Even though many East European cities can be reached quite well from Western Europe, connectivity between cities in the East is significantly lower. The number of city-to-city rela-

tions below 300 minute threshold within Eastern Europe is much lower compared to Western Europe, and if they exist travel times are on average much longer.

- Similarly, international urban connectivity between the Nordic countries is poor. Cities in the northernmost territories are mainly well connected by flights to the capitals, but not between themselves.
- For all modes results clearly visualise the 'blue banana', i.e. the area in Europe with highest accessibilities ranging from London via Benelux and Paris, along the river Rhine valley towards Northern Italy. Clearly for road and rail, but even for passenger flights origin-destination relations within this part of Europe show by far shortest travel times. This of course is first of all due to the rather dense network of cities (and consequently the short geographical distances between them), but also the high-standard transport infrastructures in these areas contribute to these high connectivity.
- Despite recent efforts to overcome the Pyrenees barrier, the Iberian Peninsula is still suspended from rest of Europe. For road and rail only very few origin-destination relations are below five hours threshold, but even for passenger flights average travel times from Portugal or Spain to other countries are quite long.

Three indicators illustrate freight accessibility of NUTS-3 regions at the European level. A travel cost type accessibility indicator provides a measure of the closeness to the nearest maritime ports. Cumulated opportunities type accessibility is measured by the size of GDP which can be reached within the legal daily driving time. Both these two indicators are related to one specific mode (water and respectively road). Potential accessibility is examined for all the alternative modes.

A large volume of freight concerning intra-Europe trade is moved by ships, however most of this volume consists of large shipments of bulk goods. As far as daily shipments of intermediate as well as final products are concerned, inland modes are however dominant. Therefore a representative picture of European freight accessibility needs to consider all modes. The accessibility to closest ports provides an integrated measure of the level of accessibility of regions with respect to maritime freight terminals, as an important element in the economy to allow exports of local commodities and imports. In this respect, the indicator is computed with reference to ports with a throughput of at least 4 million tonnes yearly, i.e. those ports which actually play a role as gates towards other regions. Not surprisingly, coastal zones are generally more accessible. Nevertheless, geographical position is not enough and even coastal zones may have a poor accessibility if infrastructures (ports) are not adequate (i.e. only minor ports are located nearby or connections are expensive).

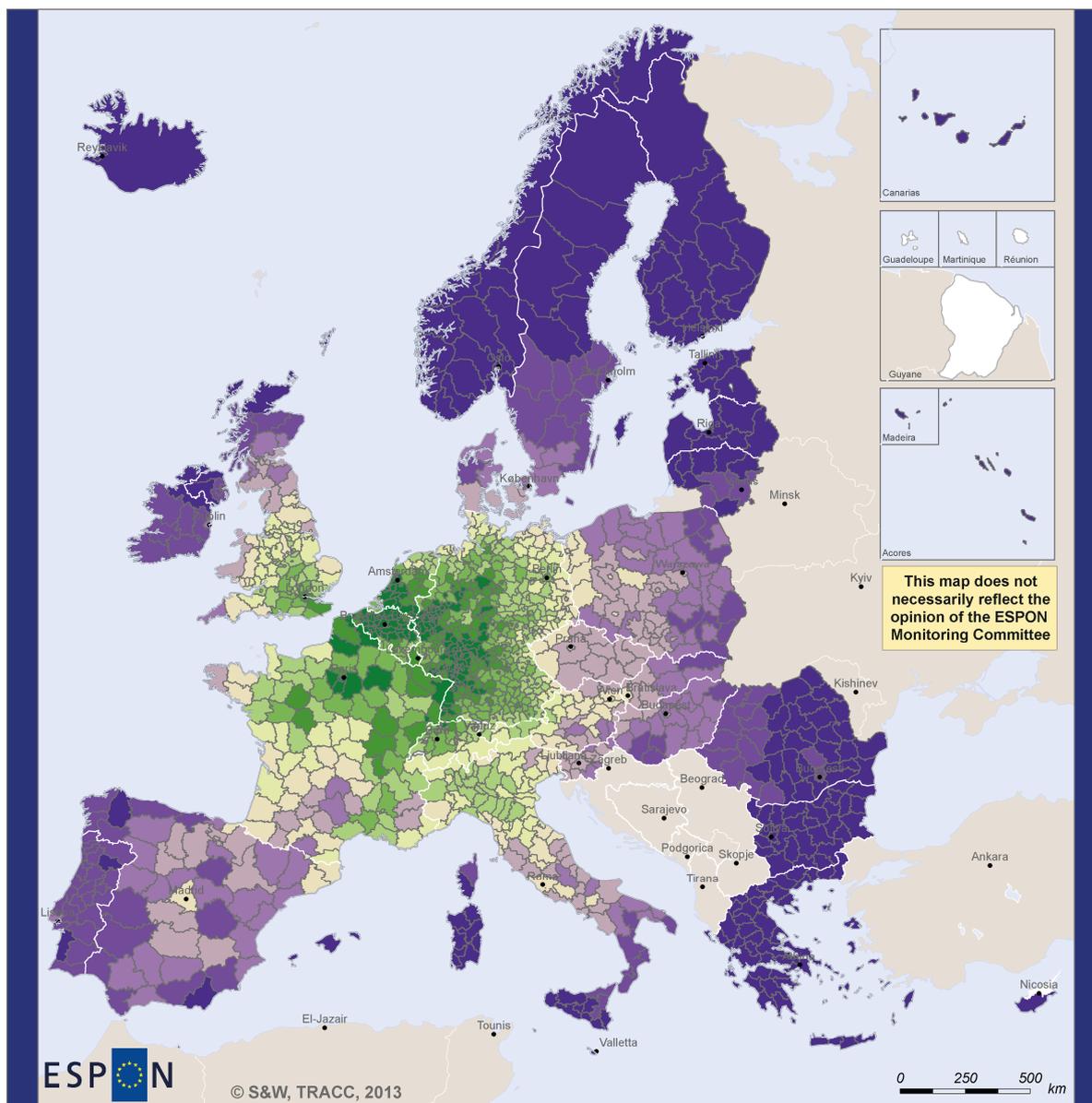
The message coming from the spatial pattern of the cumulated opportunities indicator (which is computed for trucks only, but road is the dominant inland freight transport mode) and of the potential accessibility indicators is that a group of regions in the central-western part of Europe have a clear advantage in terms of freight accessibility. This group of regions covers the Benelux, the western side of Germany, the northern edge of France and the southern side of UK. Around this core area, other neighbouring regions may be very well positioned according to one or more indicators even if there is always at least one measure for which they are significantly weaker than the core area. For instance, Denmark has good accessibility levels by water and also by unitised rail, but it is well below the average for road. The multimodal indicators reflect the prevailing role of the core area both for unitised and for non-unitised goods (Figure 7.4).

The separation between unitised and non-unitised goods is especially relevant for rail transport. Non-unitised goods represent pure rail transport, which does not need intermodal centres, but just of the rail network, which is quite homogeneously available over the whole European territory. Instead, for combined transport (road + rail) of unitised goods the proximity to intermodal centres

becomes a very significant accessibility factor. Thus, despite an overall decrement moving from the centre to periphery can still be observed, there are some regions e.g. in Italy or south France or Czech Republic with levels of European potential accessibility higher than e.g. some German regions thanks to the availability of intermodal facilities. The position of intermodal centres is also detectable in the differences of accessibility of regions in western France or in Italy.

Combined transport is the most dynamically growing segment of rail freight so promoting the accessibility for unitised rail could be considered a key strategy for the development of regions. However, it is relevant to observe that, unless a large growth of rail freight volumes is expected in the future, there are organisational reasons for intermodal centres not covering all the European territory in a homogenous fashion. Below a certain threshold of throughput, intermodal centres – which are usually private facilities – are not economically sustainable. It is therefore reasonable that they collect freight from a catchment area which can extend beyond a specific region. This means that the current pattern of unitised rail accessibility is correlated to a picture of those zones that have built a competitive advantage in infrastructural and logistical terms. This advantage could not be easily reduced by other regions in the future.

In brief, geographical position, availability of infrastructures and strength of the economy are the three key elements which describe the pattern of European accessibility. There is no need to say that these elements are correlated to each other.




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Regional level: NUTS 3
 Source: Spiekermann and Wegener
 Urban and Regional Research (S&W), 2013
 Origin of data: S&W Accessibility Model, 2013
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Accessibility potential, rail (ESPON = 100) 2011

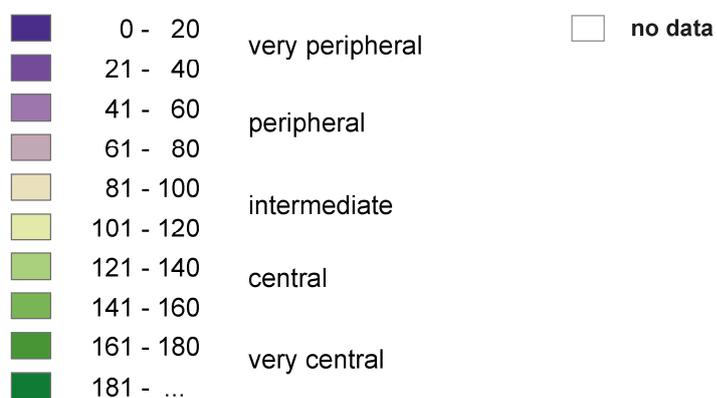
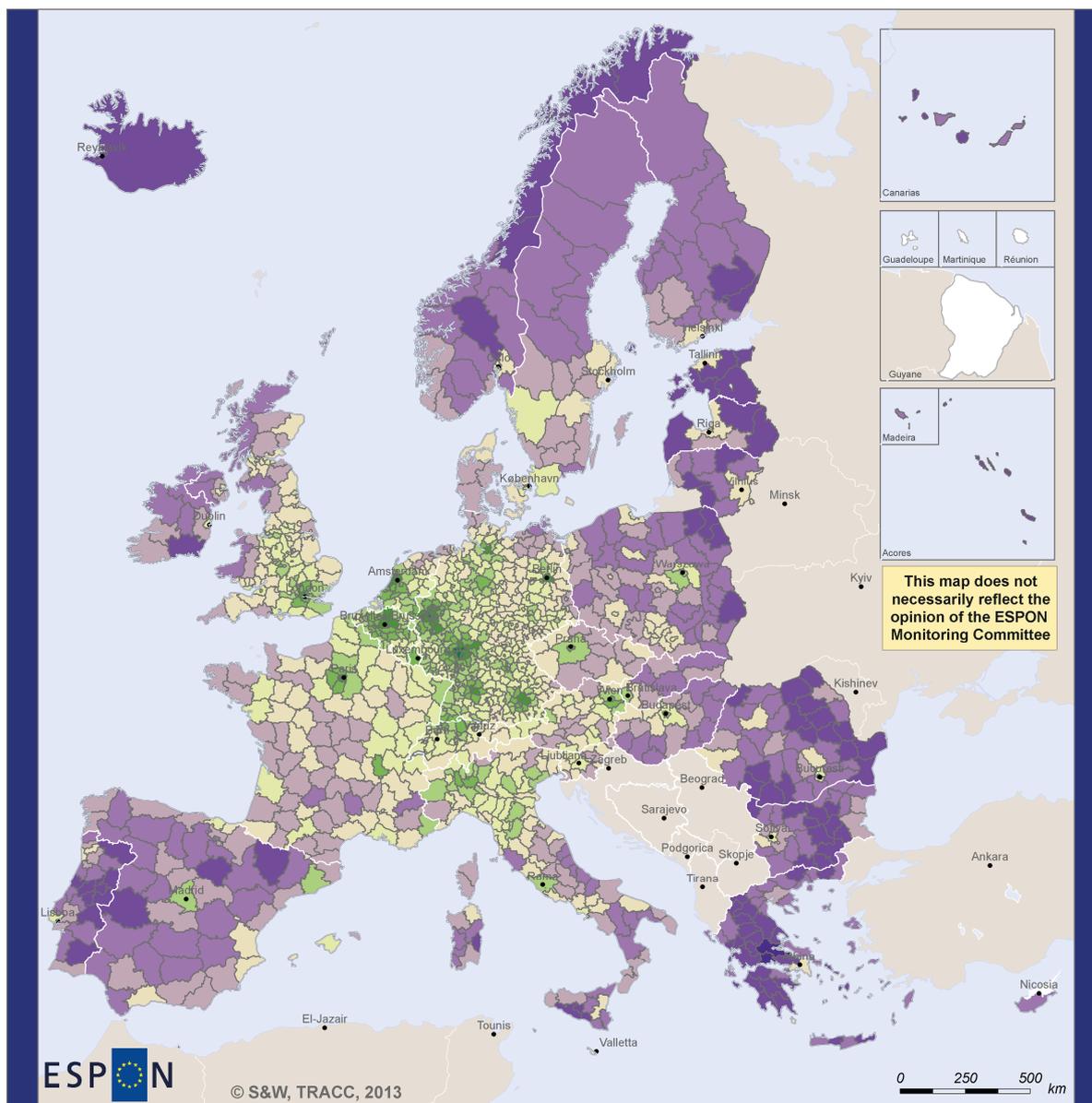


Figure 7.1. Accessibility potential to population by rail, 2011




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Regional level: NUTS 3
 Source: Spiekermann and Wegener
 Urban and Regional Research (S&W), 2013
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Accessibility potential, multimodal (ESPON = 100) 2011

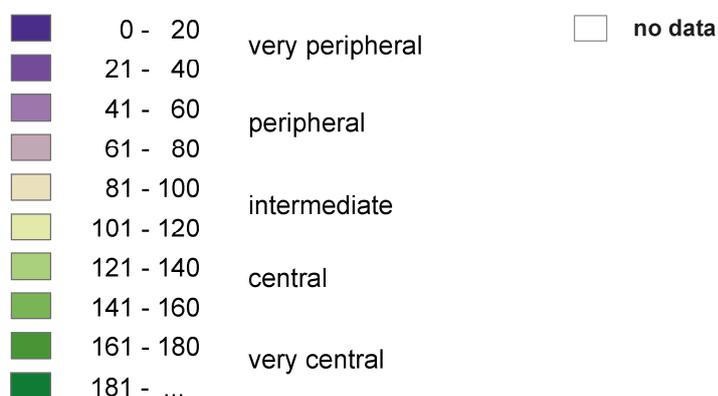
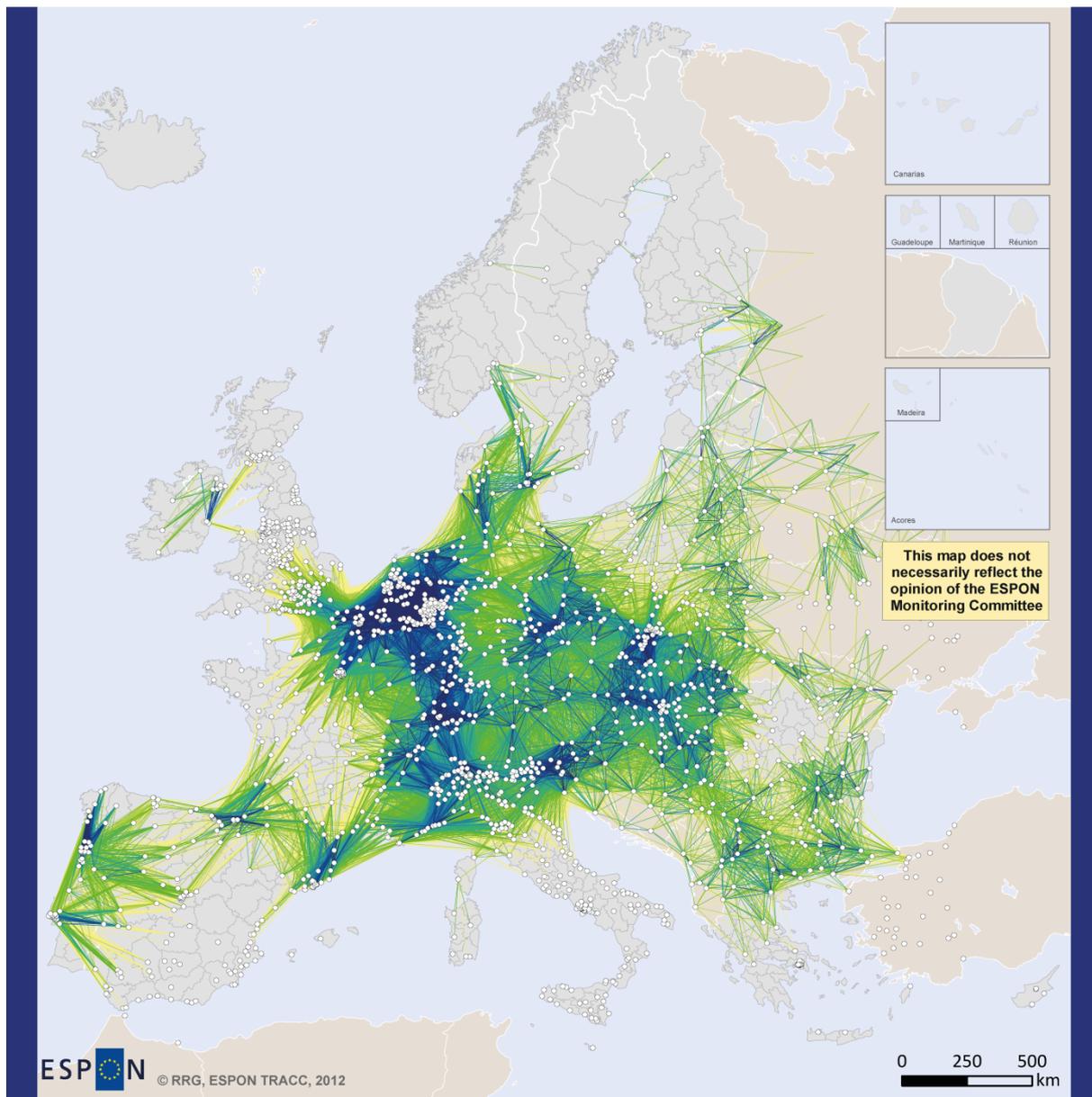


Figure 7.2. Accessibility potential to population multimodal, 2011



ESPON © RRG, ESPON TRACC, 2012

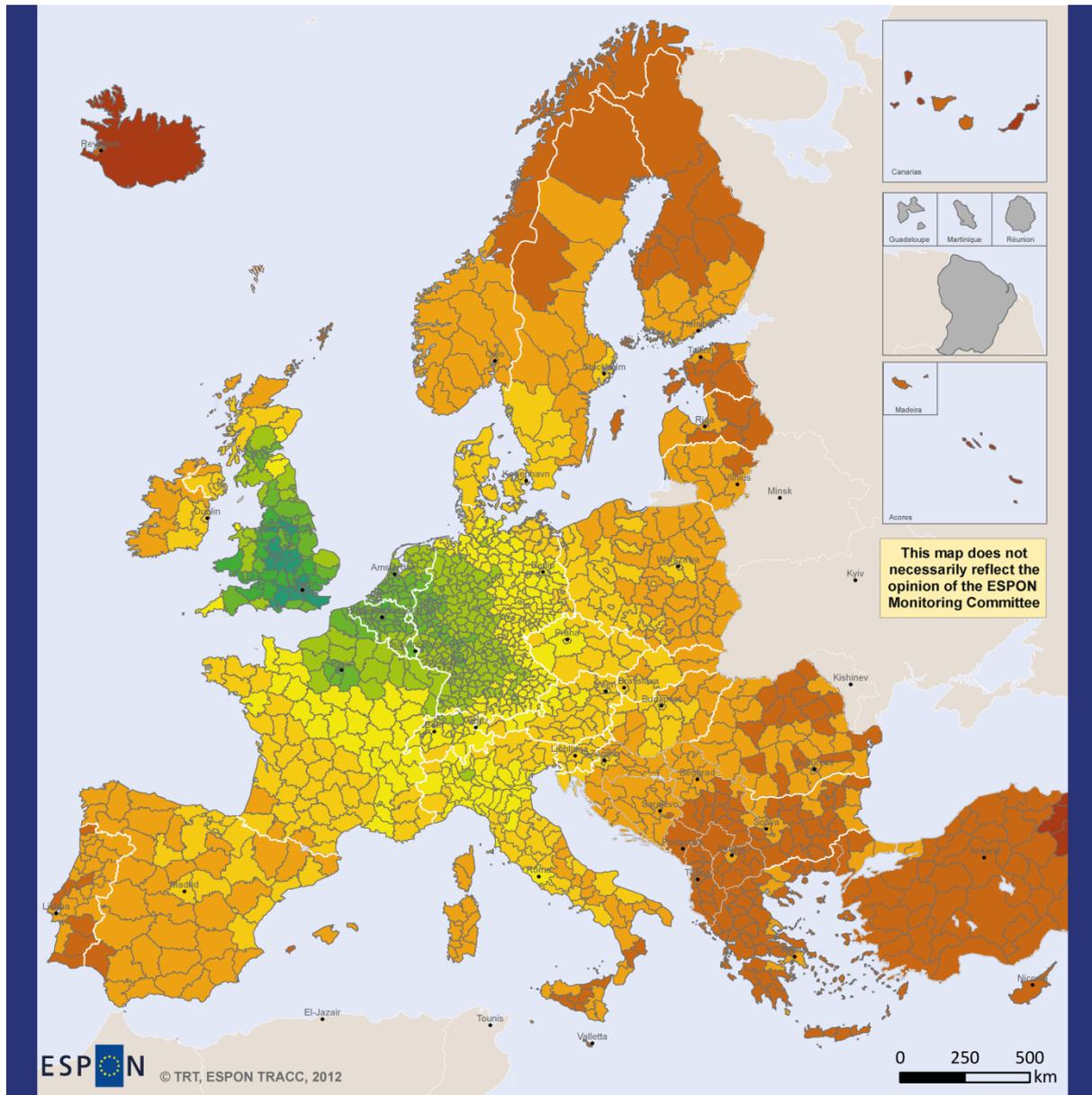
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Data source: RRG 2012, RRG GIS Database
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Urban connectivity: Road, international (2011)

- 0 - 90
- 91 - 120
- 121 - 150
- 151 - 180
- 181 - 210
- 211 - 240
- 241 - 270
- 271 - 300
- City > 50,000 inhabitants
- TRACC zones

Figure 7.3. Urban connectivity, road, international




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Source: TRUST Accessibility Model (TRT 2012), Maritime Network: TRUST Model,
 Road/Rail Network: TransTools (2005), IWW/Air Network: RRG GIS Database,
 GDP regional data (ESPON data 2005/2006, TransTools data 2005, Statistical Offices data)
 © EuroGeographics Association for administrative boundaries

Multimodal European potential accessibility freight (2011):
Accessibility potential to GDP (unitised)
(percentage of average accessibility of all areas)

- 0 - 25.0 • Capital cities
- 25.1 - 50.0
- 50.1 - 75.0
- 75.1 - 100.0
- 100.1 - 125.0
- 125.1 - 150.0
- 150.1 - 175.0
- 175.1 - 200.0
- 200.1 < ...
- n.a.

Figure 7.4. European potential accessibility freight – multimodal unitised

8 Accessibility to regional destinations

Regional accessibility indicators are to provide the base for an analysis of the restrictions and opportunities for daily life provided by the transport infrastructure in the regions to population and economic actors.

In relation to passenger transport, core areas in Europe have better access to high-level transport infrastructure than peripheral regions, as they tend to have denser motorway networks, good rail networks and concentrate most air hubs. This implies that citizens in core regions are more likely to seamlessly travel in Europe or easily access global transport gateways (higher availability of transport services, of direct point to point connections to other European cities, and shorter trip legs on local and regional road and rail networks). Outside the Core, national capitals (e.g. Warsaw, Madrid, Helsinki) and reference touristy regions (e.g. the Spanish Mediterranean coast and islands, Naples) provide areas of increased regional connectivity.

In relation to freight transport, best connectivity is recorded in the Atlantic rim between the Benelux and Germany due to the presence of largest container ports in Europe, in addition to denser motorway and freight village networks (Figure 8.1). The Mediterranean rim has large container ports as well, even if well behind Northern European ones, but less dense motorway and freight village networks in their hinterlands limit high connectivity scores only to coastal fringes, to a large extent. As Mediterranean ports are better positioned in the international shipping routes to Asia, should expansions of capacity be undertaken in these ports as planned and better connections provided with the European hinterland, overall connectivity of the Mediterranean rim could increase sensibly in the future.

Access to and availability of public and private services and functions provided in urban centres is crucial for daily life of citizens. The overall pattern of availability of urban functions is similar to that of passenger connectivity (Figure 8.2). Capacity of reaching large numbers of regional centres within limited travel time (cities larger than 50.000 inhabitants accessed in up to 60 minutes) is once again highest in the core of Europe, in selected capital city regions in other countries, and in other prominent regions such as south-western Scandinavia (Oslo-Gothenburg-Copenhagen), the Spanish Mediterranean corridor (Murcia to Barcelona), the Rhone valley, Saxony, Southern Italy, and Upper Silesia city district. From most locations in Europe, at least one regional centre can be reached in less than 60 minutes travel time by road, but only people in western Europe have options to visit more than five different cities in that time. The situation for rail is less developed. Here, inner peripheries with low accessibility values are not only located in the far North or in the Alpine space, as expected, but also in most European countries. The extent of these inner peripheries is substantially larger for rail than for car.

National Potential Accessibility for a specific NUTS-3 region is a construct of attractiveness of all other NUTS-3 regions in the country and generalised costs needed to reach these regions from the origin region. As the analysis is performed on a strict national basis, country borders are forced impermeable so foreign NUTS-3 regions become inaccessible from another country. In doing so, this indicator allows identifying a ranking of the regions within each country according to their proximity to the higher levels of national economic activity. Regions with a high potential accessibility have more opportunities to arrange a spatially distributed value chain in the domestic economy, have more alternatives in terms of national supply and demand market and so on.

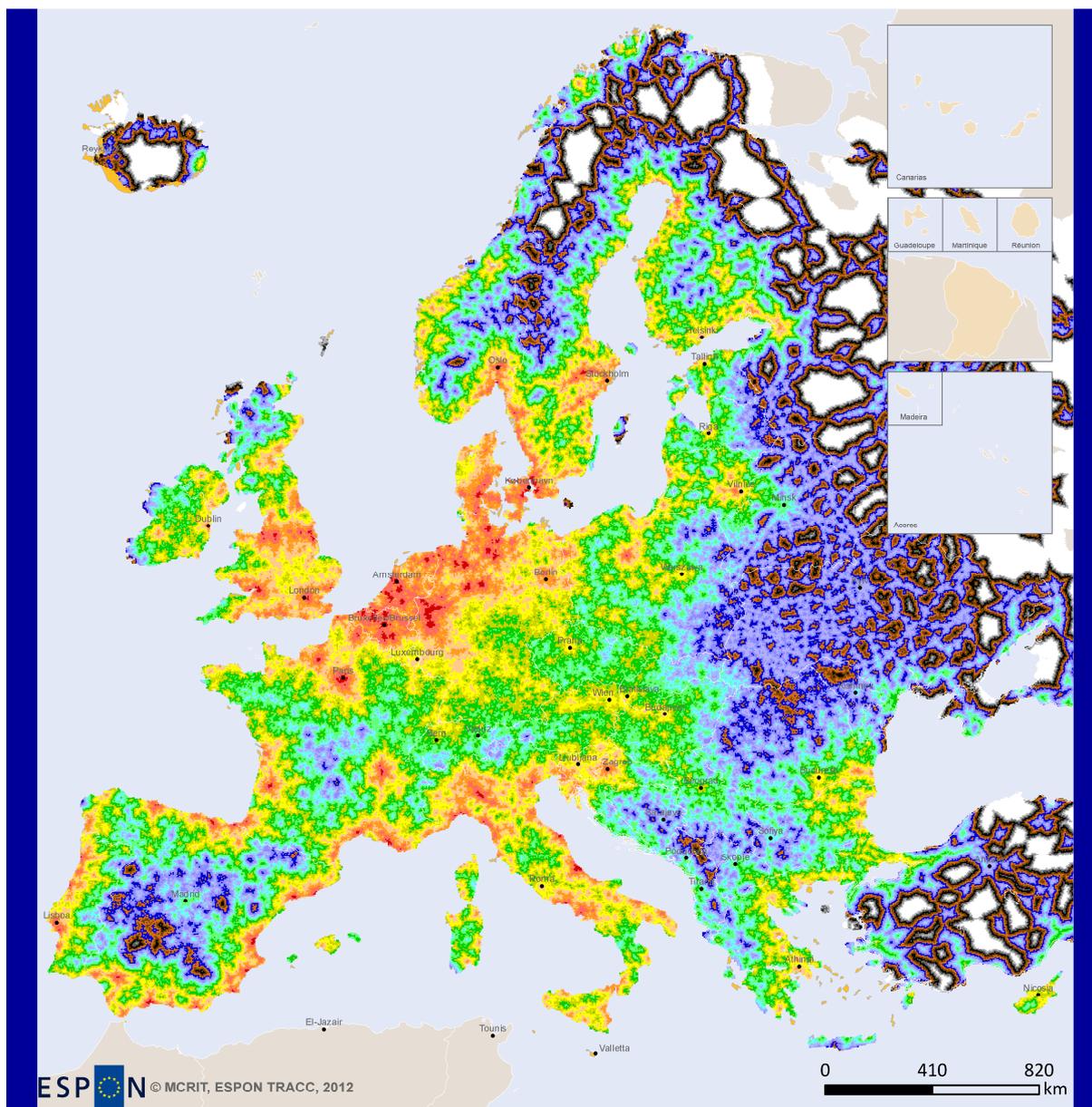
Figure 8.3 shows the spatial pattern of national potential accessibility using rail as illustrative example. Each country has its highly accessible areas and its own peripheral areas. However, the pattern differs across Europe. Most of the countries in eastern and northern Europe have a clear core periphery pattern in which mostly the capital region performs best and the border regions have lowest accessibility. In other countries, there are larger corridors of higher accessibility; a consequence of a more polycentric distribution of population and network design or a consequence of the effects of high-speed rail services. In some countries such as Italy or

Germany, highest accessibility is not to be found in the capital regions but around other important agglomerations. In some countries such as Poland or the Czech Republic areas that are located closer to the European core and thus have a fairly good European rail accessibility are rather peripheral when considering the national context.

The most significant finding in relation to the set of travel and freight national potential accessibilities is the large amount of regions that are likely to lose out substantially when they are restricted to access only national activities. This is especially important in regions such as Western Poland (at the German Border), North-eastern Germany (Danish and Polish borders), Southern Germany (Swiss, Austrian and Czech borders), Eastern France (German and Italian borders) and Southern France (Spanish borders).

This exercise, despite being fictitious up to a certain extent, reflects the potential opportunities lost from decreased or even from insufficient European integration (often due to cultural, social and even language issues). For instance, lack of integration in health and educational systems around Europe may force citizens in border regions to travel more (e.g. to national capitals) for certain higher education options or for complex health treatments that would otherwise do if integration was greater. Language obstacles may force citizens to move further within their countries for better job opportunities than would otherwise do if labour markets were more integrated and language barriers were lower.

Being to some extent economic integration larger in Europe than social and cultural integration, potential losses are more accurately portrayed under the travel national potential accessibility maps than in freight ones.




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Regional level: Raster 5x5 Km
 Source: ESPON TRACC, 2012
 Origin of data: MCRIT, TRANSTOOLS Transport Network, 2012
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Access to high-level freight transport infrastructure

ICON indicator, defined as relative connectivity to available transport networks (in minutes)

<http://www.mcrit.com/IGIS/ICON.htm>

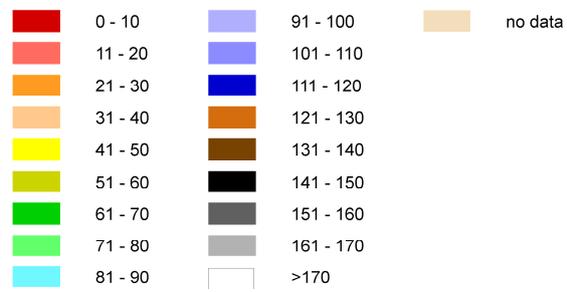
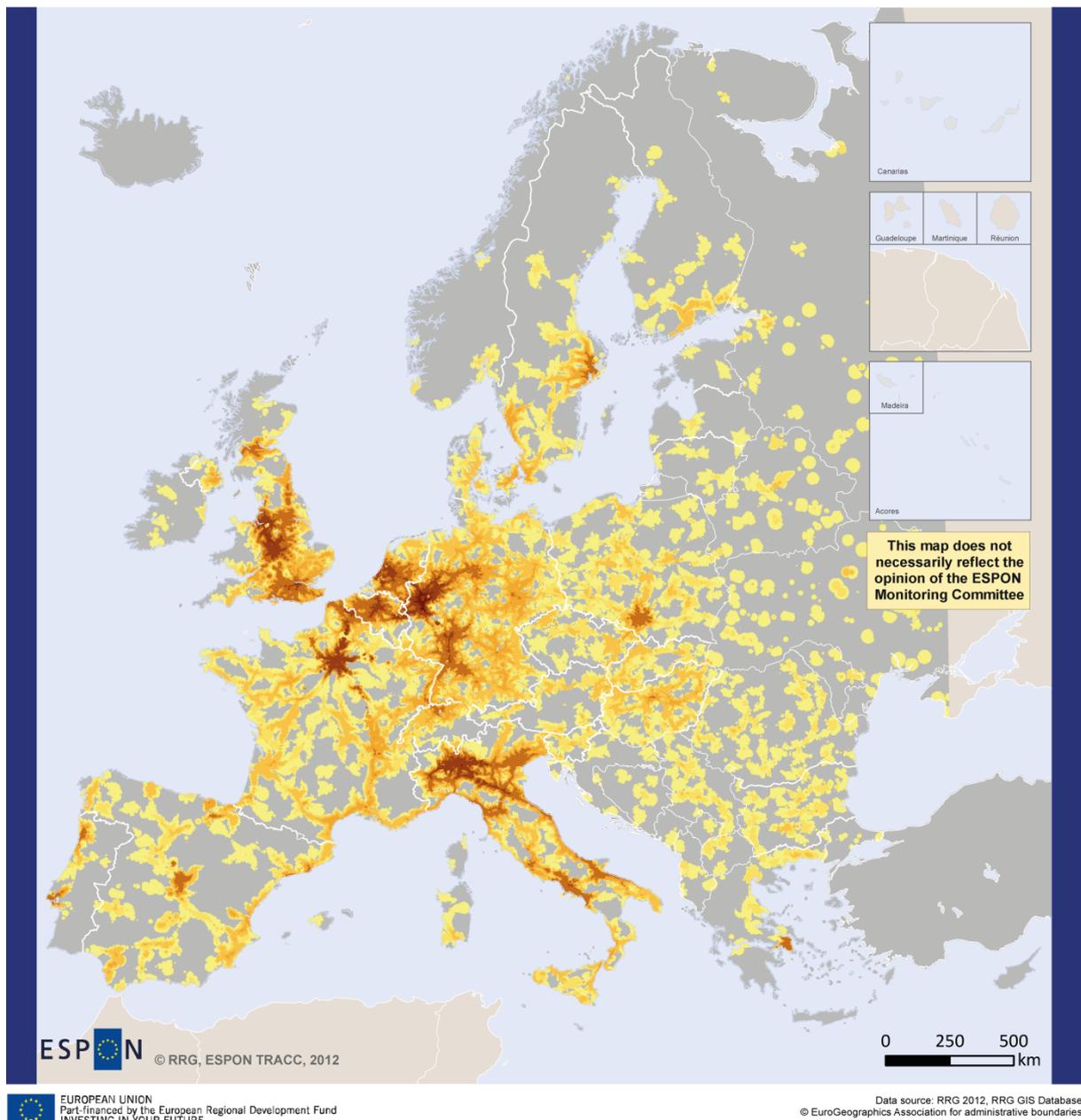


Figure 8.1. Access to high-level freight transport infrastructure by 5x5 grid cells



**Availability of urban functions (2011):
Number of cities > 50,000 inhabitants within
60 minutes rail travel time (raster level)**

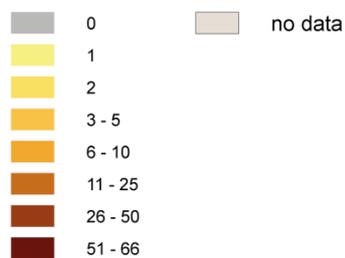
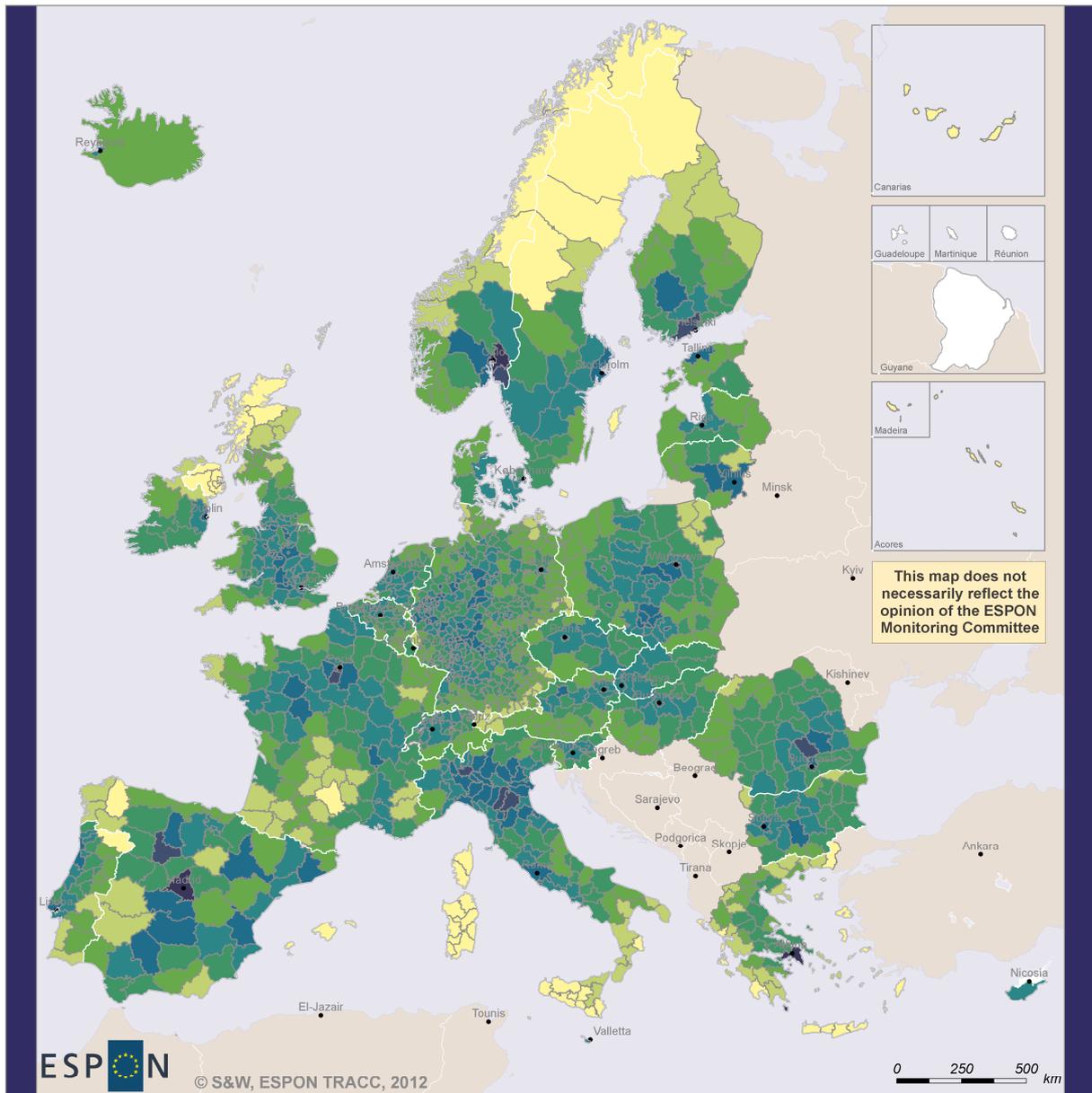


Figure 8.2. Availability of urban functions, rail




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Regional level: NUTS-3
 Source: RRG GIS Database
 S&W Flight Network
 Origin of data: S&W Accessibility model, 2012
 © EuroGeographics Association for administrative boundaries

National potential accessibility, rail (ESPON = 100)

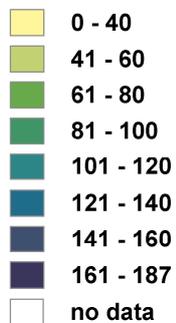


Figure 8.3. National potential accessibility, travel by rail to population

9 Accessibility to regional and local destinations

Global and European accessibility are important location factors for firms and working and leisure travel of people. However, for the daily life of citizens, regional/local accessibility to jobs, services and public facilities may be more important than global or European accessibility. One part of the TRACC project was therefore concerned with regional accessibility in a set of regional/local case studies in order to gain systematic knowledge on accessibility patterns in different types of regions throughout Europe. Case studies are presented in detail in Volume 3 of the TRACC Final Report.

One of the technical objectives for the regional case studies was to implement the methodologies as similar as possible in order to allow a comparison of the resulting accessibility patterns not disturbed by artefacts induced by methodological differences. In each case study, the set of regional accessibility indicators as defined in the TRACC set of accessibility indicators was implemented, calculated and analysed in a highly comparable way.

A pragmatic component had to be part of the case study selection process. Only those areas could be selected as case studies for which project partners had already a fairly good database for accessibility modelling. The seven TRACC case study regions selected are: West Mediterranean in Spain and France, Northern Italy, Bavaria in Germany, the Czech Republic, Poland, the Baltic States and Finland. Together, they form an arc stretching from the Mediterranean Sea in south-western Europe up to the far north of the Nordic countries.

The case study regions cover a wide range of different types of regions in different parts of Europe. They cover both core and peripheral areas, inland, coastal and insular territories, urban and rural territories, densely populated and sparsely populated areas, flat and mountainous territories, territories located both in the old EU15 countries and in the new EU member states. Contrasting the case study regions with the nine standard ESPON territorial typologies, urban-rural, metropolitan regions, border regions, island regions, sparsely populated regions, outermost regions, mountainous regions, coastal regions, regions and regions in industrial transition, yields that the 275 NUTS-3 regions of the case study regions have almost for each regional typology the same share of regions of each type of region as the whole ESPON space.

The results for the different accessibility indicators across the seven case studies can be summarised as follows:

- **Access time to next regional centre.** Results are relatively similar in all case studies for car with minimum values (25th percentile) around 20 to 30 minutes, and maximum values (75th percentile) around 40 to 60 minutes. More populated case studies tend to have better values (Poland, Northern Italy, Western Mediterranean), while case studies comprising sparsely populated regions tend to have higher access times (Finland, Baltic States, Czech Republic). Access time to next regional centre by public transport provides much more diversity of results. While minimum values (25th percentile) are fairly similar for all regions around 30 to 40 minutes (except in the Baltic States, with 60 minutes), maximum values (75th percentile) show a wider dispersion going from around 60 minutes for Northern Italy case study to 120 minutes for the Baltic States (Figures 9.1).
- **Access time to hospitals.** Minimum access times (25th percentile) and maximum access times (75th percentile) are lower than those observed for accessing regional centres, in all case studies. This reflects that the threshold for providing hospital equipments in Europe is generally below the 50.000 inhabitants. Therefore, the health system is more easily accessed than the network of medium sized cities in Europe would seem to intuitively provide a priori. The relative differences of access times between urban, intermediate and rural regions are similar for this indicator than those observed for accessing regional centres (Figures 9.2 to 9.4).

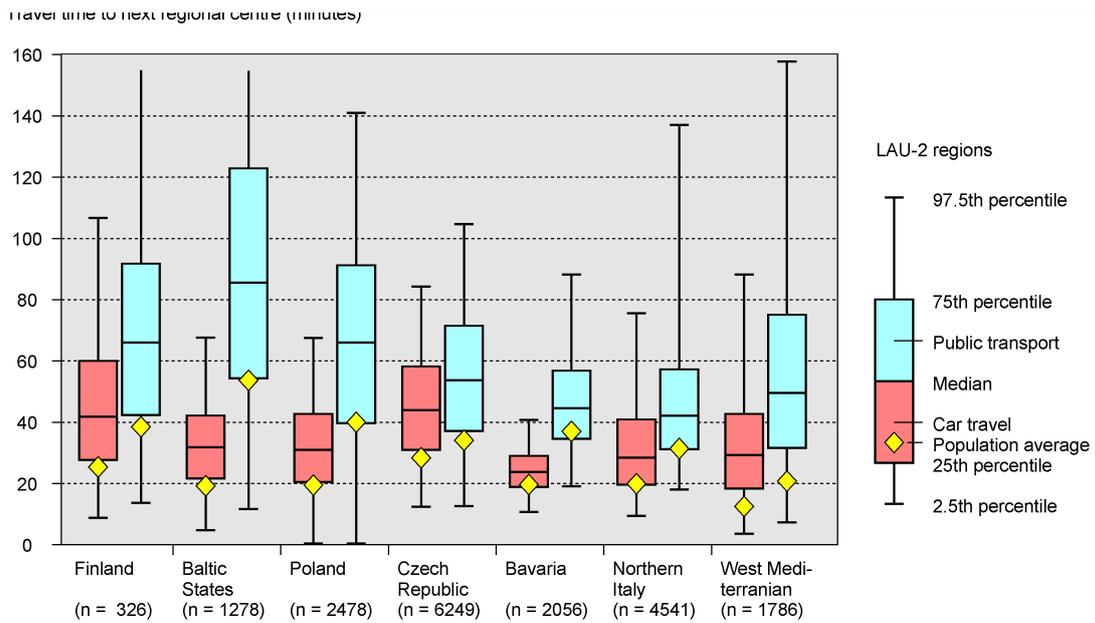


Figure 9.1. Travel time to next regional centre by case study region

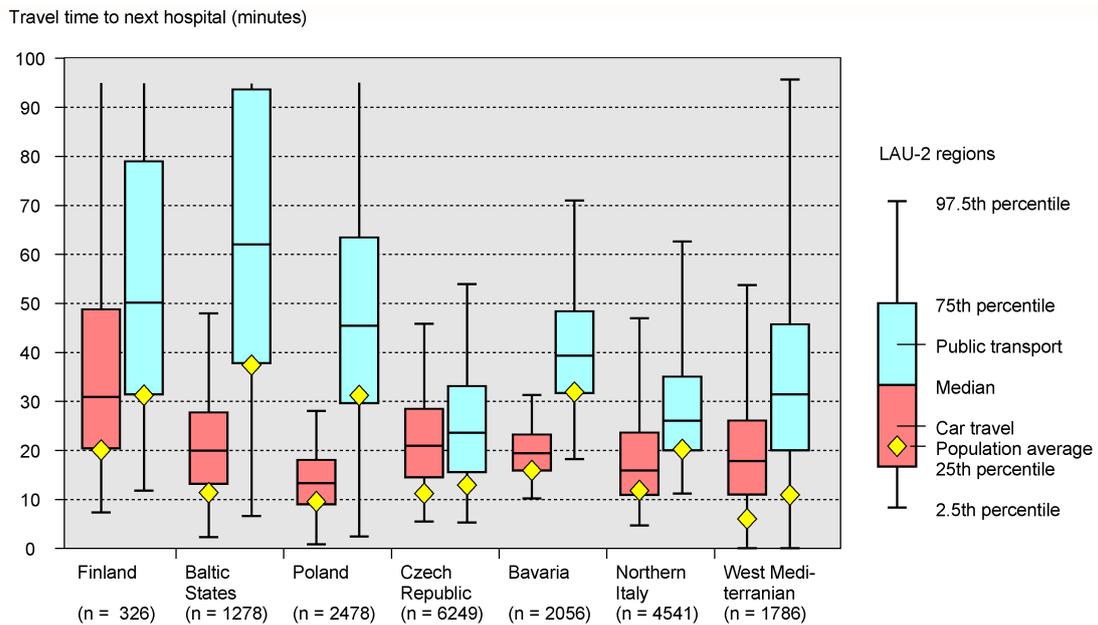


Figure 9.2. Travel time to next hospital by case study region

**Travel time to nearest hospital
by car (LAU-2, 2012)**

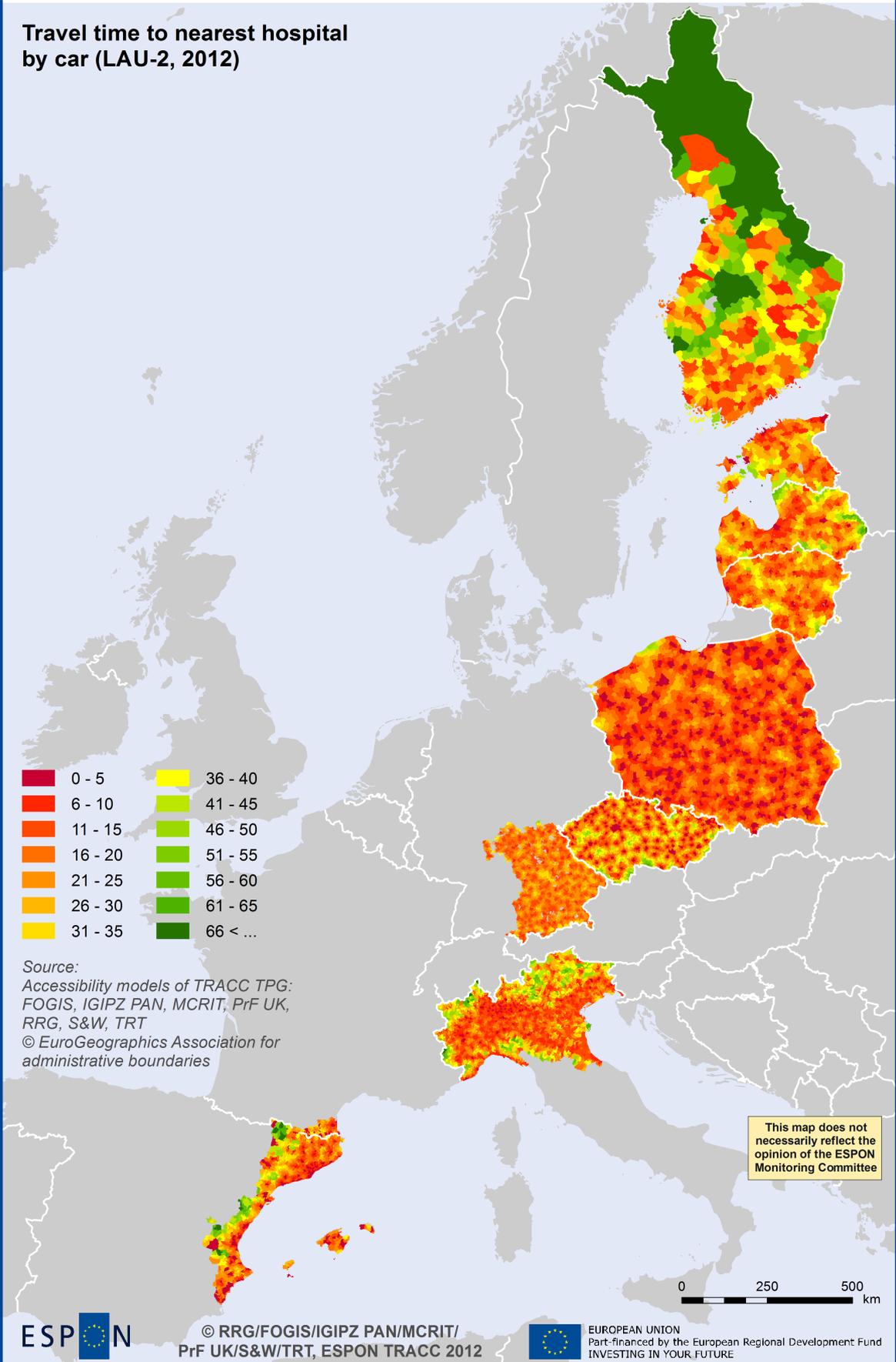


Figure 9.3. Car travel time to next hospital

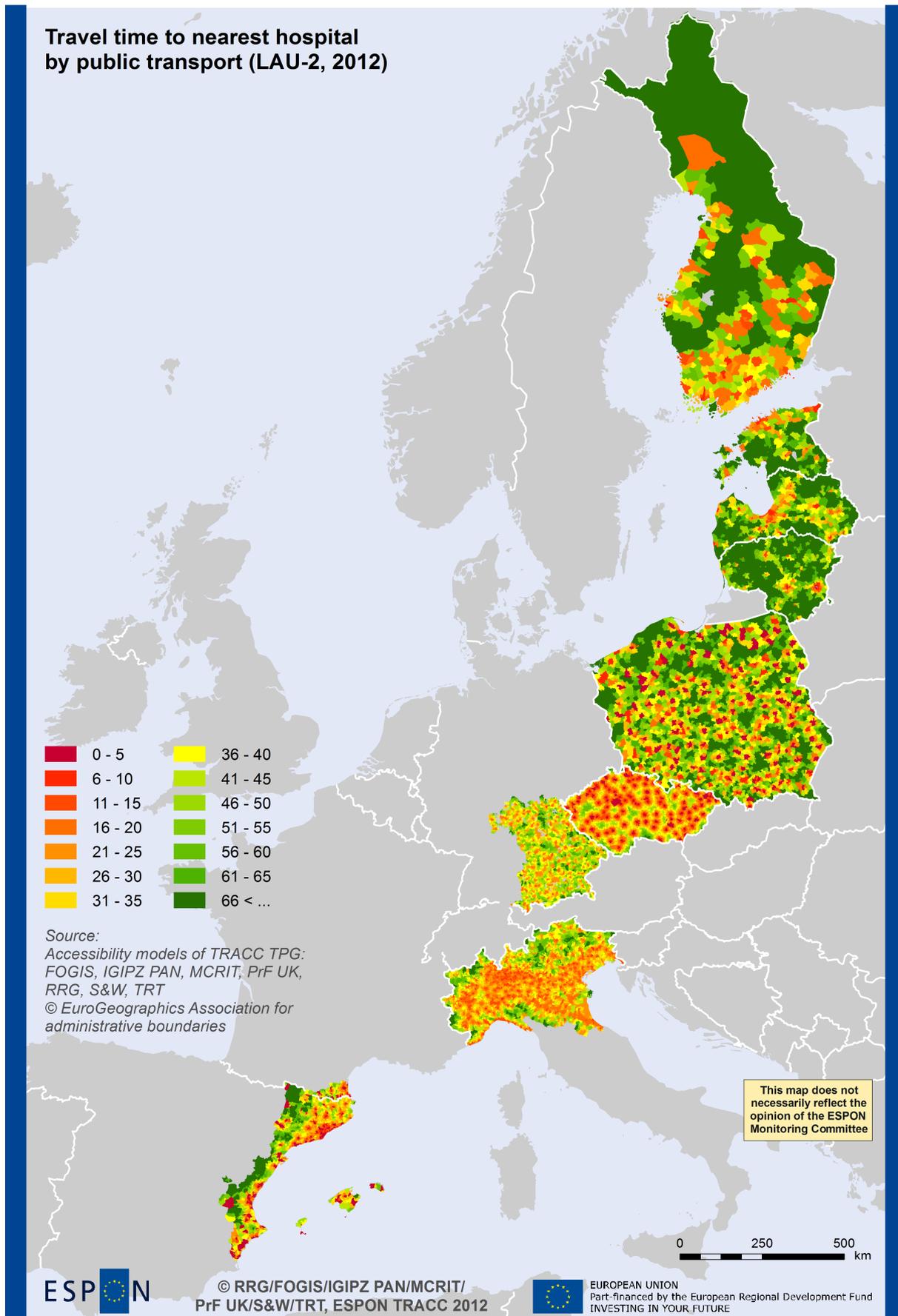


Figure 9.4. Public transport travel time to next hospital

- **Availability of jobs and higher secondary schools.** These indicators reveal in all case studies a more unbalanced performance between different territorial typologies than all other indicators. In all cases, except for Czech Republic, urban regions have a clearly differentiated behaviour in relation to intermediate and rural regions in terms of opportunities reachable. This is especially important by car, but also relevant by public transport. The overall magnitude of cumulated opportunities varies widely from one case study to another, mostly depending on the total amount of population (Figures 9.5 to 9.8).
- **Potential accessibility to population and to medical practitioners.** The potential type indicators show a much more unbalanced pattern between urban and rural regions than access time indicators. As expected, all urban regions perform substantially better than intermediate and rural regions, and much better than overall case study averages. Differences between different territorial typologies are more visible by car accessibility than by public transport (Figures 9.9 to 9.14).

The results from the case study analysis lead to the following conclusions:

- **Minimum availability of functions vs diversity of services and activity on offer.** Indicators considering merely the availability of activities and services, i.e. travel time to the closest target activity or service (Ind1 and Ind4), provide more decentralised patterns on the territory than indicators accounting for the magnitude of available offer, regardless if they consider cumulated opportunities or total potential accessibility. The latter tend to reflect polarisation in largest metropolises and well deserved transport corridors and quickly diminish towards more remote areas, while the former tend to provide more balanced patterns across territories. This reflects that minimum service and administrative endowments are granted to a reasonable extent in most areas of Europe (e.g. at least one hospital available, at least one regional centre available), but differences reveal to be more acute when analysing the amount of possible alternatives of choice for between most populated urban areas and more sparsely populated rural areas (e.g. number of jobs available, schools, doctors).
- **Public services endowment vs availability of economic / social activities and private services.** In general, out from all case studies it seems to appear that the distribution of public services in Europe is much more balanced than the distribution of economic and social activity (population, jobs). This can be attributed to the nature of European welfare systems, where administrations care for minimum endowments of services in less accessible areas, e.g. in rural areas or in peripheries. A few case studies, however, have pointed out the danger of diminishing accessibility to public services driven by the financial crisis in Europe, due mostly to the withdrawal of the public sector and the process of recentralisation of services towards larger regional centres.
- **Public transport accessibility vs car accessibility.** The results illustrate that a distinction between different modes is clearly needed. Accessibility patterns for cars and public transport differ to a large degree, both with respect to the level and also with the spatial patterns, so that modelling results for one mode cannot be used as proxy for the other mode. While accessibility indicators for cars tend to form different types of plateaus, the same indicators for public transport form 'stretches' and 'bands' of high accessibilities along certain transport axis, interrupted by areas of low accessibilities where public transport is missing. Apart from this, in general as demonstrated by the indicator calculations, the accessibility levels by car are higher than those for public transport, but still in city centres and for along some axes public transport is able to reach as high levels as cars do. Regarding public transport as such, one may furthermore think of even splitting 'public transport' mode into individual indicators for rail and bus/tram.

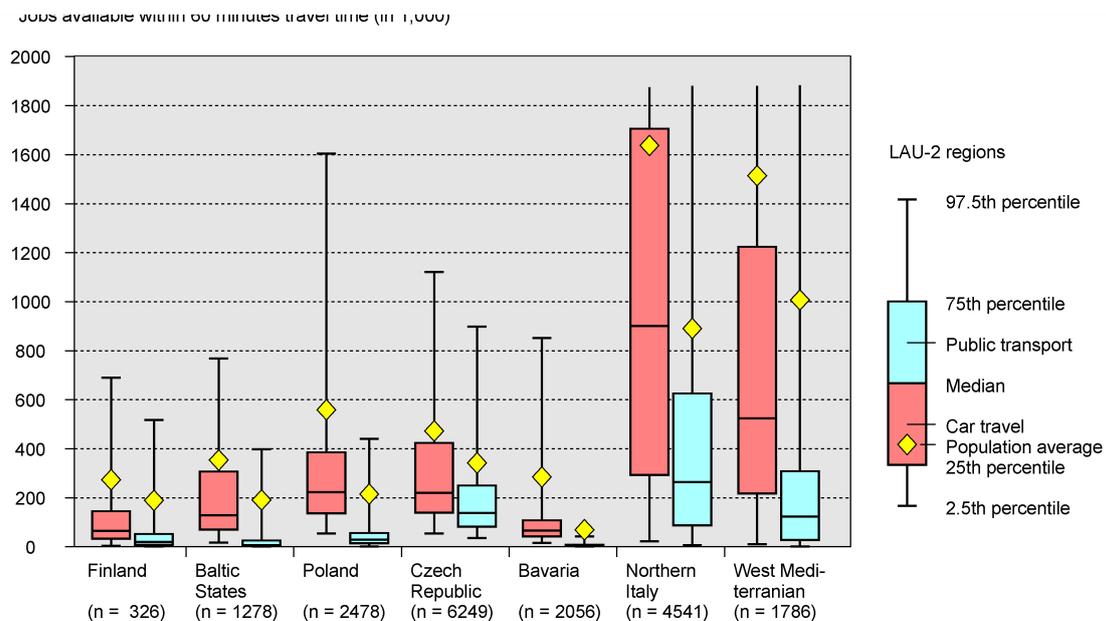


Figure 9.5. Jobs available within 60 minutes travel time by case study region

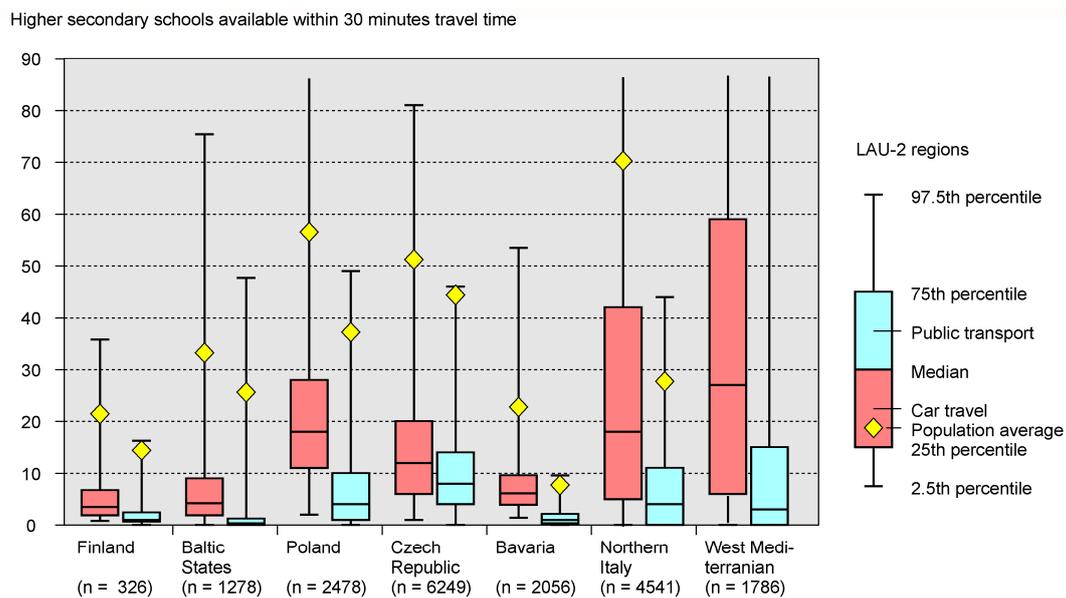


Figure 9.6. Higher secondary schools available within 30 minutes travel time by case study region

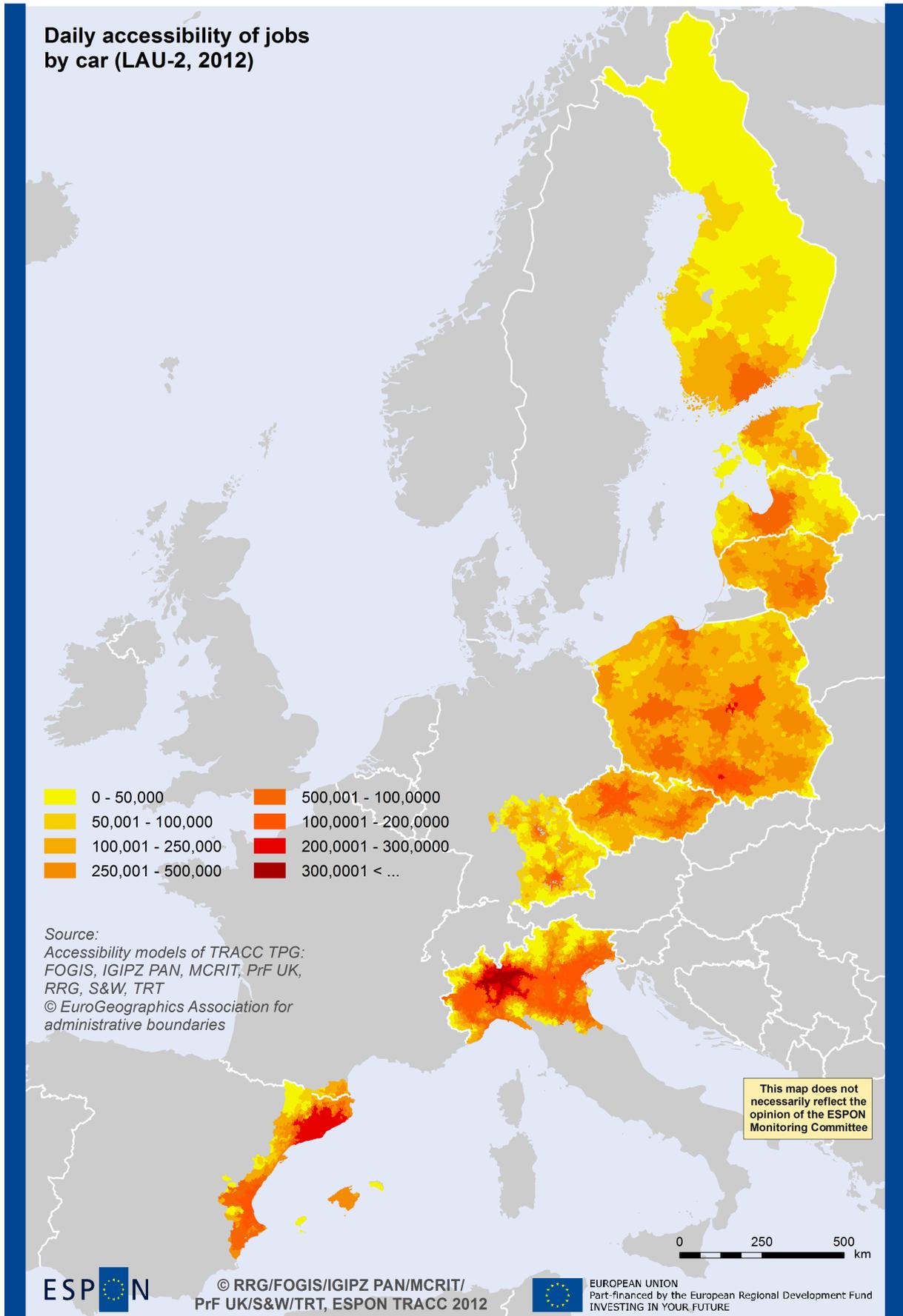


Figure 9.7 Jobs available within 60 minutes car travel time

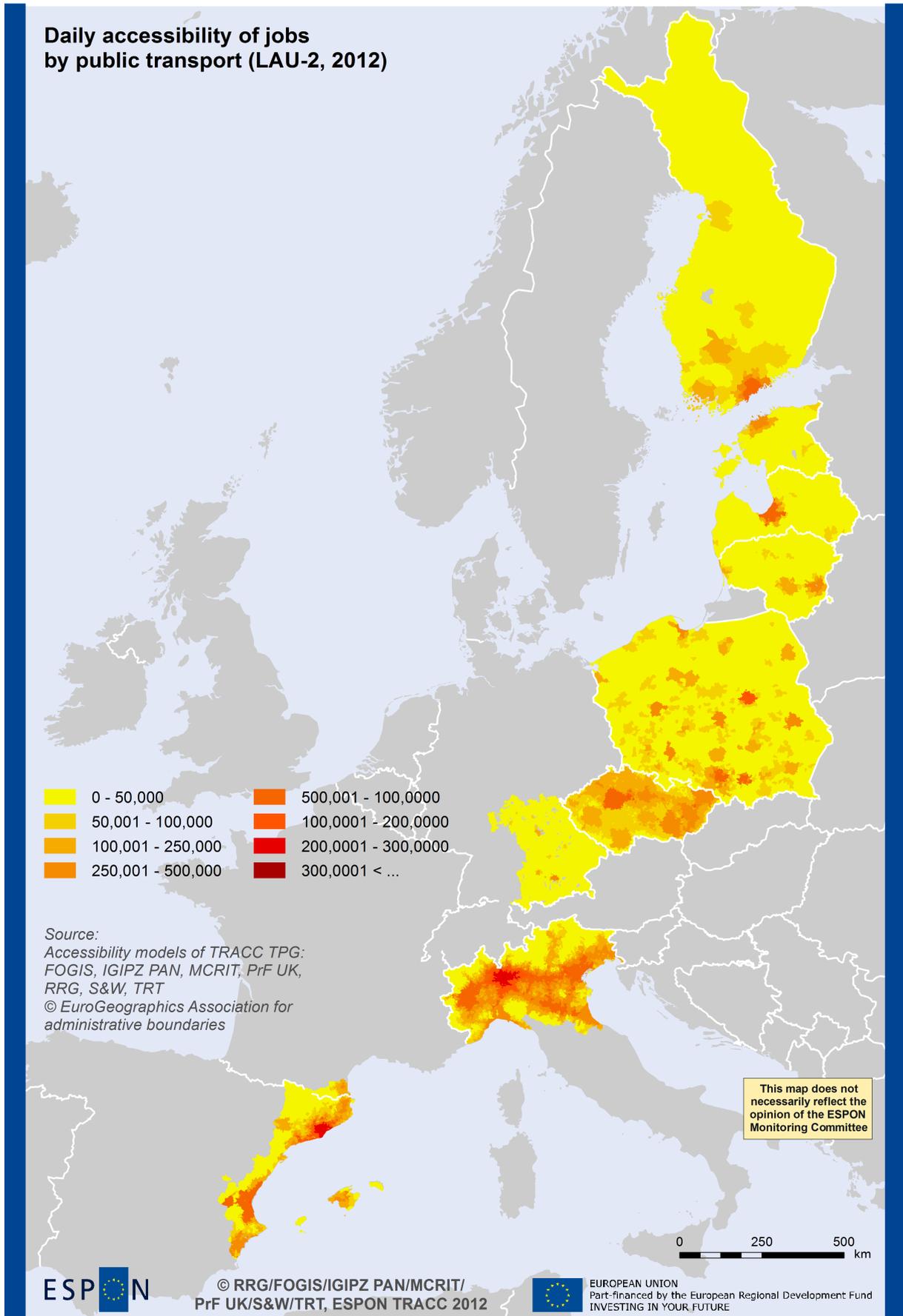


Figure 9.8. Jobs available within 60 minutes public transport travel time

Potential accessibility to population (car average = 100)

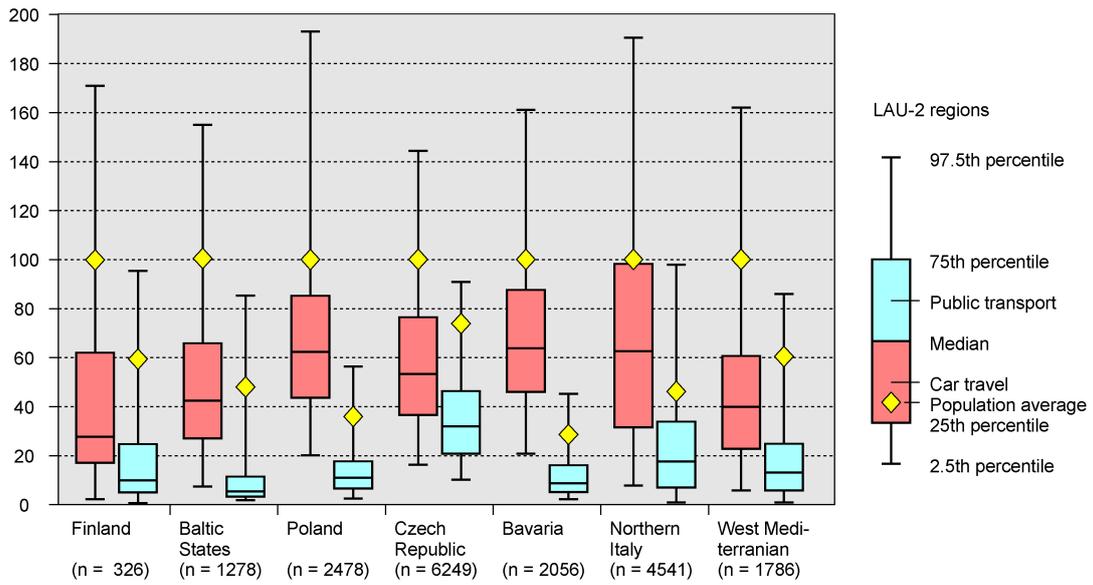


Figure 9.9. Potential accessibility to population by case study region

Potential accessibility to medical doctors (car average = 100)

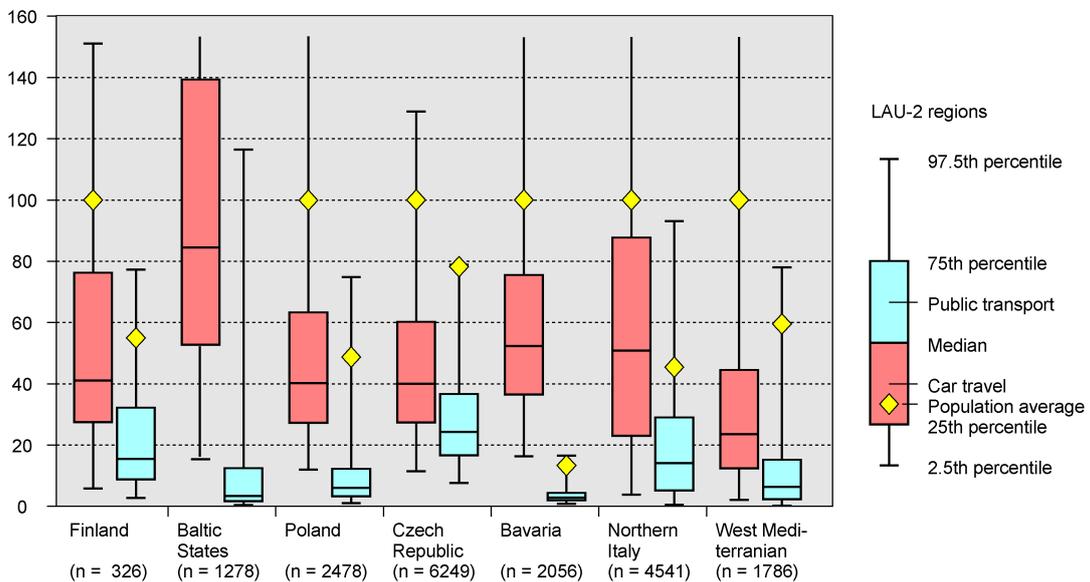


Figure 9.10. Potential accessibility to medical doctors by case study region

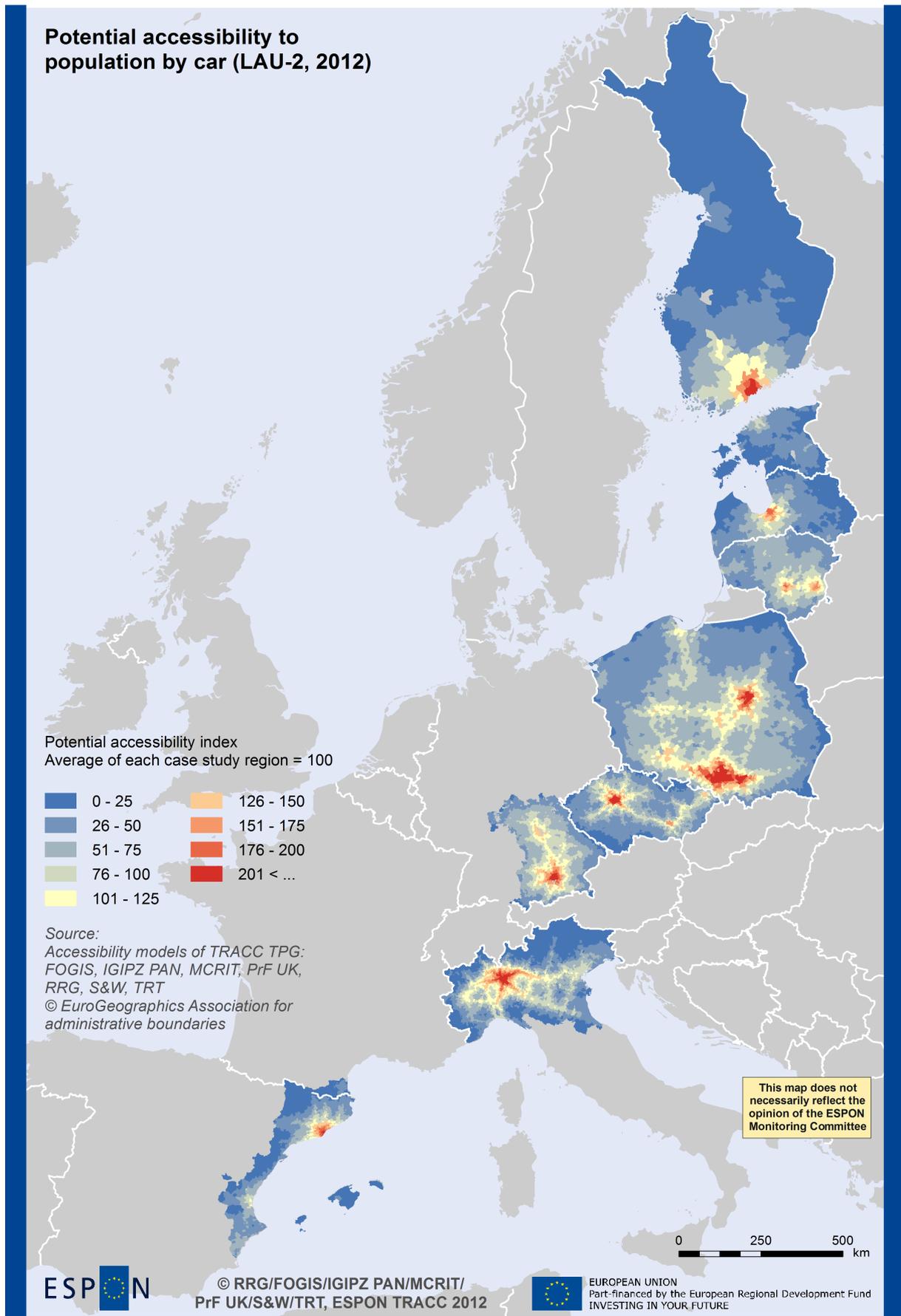


Figure 9.11. Potential accessibility to population by car (Index: each case study average = 100)

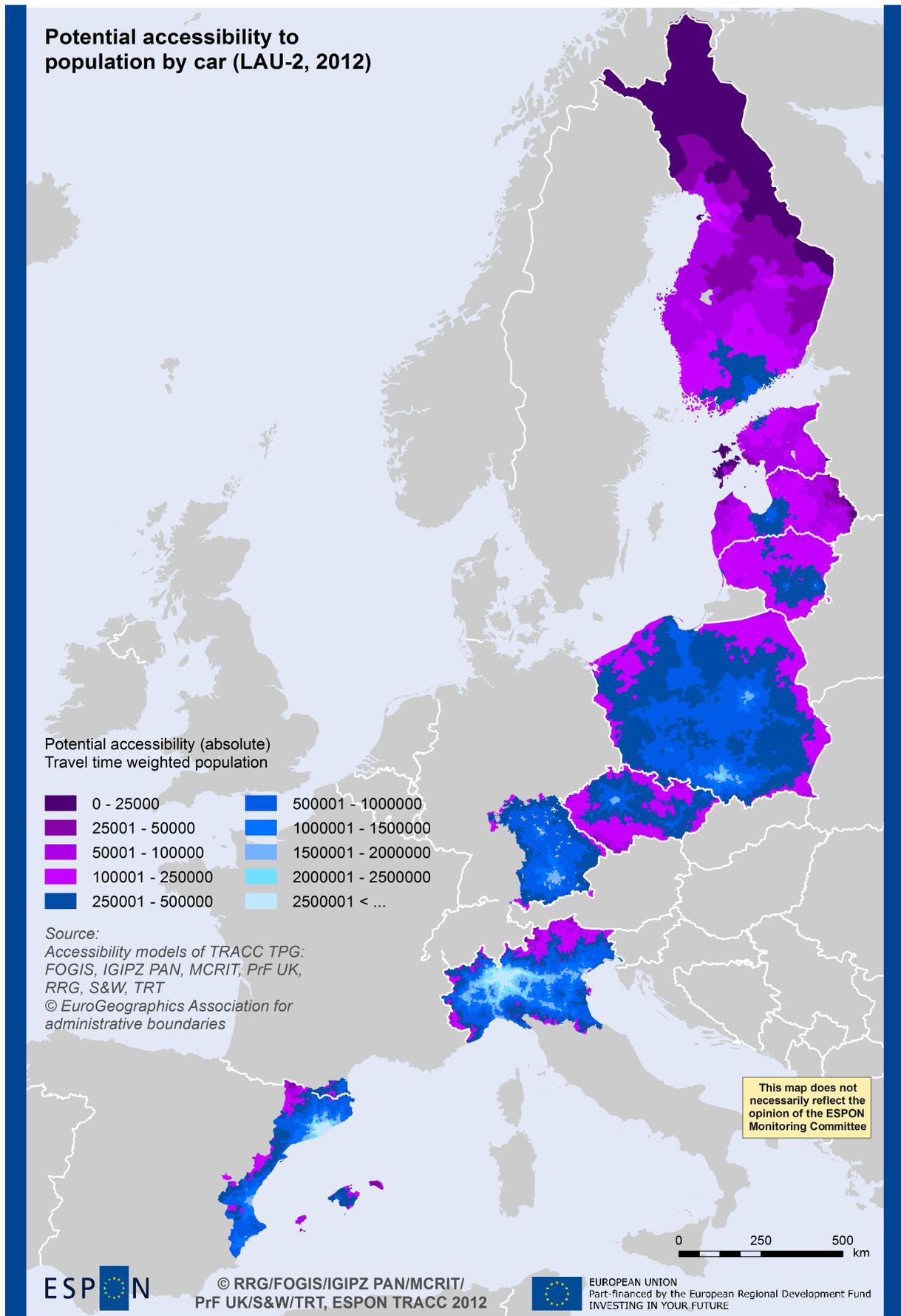


Figure 9.12. Potential accessibility to population by car (absolute values)

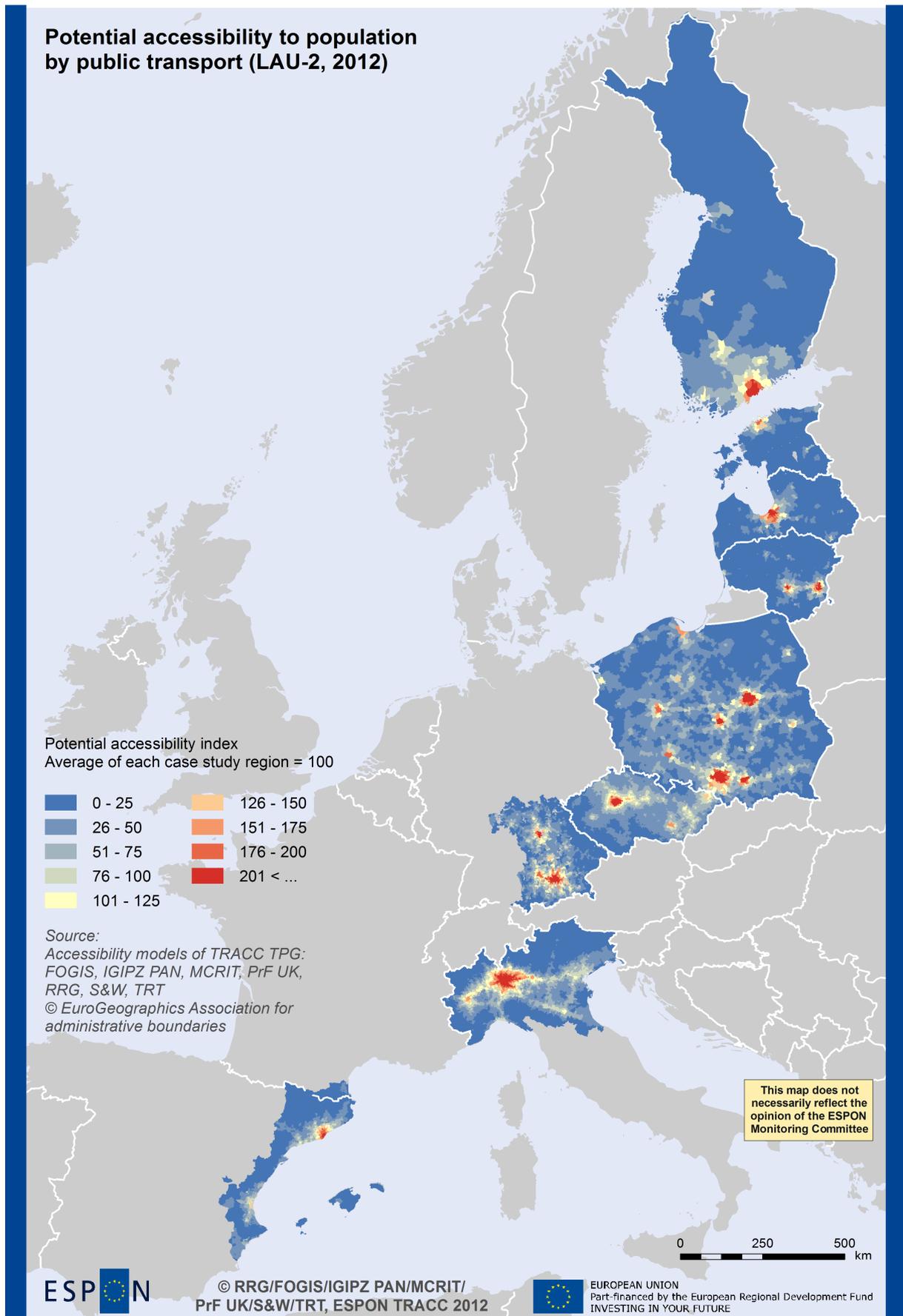


Figure 9.13. Potential accessibility to population by public transport (Index: each case study average = 100)

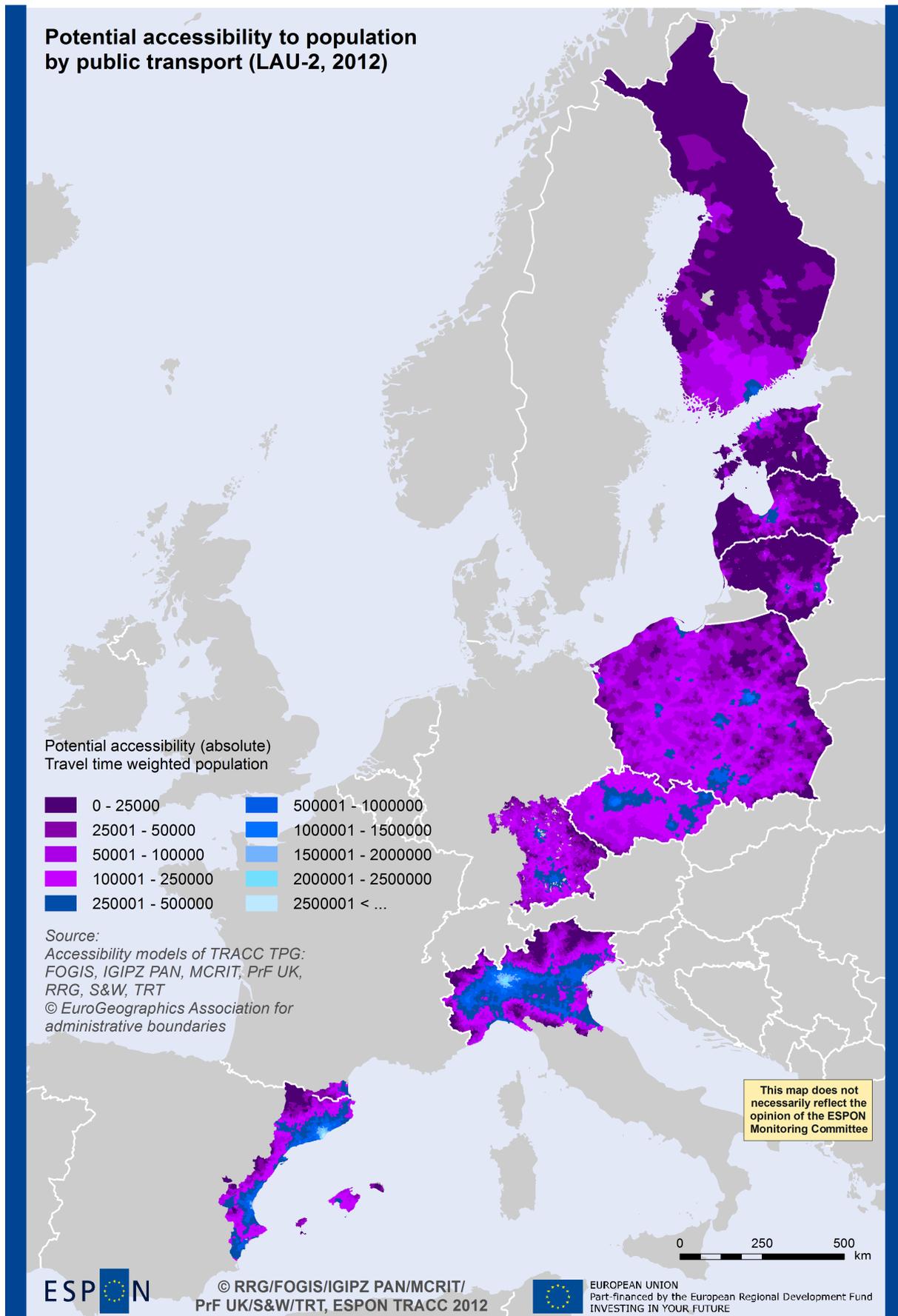


Figure 9.14. Potential accessibility to population by public transport (absolute values)

- **Lack of Services vs lack of infrastructure.** Accessibility is a matter of both transport infrastructure endowment and availability of services in destinations. In some case studies, low accessibility values tend to reflect most remote areas within regions, often substantially less populated (e.g. in interior regions of the Western Mediterranean case study or in northern regions of the Finland case study). In other case studies, low accessibilities are mostly driven by poor transport infrastructure endowment, more often in Eastern Europe than in Western Europe (e.g. in Poland, the Baltic States and Czech Republic). In this direction, reports on Economic and Social Cohesion by DGRegio (2007, 2010) point out to the fact that improved accessibility tends to create new job opportunities for rural and urban areas but that potentialities from improving accessibility depend on the previous competitiveness of the regions concerned, being some regions liable to lose out as they become more open to competition from elsewhere. The reports claim the importance of combining investment in transport infrastructure with support for businesses and human capital development to achieve sustainable economic and social development.
- **Territorial typologies.** In all countries, accessibility for capital regions or for main agglomerations differed significantly from that for rural, peripheral and landlocked regions, as well as for intermediate areas. Therefore, the aggregation of raster results to different types of regions provides additional insights into accessibility patterns of a study area. Even though in this study only six zoom-in areas and only five different types of regions were used, interesting findings were obtained. A combination of raster approach with a typology approach deems promising to obtain high-resolution results on the one hand and easy-to-communicate summary results on the other hand.
- **European peripheries vs European core.** In general, no significant differences can be observed in terms of regional and local accessibility between case studies located in the European Periphery (e.g. Finland, Baltic States or West Mediterranean) and case studies located in the European Core. Regional and local accessibility in all case studies depends to a higher extent on the total level of population living in the concerned region and the level and quality of transport infrastructure endowment.
- **On accessibility indicators.** Accessibility of a region cannot be assessed by just one indicator. In case studies a set of six different accessibility indicators were identified which should help analysing different aspects of access to markets and access to public services. In fact, the results for the different indicators have shown that this broad set is quite useful as the individual indicators are in fact able to depict different facets and different spatial structures. Only results of the last indicator, i.e. accessibility potential to basic health care, seem questionable since this indicator too much reflects the national health care systems rather than locational advantages or disadvantages. Moreover, the definition of this indicator as a potential indicator may be questionable, since one may discuss whether the number of doctors is really a good 'weight'.
- **On spatial resolution of indicators.** Several findings of this study are based on grid cell maps, free of administrative divisions. Several particular areas and spatial patterns can be noticed only on the grid cell basis. TRACC has proven that even at the level of zoom-in regions significant intra-regional disparities exist, which cannot be detected by the traditional, aggregated models. Such intra-regional disparities are often greater than those between regions, thus accessibility studies should acknowledge these disparities and should find ways how to capture them. Raster approaches allow capturing the fine grained accessibility surfaces generated by public transport and also reflect the axial structures caused by high-level transport infrastructures. Raster approaches provide more accurate images which are not dependant on the size of territorial units (e.g. NUTS-3 or LAU-2), a recurrent problem in any mapping and modelling activity. Another advantage of the raster approach is that results can be afterwards easily aggregated to any spatial level (as LAU-2 as done in this study),

10 Integrated view on accessibility of European regions

The chapter will provide an aggregate overview on accessibility of European regions. First, the relationship between different indicators of the TRACC set of accessibility indicators will be explored. Then, the results of the accessibility indicators will be analysed in terms of territorial cohesion.

Accessibility indicators compared

The TRACC set of accessibility indicators is very comprehensive ranging from global to regional indicators, including different generic types of indicators and including indicators for personal travel and for freight transport and all for different modes of transport. This section analyses the relationship between those indicators by looking at correlations between them to depict which indicators have similar and which have different messages. The correlation analysis is done for four relationships, i.e. to compare different generic indicator types, to compare similar indicators for different modes, to compare indicators for different spatial contexts and to compare indicators for travel and freight accessibility.

Comparison between generic indicator types

The first comparison looks at the different generic indicator types. The correlation (as coefficient of determination, r^2) for the relationship between two indicators of different generic type was calculated, however, for the same spatial context and basic characteristic. The coefficient of determination varies considerably across the different indicator pairs considered, lowest r^2 values are almost zero, i.e. there is no statistical relationship and the indicators measure very different aspects of accessibility, highest go up to 0.9, i.e. there is a very high relationship meaning that the variation of one indicator corresponds to the variation of the other.

The relationship between travel cost indicators and indicators of cumulated opportunities is given, however, the coefficient of determination has middle-range values or rather low values. For instance, for the relationship between "Access to global cities" and "Global travel connectivity" r^2 is 0.47, for "Access to top MEGAs" and "European daily accessibility travel" it is 0.62 which means that those different indicator types measure to a certain degree similar aspects. However, for different freight indicator types r^2 is much lower, for "Access to nearest maritime port" and "Daily accessibility freight" it is 0.02, for "Access to freight terminals" and "Availability of freight terminals" it is 0.27 which means that the different indicator types measure very different aspects.

The relationship between travel cost indicators and accessibility potential type indicators is comparable to the previous group, i.e. it is fairly good for some of the indicator types reflecting personal travel, but it is almost not existing for the freight indicators.

Much better is the correlation between indicators measuring cumulated opportunities and potential type indicators. For travel indicators, r^2 is between 0.8 and 0.9 for global and European accessibility indicators, but r^2 is only around 0.2 at the regional level. Highest r^2 is for the relationship between "European daily accessibility travel" and "European potential accessibility travel" for road transport, lowest r^2 is for the relationship between the "Availability of urban functions" and the "National potential accessibility travel". But again, for freight transport indicators the correlation between cumulated opportunity type indicator and potential type indicators is somewhat lower than for travel. Highest correlation between these two types is for the indicators "Daily accessibility freight" and "European potential accessibility freight" for road transport ($r^2 = 0.68$).

Comparison between transport modes

Several indicators in TRACC were calculated for different transport modes. A second analysis gives the correlation between different transport modes for the same indicator. For travel, there is mostly a relative high degree of similarity between road and rail accessibility, and the correlation of road and rail with air accessibility is much lower. Not surprisingly, correlation between those three modes with the multimodal aggregate is rather high with r^2 of between 0.7 and 0.9.

For freight transport, the relationship between transport modes is in many cases much lower. This is in particular true for correlations with water transport and air transport. The correlation between road and rail freight transport accessibility indicators is higher and goes up to a r^2 of 0.75 for the European potential accessibility freight indicator. Road and rail freight accessibility explain to a very high degree multimodal accessibility freight, however road is even higher than rail.

Comparison between different spatial contexts

Another question is to what degree accessibility at a certain spatial levels is similar to accessibility in a different spatial context. Table 10.1 presents the correlation for indicators of the same generic type, but calculated for different spatial contexts. When interpreting the results, one has to consider that the indicator definition is not always exactly the same for different spatial contexts.

Looking first at global v. European accessibility, there seems to be a high degree of similarity for travel as well as for freight accessibility. Lowest correlation for travel indicators is for "Access to global cities – New York" and "Access to top MEGAs" with a r^2 of 0.50 only. But for the cumulated opportunity indicator, the relationship is more closely. And, for the potential type of indicator, the correlation is very high, the r^2 for "Global potential accessibility travel" and "European potential accessibility travel" is 0.89 for multimodal and 0.94 for intermodal. That means that regions that have a good European accessibility usually have also a good global accessibility and vice versa. This finding is confirmed by freight accessibility indicators. In particular for the potential type of indicators, the correlation between global and European accessibility is very high with r^2 ranging from 0.75 to 0.96 for different modes of freight transport.

The relationship between regional and European accessibility is completely different, i.e. much weaker. It is still moderate when looking at the indicator type of cumulated opportunities. That means, if there are several cities within 1 hour travel time or freight terminals available within two hours travel time, the daily accessibility for travel or freight is also good. But r^2 for these relationships are only between 0.40 and 0.49 for travel and 0.56 for freight. Looking at the potential accessibility indicator, the correlation does almost not exist. The coefficient of determination between European and national potential accessibility goes down to 0.24 (road travel) and 0.21 (rail travel) and even down to 0.10 for road freight. That means that a region that has a low accessibility in the national context, does not necessarily has a low European accessibility. In particular, several border regions in Europe demonstrate the opposite, i.e. fairly good European accessibility compared to other parts of the country, but relatively low national accessibility.

Comparison between travel and freight accessibility

How similar are the results of travel accessibility indicators compared to those for freight? From the results for comparable indicators at global, European and regional scale it can be seen that there is a certain relationship between travel and freight accessibility as there is no extremely low value for the coefficient of determination. Lowest r^2 is for "European potential accessibility" by air (0.32). Highest correlations are for "Daily accessibility" by road (0.84) and "European potential accessibility" by rail (0.86), all other relationships are between these extremes.

Table 10.1. Correlation between indicators for different spatial contexts

Spatial context	Basic characteristic	Indicator 1	Indicator 2	Correlation (r ²)
Global v. European	Travel	Access to global cities (Travel time to New York)	Access to top MEGAs (Average travel time to main MEGAs by fastest mode)	0.50
		Global travel connectivity (Number of intercontinental flights reachable in five hours)	European daily acc. travel (pop. in 5 h by fastest mode)	0.66
		Global pot. acc. travel (Intermodal acc. to seat capacity of intercontinental flights)	Europ. pot. acc. travel (to population multimodal)	0.89
		Global pot. acc. travel (Intermodal acc. to seat capacity of intercontinental flights)	Europ. pot. acc. travel (to population intermodal)	0.94
	Freight	Global freight connectivity (Intercontinental container throughput reachable within 36 hours travel time by road)	Daily accessibility freight (GDP within allowed lorry driving time of 13 h)	0.69
		Global pot. acc. freight (to intercontinental container throughput by road)	Europ. potential acc. freight (to GDP by road)	0.75
		Global pot. acc. freight (to intercontinental container throughput by rail)	Europ. potential acc. freight (to GDP by rail unitised)	0.97
		Global pot. acc. freight (to intercontinental container throughput by water)	Europ. potential acc. freight (to GDP by water unitised)	0.96
		Global pot. acc. freight (to intercontinental container throughput multimodal)	Europ. potential acc. freight (to GDP by multimodal)	0.73
	European v. regional	Travel	European daily acc. travel (pop. in 5 h by road)	Avail. of urban functions (Cities in 60 minutes by road)
European daily acc. travel (pop. in 5 h by rail)			Avail. of urban functions (Cities in 60 minutes by rail)	0.49
Europ. pot. acc. travel (to population by road)			National pot. acc. travel (to population by road)	0.24
Europ. pot. acc. travel (to population by rail)			National pot. acc. travel (to population by rail)	0.21
Freight		Daily accessibility freight (GDP within allowed lorry driving time of 13 h)	Avail. of freight terminals (within 2 hours by lorry)	0.56
		Europ. potential acc. freight (to GDP by Road)	National potential acc. freight (to national GDP by lorry)	0.10

To conclude the correlation analysis for the TRACC set of accessibility indicators it can be argued that there is some overlap between a few accessibility indicators, but that in general a set with different accessibility indicators is to be justified. The coefficients of determination are only for a few relationships very high, more often they are in a moderate range or even rather low, i.e. one accessibility indicator can only to a limited degree explain the variation in another accessibility indicator. Thus, there is no single accessibility indicator that might serve all purposes. That means that different analytical questions for different context require always the definition and implementation of appropriate customised accessibility indicators. So, it is important (i) to have

indicators at different spatial contexts, ranging from the global down to regional or even local scale, (ii) to have different types of generic indicators with customised definitions ranging from easy to understand travel cost indicators to more complex potential type indicators, and (iii) finally, it is important to differentiate between different transport modes and between travel and freight indicators.

Disparities in accessibility

Finally, the results of the accessibility indicators will be analysed in terms of territorial cohesion. For all accessibility indicators calculated at NUTS-3 level for the ESPON space, the coefficient of variation gives an indication how disparate or how homogeneous the specific accessibility is distributed across regions in Europe (Table 10.2). This dispersion measure gives for a data set the ratio of the standard deviation to the mean; in the table this is expressed as percent of the mean. The higher the standard deviation the higher the disparities. To give a benchmark, the coefficient of variation for GDP per capita in the European Union is around 40 percent. That means that the GDP per capita of a region in the European Union deviates on average around 40 percent from the EU mean for GDP per capita.

Regional disparities for global accessibility depend on the indicator type. It is rather low for travel cost indicators, only about 14 percent for "Access to global cities" for travel and between 10 and 25 percent for "Access to global freight hubs". However, as for this travel cost indicator, the costs for the part of the transport outside Europe is much higher than the part within Europe, the average is high and the variation around the average is low, i.e. the dispersion measure gives no substantial dispersion in total costs. This is very different for cumulated opportunities for global accessibility. The coefficient of variation is at 77 percent for travel, for freight transport it is 58 percent for road, 47 for rail and 285 for water transport. Potential type indicators are inbetween with about 40 percent for travel and around 30 percent for freight.

Disparities for European accessibility travel are lowest for the travel cost indicator. The variation is only 23 percent for the "Access to top MEGAs". The disparities for the other two indicator types are much higher, between 70 and 90 percent depending on mode for "European daily accessibility travel". Also the "European potential accessibility travel" sees considerably disparities among European regions. The coefficient of variation is highest for road (60 percent) and rail (62 percent), and somewhat lower than 40 percent for air, multimodal and intermodal. The latter means that when considering several modes together, a deficit in one mode can be substituted by another transport mode.

European freight disparities are highest for the "Access to nearest maritime port" (106 percent), a consequence of the uneven spatial distribution of sea ports in Europe. However, also "European daily accessibility freight" sees considerable disparities between regions in Europe (73 percent). The potential accessibility indicators for freight show clear disparities, but they are below the value for daily accessibility. Interesting to note that for those modes that have a distinction between "normal" freight transport and unitised (container) freight transport, the disparities for unitised transport are much larger, an outcome of the differences in the availability of intermodal transshipment facilities in Europe.

At the regional level, disparities with respect to the availability of urban functions within 1 hour travel time (136 percent for road, 155 percent for rail) and availability of freight terminals (111 percent for road) is extremely high. On the contrary, national potential accessibility shows lower disparities with around 30 percent for travel by road or rail and of 24 percent for freight by road.

Table 10.2. Coefficient of variation (in percent of the mean) for accessibility indicators

<i>Spatial context</i>	<i>Basic characteristics</i>	<i>Generic type of accessibility indicator</i>		
		<i>Travel cost</i>	<i>Cumulated opportunities</i>	<i>Potential</i>
Global	Travel	Access to global cities Travel time to New York 13.8 intermodal	Global travel connectivity Flights to intercontinental destinations reachable in five h 76.7 intermodal	Global potential accessibility travel To seat capacity of intercontinental flights departing in Europe 40.8 intermodal
	Freight	Access to global freight hubs Generalised travel cost to intercontinental hubs 9.5 maritime New York 25.6 air New York 17.3 maritime Shanghai 22.8 air Shanghai	Global freight connectivity Intercontinental container throughput reachable within 36/48/72 hours 57.9 road 46.9 rail 285.7 water	Global potential accessibility freight To container throughput of European sea ports 27.1 road 25.7 rail 31.2 water 25.5 multimodal
Europe	Travel	Access to top MEGAs Average travel time to top MEGAs 22.8 fastest mode	European daily accessibility travel to population 72.2 road 87.1 rail 84.6 fastest mode	European potential accessibility travel To population 59.5 road 61.6 rail 38.6 air 39.0 multimodal 35.5 intermodal
	Freight	Access to nearest maritime port Average generalised cost to nearest maritime port 106.4 all modes	European daily accessibility freight GDP accessible within allowed lorry driving time 72.9 road	European potential accessibility freight To GDP 42.7 road 23.8 rail 41.2 rail unitised 30.4 water 51.4 water unitised 41.2 air 26.6 multimodal 40.6 multimodal unit.
Regional	Travel (Europe-wide)	Access to high-level transport infrastructure Weighted access time to motorway exits, rail stations, airports	Availability of urban functions Cities > 50.000 within 60 minutes travel time 135.9 road 155.3 rail	National potential accessibility travel To national population 30.9 road 31.5 rail
	Freight (Europe-wide)	Access to freight terminals Weighted based access time to freight terminals 49.1 all modes	Availability of freight terminals Freight terminals within 2 h travel time 111.4 road	National potential accessibility freight To national GDP 23.7 road

Overall, the degree of spatial disparities in accessibility varies substantially across different indicators. Indicators of the type cumulated opportunities tend to show much higher disparities than indicators of the potential type which are based on a more smoothing definition. For the travel cost type indicator, the degree of disparities depends very much on the selected types of destinations. Compared with the disparities in GDP per capita, cumulated opportunity indicators show in general much less cohesion than the economic performance. For potential type indicators this depends on the spatial context and the transport mode. Most of the indicators are in the range or somewhat below the disparities of GDP per capita, however, for important aspects such as European potential accessibility by road and rail, the coefficients of variation for accessibility are about 50 percent higher than for the economic performance, i.e. disparities in accessibility potential are much higher than disparities in economic performance.

11 Accessibility dynamics

Accessibility is not static, but changes over time. According to the basic concept of accessibility underlying this report, changes can either be induced by change in the impedance term, i.e. infrastructure, transport services, transport costs etc., or by changes in the opportunities to be reached, e.g. population, GDP, jobs, services of general interest and other. In the corresponding chapter of the Scientific Report, such changes are analysed at the European level and at the local/regional level using accessibility potential indicators. First, accessibility changes at European level that happened during the period 2001 – 2011 are presented for different transport modes. Then, the accessibility changes to be expected from the future trans-European transport networks at local and regional level will be presented by using the case studies as examples. Here, only the Europe-wide accessibility changes are briefly presented.

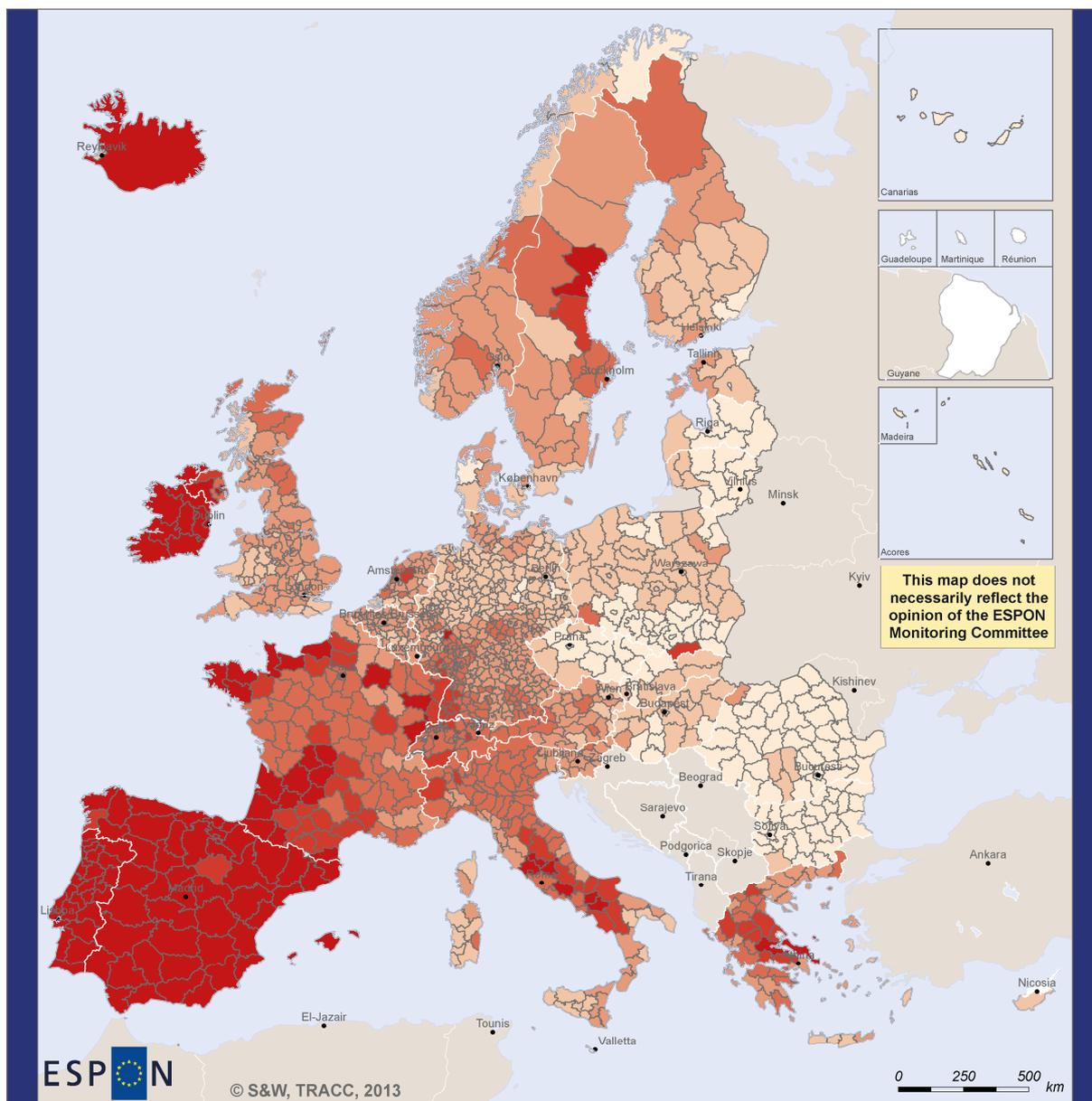
In Europe, the last decade has seen huge investments in the trans-European transport infrastructure and changes in transport services, but also regional population change, mainly due to migration. The combined working of these two factors has changed the European accessibility pattern. However, as seen in Chapter 7, the overall patterns have not changed substantially compared to accessibility pattern of previous studies. However, a closer look at the changes via analysing the differences shows substantial shifts of accessibility for European regions.

In the decade between 2001 and 2011, highest relative accessibility potential changes by road happened in regions outside the European core. Spain, Portugal and south-western France, regions in Ireland and the Nordic countries, and many regions in eastern European countries have experienced significant accessibility gains by road transport. Clearly visible are the accessibility impacts of new motorways such as the east-west motorway in Poland or the Via Egnatia in northern Greece.

The pattern of change of accessibility by rail is somewhat different due to other investment strategies of European countries (Figure 11.1). Clearly visible are the effects of investments in high-speed rail infrastructure in the Iberian Peninsula, France, Italy, Germany and Belgium. Gains in accessibility potential often exceed 50 percent. Very distinct to rail is the very modest development of accessibility by rail in eastern European regions. The main focus of transport infrastructure development in these countries was on road, not on rail, so the improvements are modest.

Another pattern of changes emerges for accessibility potential by air.. Largest improvements are in regions that have smaller airports. This is particular true for the countries in Eastern Europe in which many airports have been developed outside the capital regions. The capital regions had already fairly good accessibility potentials by air a decade ago.

The combined working of the three transport modes is expressed in the multimodal accessibility indicator. The changes of multimodal potential accessibility are presented in Figure 11.2. The tendency is that higher relative gains did occur in less central areas, but not everywhere in the periphery. Central areas did grow less in relative terms in multimodal accessibility.




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Regional level: NUTS 3
 Source: Spiekermann and Wegener
 Urban and Regional Research (S&W), 2013
 Origin of data: SASI Model, 2013
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Accessibility potential, rail Change 2001 - 2011 (%)

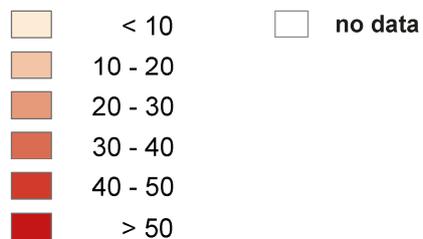
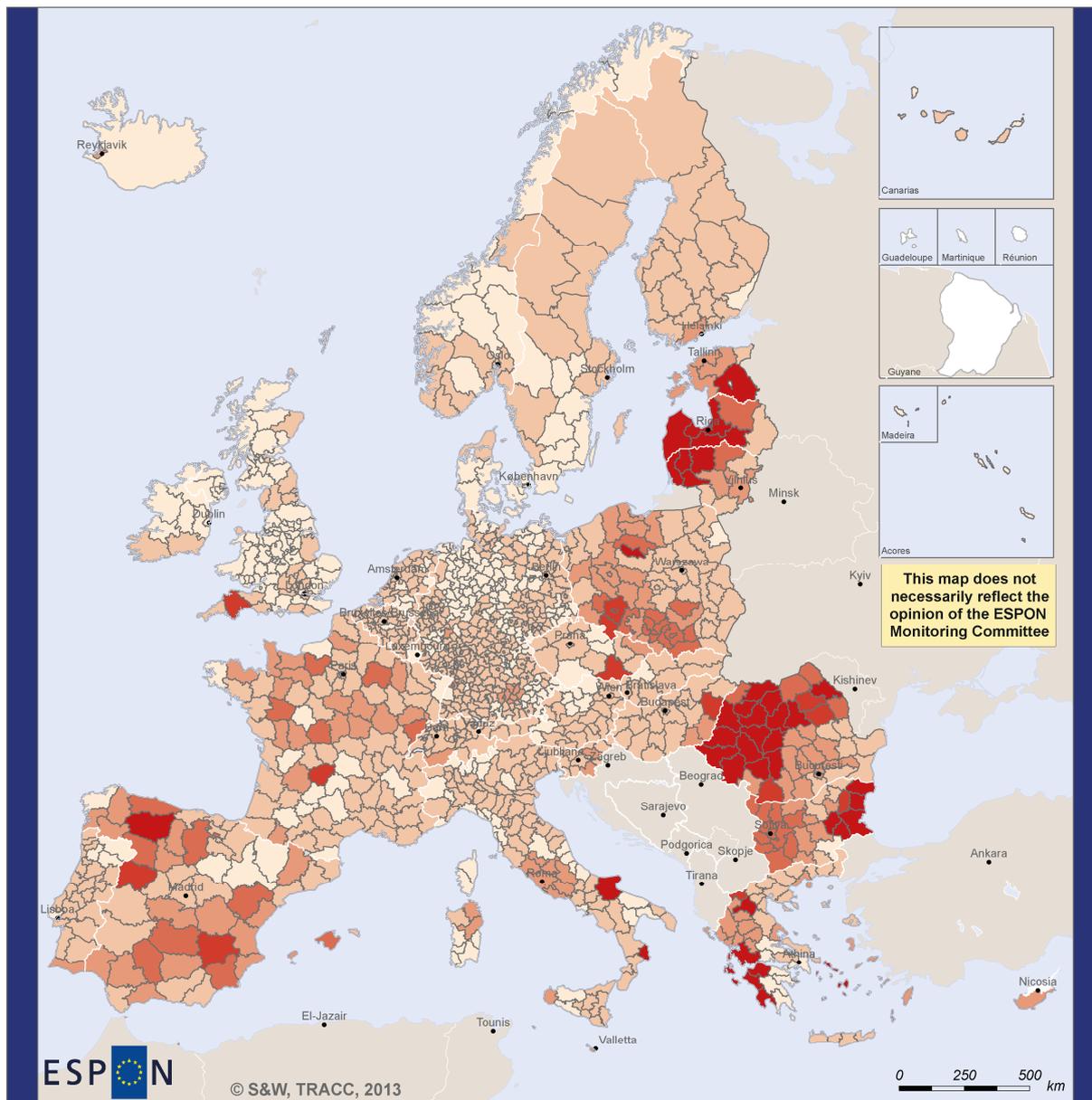


Figure 11.1. Potential accessibility to population by rail, relative change 2001 – 2011



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Regional level: NUTS 3
Source: Spiekermann and Wegener
Urban and Regional Research (S&W), 2013
Origin of data: SASI Model, 2013
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Accessibility potential, multimodal Change 2001 - 2011 (%)

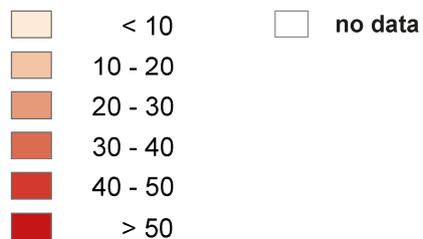


Figure 11.2. Potential accessibility to population multimodal, relative change 2001 – 2011

12 Accessibility and regional development

As discussed in Chapter 4, the important role of transport infrastructure for regional development is one of the fundamental principles of regional economics. In its most simplified form this principle implies that regions with better access to the locations of input materials and markets will, *ceteris paribus*, be more productive, more competitive, and hence more successful than more remote regions.

Today the relationship between transport infrastructure and economic development has become more complex than ever. There are successful regions in the European core confirming the theoretical expectation that location matters, but there are also centrally located regions suffering from industrial decline and high unemployment. On the other side of the spectrum, the poorest regions, as theory would predict, are at the periphery, but there are also prosperous peripheral regions such as the Nordic countries. To make things even more difficult, some of the economically fastest-growing regions are among the most peripheral ones. Figure 12.1 (ESPON 1.2.1 2004, 22) illustrates this complexity by showing the regions that perform better or worse than their geographical position would suggest.

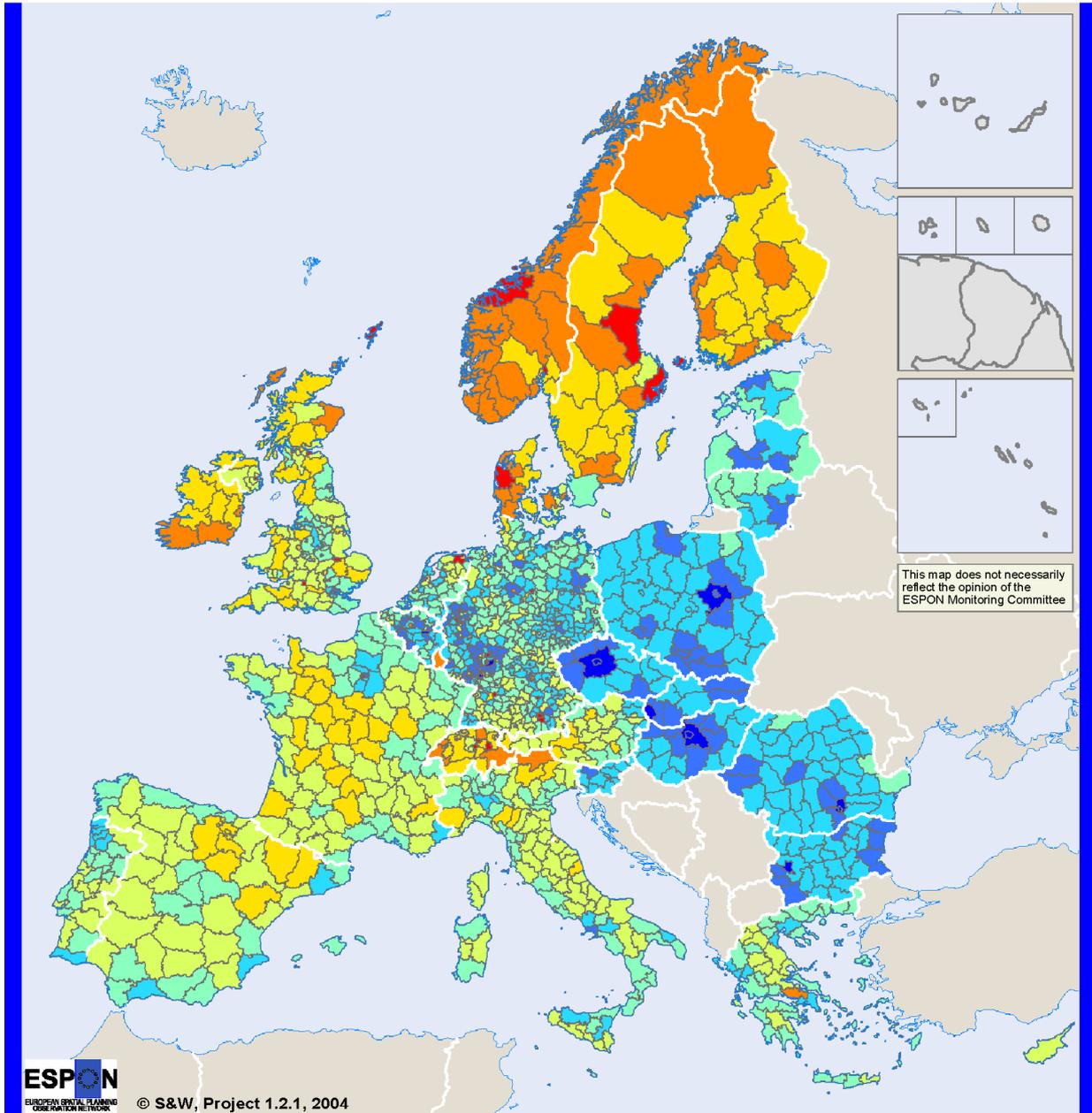
The EU hopes to contribute to reducing the socioeconomic disparities between its regions by developing the trans-European transport networks (TEN-T). However, although they are among the most ambitious initiatives of the European Community, the value of the TEN-T programme is not undisputed.

Critics argue that many of the new connections fail to link peripheral countries to the core and instead strengthen the ties between central regions, reinforcing their accessibility advantage. Some argue that regional development policies based on the creation of infrastructure in lagging regions have not succeeded in reducing regional disparities in Europe, whereas others point out that it has yet to be ascertained that the reduction of barriers between regions has disadvantaged peripheral regions. From a theoretical point of view, both equalising and polarising can occur. A new motorway or high-speed rail connection between a peripheral and a central region, for instance, makes it easier for producers in the peripheral region to market their products in large cities; however, it may also expose the region to the competition of more advanced products from the centre and so endanger formerly secure regional monopolies. These issues have received new attention through the enlargements of the European Union in 2004 and 2007 and the recent economic crisis.

There have already been several ESPON projects addressing the regional economic impacts of changes in accessibility through transport infrastructure investments. ESPON 2.1.1 (Territorial Impacts of EU Transport and TEN Policies) assessed the impacts of EU and national transport and telecommunications policies on regional economic development and cohesion in the enlarged European Union using three forecasting models (ESPON 2.1.1, 2003). The transport policy scenarios included different priorities of TEN-T infrastructure investments (e.g., all priority projects, all projects, only cross-border projects, or only projects in lagging regions), different options of transport pricing, and combinations of both.

The main general result from the scenario simulations was that the overall effects of transport infrastructure investments and other transport policies are small compared with those of socio-economic and technical macro trends such as globalisation, increasing competition between cities and regions, aging populations, and increasing labour force participation and labour productivity. The second main result was that even large increases in regional accessibility translate into only very small increases in regional economic activity. However, that statement needs to be qualified, as the magnitude of the effect depends on the already existing level of accessibility:

- For regions in the European core with all the benefits of a central geographical location *plus* an already highly developed transport and telecommunications infrastructure, additional gains in accessibility bring few additional incentives for economic growth.



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Relation of economic performance to location

- Strong underperformance
- Clear underperformance
- Underperformance
- Little underperformance
- Little overperformance
- Overperformance
- Clear overperformance
- Strong overperformance

Origin of data: Spiekermann & Wegener (S&W)

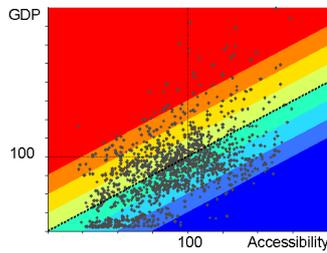


Figure 12.1. Accessibility v. economic performance, 2001 (ESPON 1.2.1, 2004, 22)

- For regions at the European periphery, however, which suffer from a remote geographical location *plus* an underdeveloped transport infrastructure, a gain in accessibility brings significant progress in economic development. But the opposite may happen if the new connection opens a formerly isolated region to external competition.
- The magnitude of the effects of infrastructure projects is related to the number and size of projects. The effect of pricing scenarios depends on their direction: Scenarios that make transport less expensive have a positive, scenarios that make transport more expensive, a negative economic effect. Negative effects of pricing policies can be mitigated by their combination with network scenarios with positive economic effects, although the net effect depends on the magnitude of the two components.

Similar scenarios were calculated in ESPON 1.1.3 (Enlargement of the European Union and the Wider European Perspective as Regards its Polycentric Spatial Structure) for the new EU member states. There the scenarios examined the effects of enlargement as such and the associated reductions in border waiting times and different strategies of transport infrastructure investments in the new member states (ESPON 1.1.3 2006). The results were in general agreement with those achieved in ESPON 2.1.1 indicating that transport infrastructure investments in the new member states could make a significant contribution to help those countries' economies catch up with those of the old member states.

ESPON 3.2 (Spatial Scenarios and Orientations in Relation to the ESDP and Cohesion Policy) examined the effects of different transport infrastructure programmes (ESPON 3.2, 2006). Although the contribution of accessibility to the changes in regional socioeconomic impacts could not be clearly identified as they were packaged with other policies, the evaluation confirmed the results of ESPON 2.1.1 showing that the strongest economic effects of accessibility changes can be expected in the western regions of the new member states and the Iberian peninsula.

Similar scenarios in which transport infrastructure changes are combined with other policies in complex policy packages are currently being examined in ESPON ET2050 (Territorial Scenarios and Visions for Europe 2050). The preliminary results confirm that the impacts of accessibility are small where accessibility is already high but are significant in peripheral regions where accessibility is low (ESPON ET2050, 2013).

The SASI model

In the ESPON TRACC project the SASI regional economic model was used to investigate the likely economic, social and environmental impacts of different EU and EU member states strategies to influence the spatial development of the European territory, i.e. to assess these impacts with respect to the major European Union goals competitiveness, cohesion and sustainability.

The SASI model is a recursive simulation model of socio-economic development of regions in Europe subject to exogenous assumptions about the economic and demographic development of the European Union as a whole and transport and other spatial policies. The SASI model differs from other approaches to model regional development by modelling not only production (the demand side of regional labour markets) but also population (the supply side of regional labour markets). The model was developed at the University of Dortmund in co-operation with the Technical University of Vienna (Wegener, Bökemann, 1998) and has since been applied in several EU projects, among them IASON (Integrated Appraisal of Spatial Economic and Network Effects of Transport Investments and Policies), ESPON 2.1.1 (Territorial Impacts of EU Transport and TEN Policy), ESPON 1.1.3 (Enlargement of the European Union and the Wider European Perspective as Regards its Polycentric Spatial Structure), the Interreg-IIIb project AlpenCORS (Alpen Corridor South) and the 6th RTD Framework Programme project STEPs (Scenarios for the Transport System and Energy Supply and their Potential Effects).

For forecasting regional economic development the SASI model applies an extended production function with regional economic structure, productivity, accessibility, availability of labour, R&D investments, population density and availability of developable land as explanatory variables. In addition it uses a migration function in which net migration is forecast with regional wage level and quality of life as explanatory variables. To take account of the slow process of economic structural change, the economic variables are lagged by five years. A detailed documentation of the SASI model is contained in Wegener (2008) and S&W (2013).

The spatial dimension of the model is established by the subdivision of the European Union plus Norway, Switzerland, Liechtenstein, Iceland and the Western Balkan countries in 1,338 NUTS-3 regions and by connecting these by road, rail and air networks. For each region the model forecasts the development of accessibility and GDP per capita. In addition cohesion indicators expressing the impact of transport infrastructure investments and transport system improvements on the convergence (or divergence) of socio-economic development in the regions of the European Union are calculated. The temporal dimension of the model is established by dividing time into periods of one year duration. By modelling relatively short time periods both short- and long-term lagged impacts can be taken into account. In each simulation year the submodels of the SASI model are processed in a recursive way, i.e. sequentially one after another. This implies that within one simulation period no equilibrium between model variables is established; in other words, all endogenous effects in the model are lagged by one or more years.

All simulations with the SASI model start from the year 1981 to demonstrate that the model is able to reproduce the past development and how the future development continues or deviates from the past development. The forecasting horizon of the model has recently been extended to the year 2051.

The SASI model has six forecasting submodels: European Developments, Regional Accessibility, Regional GDP, Regional Employment, Regional Population and Regional Labour Force. A seventh submodel calculates Socio-Economic Indicators with respect to efficiency and equity.

TRACC scenarios

To examine the impacts of accessibility changes on regional competitiveness, cohesion and sustainability one Baseline Scenario and three policy scenarios were defined (see Table 11.1):

- The *Baseline* scenario represents the most likely development of the transport infrastructure with implementation of the core TEN-T network until 2020 and no further network extensions thereafter, yet moderate reductions of travel times through upgrading of the existing network.
- The *Growth* scenario TA assumes concentration of TEN-T investments on the 15 old EU member states before 2004 (EU15) and no such investments in the new member states that joined the EU after 2004 (EU12) and similar focus of the upgrading of the existing network.
- The *Cohesion* scenario TB assumes concentration of TEN-T investments on the new member states (EU12) and no such investments in the old member states (EU15) and similar focus of the upgrading of the existing network.
- The *Sustainability* scenario assumes only rail investments after 2021 and an environmental tax on road and air travel.

Table 12.1. TRACC scenarios

Scenario		Countries	Network development	Infrastructure system improvement (travel time reduction by factor below)			
Code	Name			2026	2031	2041	2051
00	Baseline	All	Nothing after 2021	0.99	0.98	0.96	0.94
TA	Growth	EU15	TEN-T after 2021	0.90	0.85	0.75	0.65
		EU12	Nothing after 2021	0.99	0.98	0.96	0.94
TB	Cohesion	EU15	Nothing after 2021	0.99	0.98	0.96	0.94
		EU12	TEN-T after 2021	0.90	0.85	0.75	0.65
TC	Sustainability	All	TEN-T rail after 2021 Environmental tax on road and air	rail:	rail:	rail:	rail:
				0.90	0.85	0.75	0.65
				road:	road:	road:	road:
				0.99	0.98	0.96	0.94

Scenario results

Figure 12.2 compares the assumed accessibility changes in the four scenarios over time, separately for the old (EU15) and new (EU12) member states. Each trajectory indicates the development of accessibility travel road/rail in one scenario; the heavy black line represents the development in the Baseline scenario.

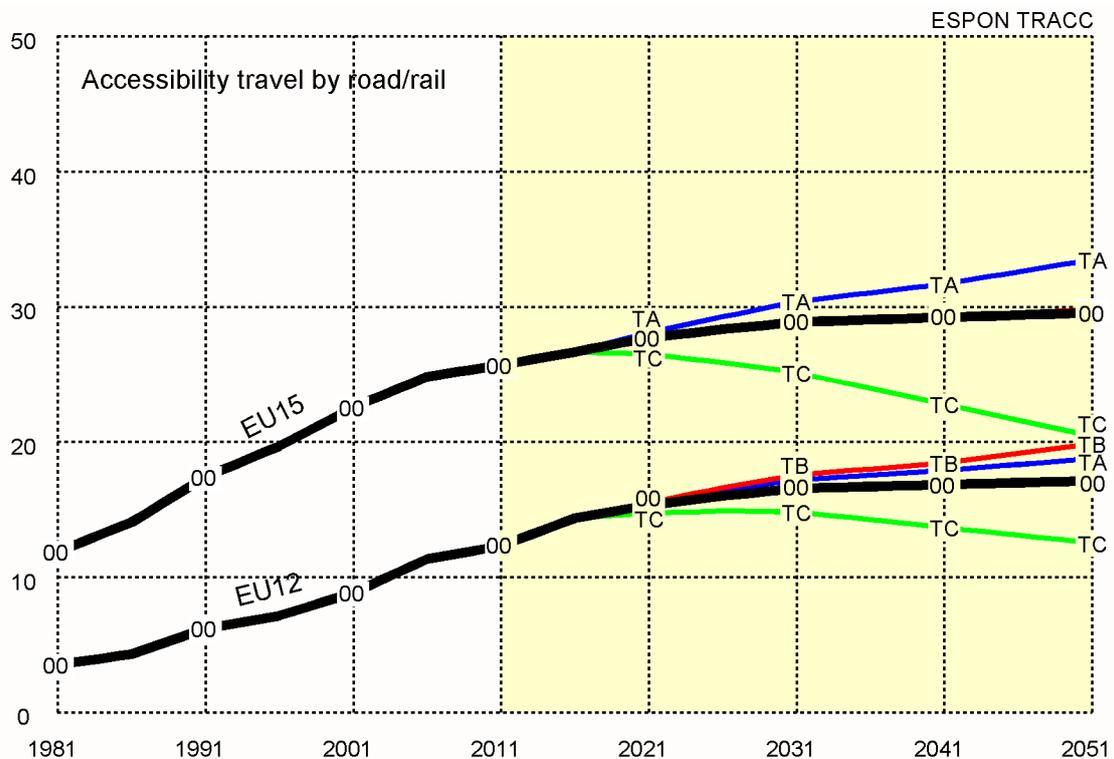


Figure 12.2. TRACC SASI scenarios: Scenario comparison: accessibility travel road/rail in EU15 and EU12, 1981-2051

In summary, it can be seen that accessibility travel road/rail has increased continuously since the 1980s due to infrastructure investment and technological advance and is assumed to continue to increase, though with decreasing speed, until 2051. It is also apparent that the new and upgraded infrastructure in scenarios TA and TB affect accessibility positively only moderately, whereas cost increases, such as in scenario TC, have a strong negative effect. Moreover, the effects are in general larger in absolute terms in EU15 than in EU12.

Figure 12.3 compares the development of GDP per capita averaged over NUTS-3 regions in EU15 and EU12 over time. It becomes understandable that while GDP per capita in EU12 grows much faster in relative terms than GDP per capita in EU15, in absolute terms the regions in EU15 gain more. It is also confirmed again that the negative economic impacts of reductions in accessibility tend to be much stronger than the positive impacts of improvements of accessibility (the trajectories of the TA and TB scenarios are hidden behind the trajectory of the Baseline scenario).

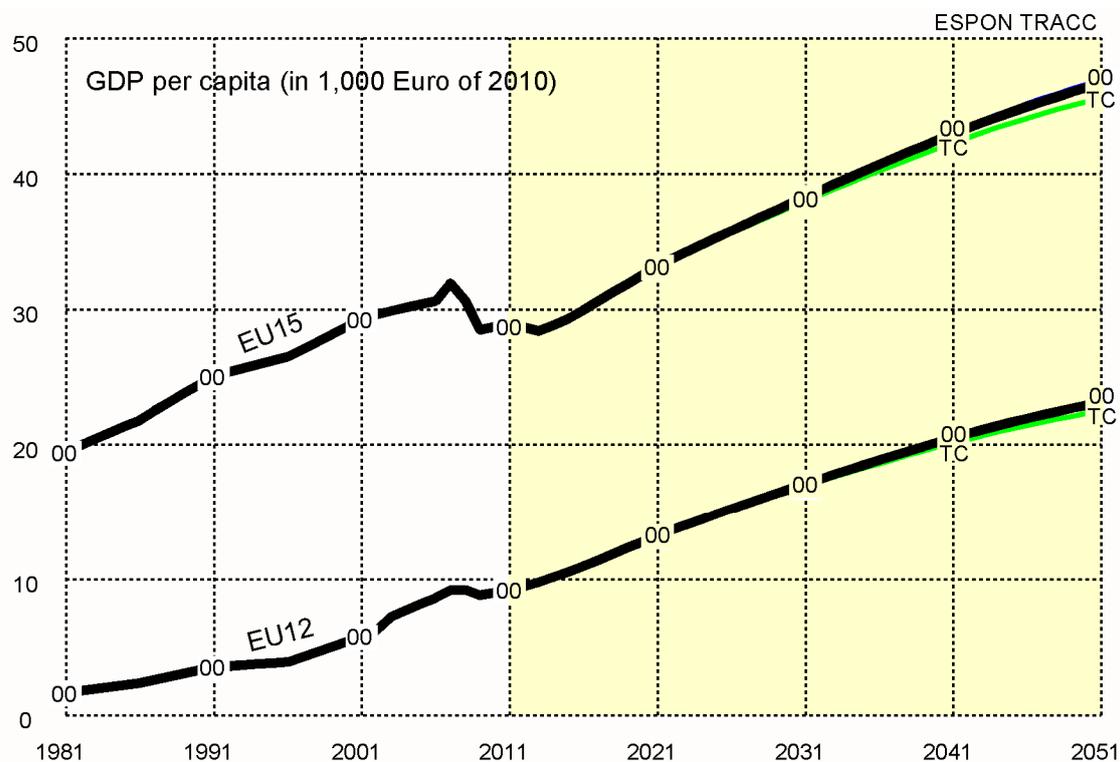


Figure 12.3. TRACC SASI scenarios: Scenario comparison: GDP per capita in EU15 and EU12, 1981-2051

Figures 12.4 and 12.5 shed some light on the cohesion and sustainability impacts of changes in accessibility:

Figure 12.4 compares the trajectories of the cohesion indicator most frequently used by the European Commission to assess the effectiveness of its Cohesion policy in reducing economic disparities between regions, the coefficient of variation, a measure of deviation of regional indicators from their European average. The higher the measure, the greater the disparities. In the figure the development of the coefficient of variation of GDP per capita and accessibility travel road/rail are compared. It can be seen that both indicators have since the 1980s become significantly lower indicating a massive trend towards convergence, and that this trend, according to the SASI model, is likely to continue in the future, though at a slower speed. It can also be seen that accessibility is more evenly distributed across regions than GDP per capita, and that the extra costs of mobility in scenario TC turn convergence into divergence.

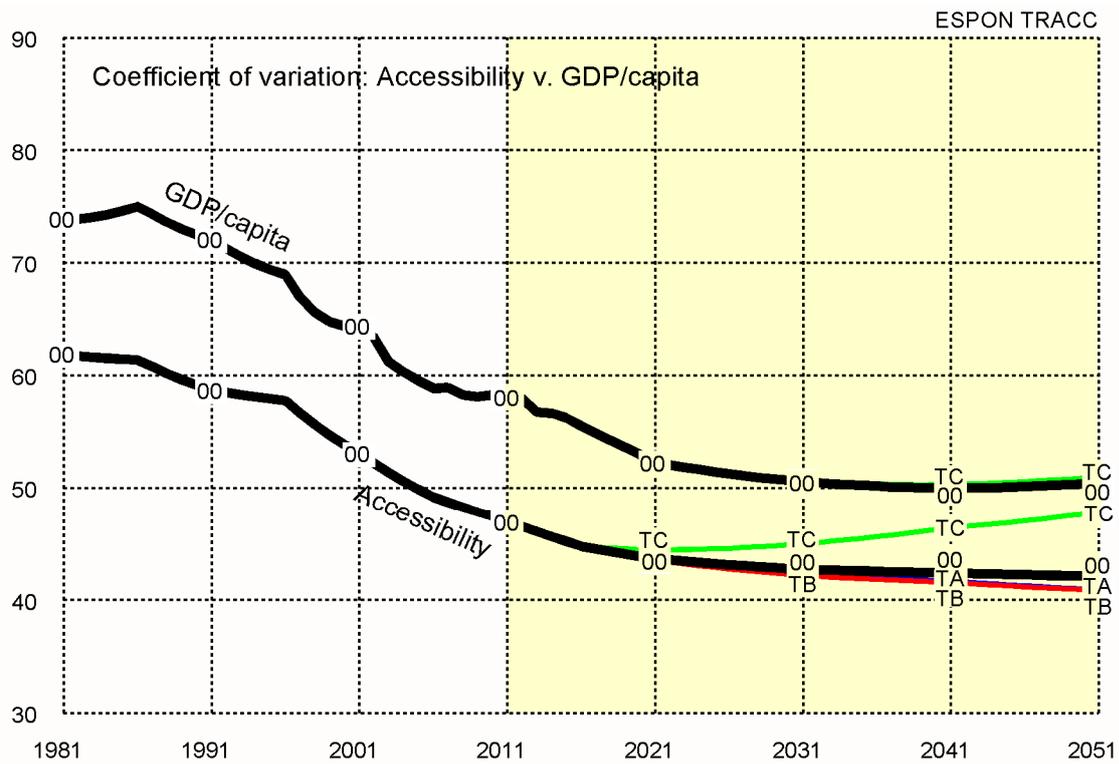


Figure 12.4. TRACC SASI scenarios: Scenario comparison: coefficient of variation, accessibility travel road/rail v. GDP per capita, 1981-2051

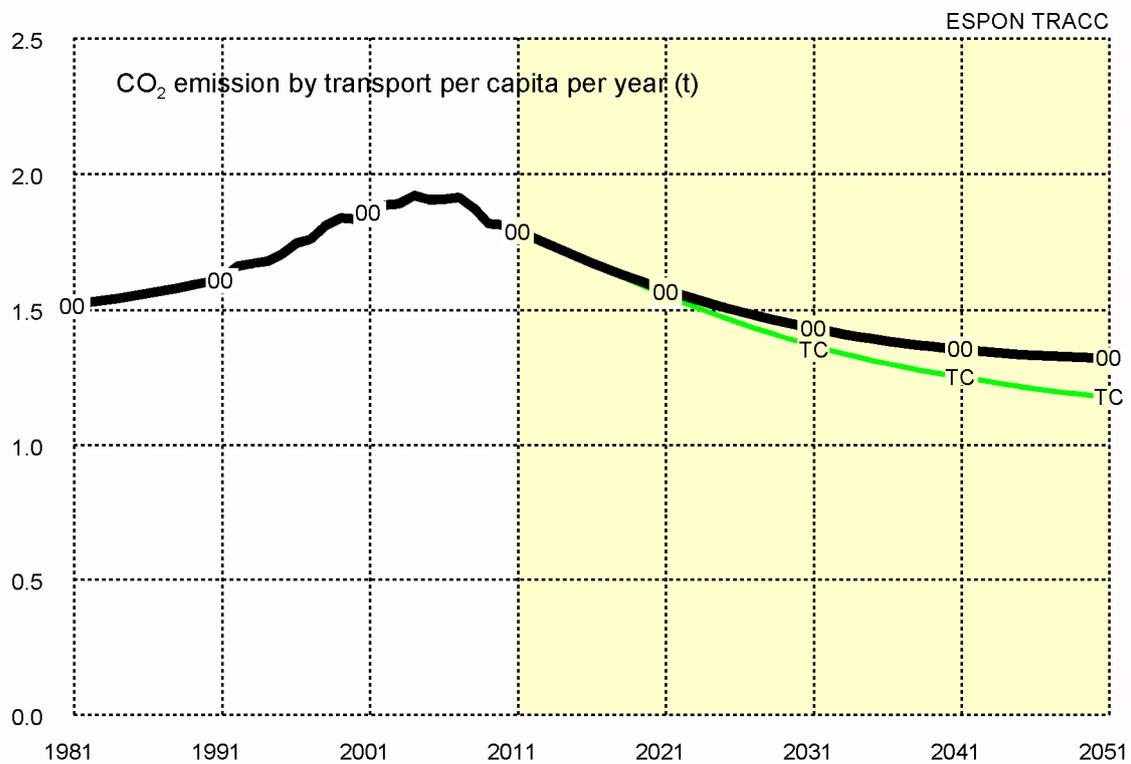


Figure 12.5. TRACC SASI scenarios: Scenario comparison: CO₂ emission of transport, 1981-2051

Figure 12.5 finally allows a view on the sustainability of the scenarios with respect to energy consumption and greenhouse gas emissions of transport. The diagram reproduces the well-known growth of CO₂ emission of transport since the 1980s and the modest trend change since the economic crisis. The diagram also suggests that under the assumptions made in the transport part of the SASI model about drivers of travel and freight transport demand and the diffusion of renewable energy in transport the ambitious targets of the European Union for the reduction of greenhouse gas emission by transport of 60 percent compared to 1990 are not likely to be achieved. The diagram also informs about the possible contribution of accessibility to achieving this target. Whereas infrastructure improvements and efficiency increases have no discernible effect, transport pricing measures as in Sustainability scenario TC can deliver a sizable contribution.

Conclusions

Based on the empirical and modelling analyses in ESPON TRACC and previous ESPON projects the impacts of changes in accessibility on competitiveness, cohesion and sustainability can be summarised as follows:

- Good accessibility is a precondition for economic development. Regions with good access to suppliers and markets are *ceteris paribus* more economically successful than remote and isolated regions.
- Even large changes in accessibility lead to only small changes in economic development. The magnitude of the effect depends on the existing level of accessibility: Further improvements of the already high accessibility of central regions will have only little effect, improvements of the accessibility of remote regions can have significant effects on their economic development.
- A reduction of accessibility through higher fuel prices or environmental taxes will reduce the accessibility of central regions more than that of remote regions, but will negatively affect economic development of remote regions more than that of central regions.
- Transport infrastructure improvements, even if focused on rail, have very little impact on energy consumption and greenhouse gas emissions by transport unless they are accompanied by pricing policies making road and air transport more expensive.

13 Policy implications

What are the main lessons learned from the TRACC project on accessibility for policy making at different territorial levels? In the following bullet points main findings of the project are summarised and some tentative conclusions are drawn.

- **Accessibility is a 2 dimensions driven variable:** Accessibility consists of two components, available activities of interest and transport infrastructure leading to them. Low accessibility values reflect in some cases sparsely populated areas and/or low service endowment, often in the European peripheries; but in others cases low accessibility values are driven by poor transport infrastructure, more often in Eastern Europe than in Western Europe. Accessibility related policy should not only concentrate on the transport infrastructure side as investments in the points of interest might be more efficient. That means that transport and spatial development policies should be more integrated at all territorial levels.
- **Global travel accessibility.** Seen from an accessibility perspective, the integration of European regions in the global economy is very heterogeneous. In particular for passenger travel, huge differences exist between European regions in terms of linkages to global destinations and global accessibility.
- **Global freight accessibility changing.** The progressive rise of Far East as trade partner opens to Mediterranean regions the perspective of exploiting a position advantage. In this respect, efficient multimodal infrastructures (ports, transshipment facilities, intermodal centres, roads, railways) might increase the global accessibility of Southern European regions thus reducing the current differences with respect to the North Sea area.
- **European travel accessibility patterns.** The dominating accessibility pattern in Europe for passenger transport is as follows: highest values in the Core of Europe, in capital city regions in other countries, and in other selected industrial or touristy regions such as Southwestern Scandinavia (Oslo-Gothenburg-Copenhagen), the Western Mediterranean coastal corridor (from southern Spain to northern Italy), the Rhone valley, Southern Italy, Saxony and Upper Silesia. Citizens in core regions are more likely to seamlessly travel in Europe or access global transport gateways (more transport services and point to point connections, shorter local trip legs) as they have denser motorway and rail networks and concentrate a higher number of European and global air hubs.
- **European freight accessibility patterns.** Geographical position, availability of infrastructures and strength of the economy are the three key elements which describe the pattern of European accessibility in relation to freight. Logistic activities tend to follow population and economic concentrations. Best connectivity to freight transport networks is recorded in the North Sea due to the presence of largest container ports in Europe, in addition to denser motorway and freight village networks. The Mediterranean rim has large container ports but less dense motorway and freight village networks in their hinterlands limit to a large extent high performance to coastal fringes. Main inland waterway axes (Rhine, Danube, Elbe) and canal systems in Germany back up good freight accessibility performance.
- **The cost of low EU Integration.** The comparison of potential accessibility patterns restricting origins and destinations within EU Member States against Europe-wide mobility shows that an important number of European regions are likely to lose out when they are restricted to access only national activities, or in other words under lower EU integration conditions. This is especially obvious in border regions like western Poland, north-eastern and southern Germany, eastern and southern France. Seen it the other way round, border regions are largely benefitting in terms of accessibility of the diminishing importance of those borders and the gain in opportunities available to their citizens.

- **Local and regional peripheries do not match EU peripheries.** No significant differences can be observed for performance in regional and local accessibility between regions located at the European Periphery and regions located at the European Core. Regional case studies have revealed relatively homogeneous patterns within regions. Regional and local accessibility in case studies is much more dependent on the local conditions of population and economic activity than to their overall European localisation.
- **The East-West divide still persists at regional level.** From most locations in Europe, at least one regional centre can be reached in less than 60 minutes travel time, but only people in Western Europe have options to visit more than five different cities in that time. Infrastructure endowment is still much lower in Eastern Europe, so despite having relatively similar levels of service provision, accessibility to services remains lower than in Western Europe. Accessibility to transport infrastructure is also lower in Eastern Europe.
- **The Urban-Rural divide still persists at regional level.** Accessibilities for capitals regions or for main agglomerations differ significantly from those for rural, peripheral and landlocked regions, as well as for intermediate areas. Minimum services are available with reasonable cost in most areas of Europe, even remote rural or sparsely populated, but the possibility to choose amongst different alternatives is concentrated in highly populated urban areas. Indicators focussing on availability of activities and services (travel cost) provide more balanced patterns on the territory than indicators focussing on the diversity of offer (cumulated opportunities, potential accessibility) which tend to provide more polarised patterns around largest metropolises and well deserved transport corridors.
- **Inner peripheries in all regions.** Inner peripheries with low accessibility values are not only located in the far North or in the Alpine space, as expected, but also in most European countries. The extent of these inner peripheries is substantially larger for rail than for car.
- **Balanced access to services of general interest.** The analysis of case studies show a balanced geographical distribution of public services in Europe, allowing for minimum service availability despite of population figures or economic activity of regions. Many case studies have identified the threat of diminishing accessibility to services of general interest caused by withdrawal of the public sector in the framework of the current financial crisis.
- **Public transport accessibility below car accessibility.** Accessibility patterns for cars and public transport differ to a large degree, both with respect to the level and also with the spatial patterns. Accessibility levels by car are in general higher at regional and local level than those for public transport, but public transport is still able to provide high levels of accessibility within metropolitan areas and in city centres, and along well deserved axes is. Accessibility indicators for cars tend to form different types of plateaus, while for public transport the same indicators form 'stretches' and 'bands' of high accessibilities along transport axis, interrupted by areas of low accessibilities where public transport is missing. Most of the case studies and most of the indicators applied demonstrate that accessibility by car is superior to accessibility by public transport. Only in a few metropolitan areas public transport is providing comparable accessibility to the population.
- **Impact of financial crisis.** Accessibility is a matter of transport infrastructures and of availability of functions. As for transport infrastructures, the impact of the financial crisis is likely to be detrimental in the light of the pro-cyclic approach in public investments dominating the EU architecture. Shortage of financial resources can easily lead to postpone or even cancel planned public investments, whilst private investments are also likely to slow down significantly. The picture could be different if the role of public expenditure as engine of aggregate demand to tackle economic crisis is re-discovered. As for availability of functions, two main linkages with the crisis can be mentioned. First, for some of the TRACC indicators public services (schools, hospitals) are involved. The concentration of services with the

closure of minor local sites has been announced often in the last years. The financial crisis could provide the rationale for put this into practice. In that case, especially accessibility based on travel costs could significantly worsen for many (mostly peripheral) areas. Second, the crisis has been deepening (further than being fuelled by) disparities between European countries. So, current unbalances in accessibility to economic activity are likely to increase.

- **No clear significant overall patterns observed in relation to impacts of TEN-T projects in case studies.** Impacts observed varied largely from one case to another. The diversity of typologies of projects in each case, and the use of particular hypothesis for final performance of envisaged infrastructures (e.g. speeds in new rail links) may be in part responsible for these differences. In a number of case studies, largest metropolitan areas and urban regions tended to win less in relation to intermediate and rural regions (e.g. in the Czech Republic, in the Baltic States, and to some extent in the Western Mediterranean and in Finland). In Poland, road projects benefit to a higher extent the Warsaw – Katowice region, but also important gains can be observed in the far less populated eastern regions bordering with Belarus and Ukraine.
- **Specialised accessibility indicators.** Individual accessibility indicators are to depict different facets and different spatial structures. Accessibility cannot be assessed by just one indicator. Travel cost indicators to next “function” indicate the possibility of regions to have access to certain functions, while cumulated opportunities and potential accessibility indicators also include the variety of functions and therefore reflect the magnitude of alternative choices available. Potential indicators tend to show more laminar patterns (progressive), while availability of functions are more affected by singularities in the territory.
- **Accessibility and regional development.** Based on the empirical and modelling analyses in ESPON TRACC and previous ESPON projects the impacts of changes in accessibility on competitiveness, cohesion and sustainability can be summarised as follows: Good accessibility is a precondition for economic development. Regions with good access to suppliers and markets are ceteris paribus more economically successful than remote and isolated regions. Even large changes in accessibility lead to only small changes in economic development. The magnitude of the effect depends on the existing level of accessibility: Further improvements of the already high accessibility of central regions will have only little effect, improvements of the accessibility of remote regions can have significant effects on their economic development. A reduction of accessibility through higher fuel prices or environmental taxes will reduce the accessibility of central regions more than that of remote regions, but will negatively affect economic development of remote regions more than that of central regions. Transport infrastructure improvements, even if focused on rail, have very little impact on energy consumption and greenhouse gas emissions by transport unless they are accompanied by pricing policies making road and air transport more expensive.

Research implications

The TRACC project has further developed and implemented different methodologies to measure accessibility and to evaluate regional impacts of changing accessibility. The following bullet points summarise some implications for further research into accessibility:

- **Accessibility indicator set.** The accessibility indicator set in TRACC and its implementation is a first attempt to assess accessibility from very different viewpoints and for different purposes. More research should be devoted to develop commonly accepted standard indicators like the European potential accessibility also for other spatial contexts and purposes.
- **Raster approach to increase resolution of accessibility analysis.** A good part of the findings in TRACC is based on grid cell maps, free of administrative divisions. Several

particular areas and spatial patterns can be noticed only on the grid cell basis. TRACC has proven that even at the level of zoom-in regions significant intra-regional disparities exist, which cannot be detected by the traditional, aggregated models. Such intra-regional disparities are often greater than those between regions, thus accessibility studies should acknowledge these disparities and should find ways how to capture them. Raster analysis allows for a more accurate identification of territorial patterns generated by high level and public transport corridors.

- **Public transport modelling approach.** The quantification of public transport accessibility could be improved by modelling different services (road public transport, regional trains, intercity trains etc.) as independent modes, allowing for multimodal trip chains. On the one hand this would allow to better identify the role of each mode (e.g. road public transport for short distances, often when train is not available, regional trains mostly for commuters, etc.), thus providing more precise estimations of times and costs for different demand segments/travel purposes (e.g. accessibility to schools would probably use different input than accessibility to hospitals or potential accessibility to population. On the other hand, modelling multimodal chains (even if in a simplified way) would allow to explore the role of interconnectivity and co-modality, which are increasingly relevant concepts in public transport planning to provide efficient accessibility.
- **Freight transport modelling approach.** Some freight services are based on lines with fixed paths and stops (likewise public transport). Modelling these lines more explicitly would improve the representativeness of the accessibility indicators as the information on the regions pairs actually connected would be more precise. A pre-condition for implementing this approach on an European scale would be however the availability of a reliable and frequently refreshed database of the lines, which are continuously evolving. For rail-road combined transport some information exists, but for maritime container data is much more scattered and difficult to access. Still about freight, road freight accessibility is significantly influenced by assumptions on driving times and costs (e.g. respect or not of the maximum driving limits per day, use of two drivers, accompanied and unaccompanied trucks on ferries). Improvements on modelling of these aspects could be useful.
- **Transport scenario modelling.** The modelling of transport infrastructure and policy scenarios was based on very global assumptions on the scenarios and the development of transport infrastructure. Further research in this direction might concentrate on the impacts of individual projects, of basic infrastructure alternatives and on the integration of transport policies and territorial and regional policies.
- **Case study approach.** The accessibility modelling for the seven case studies in TRACC was done with a rather strict definition of the accessibility indicators and a subsequent research programme. Together with a very identical structure of the case study reports, including the same type of maps, diagrams, even the colour ramps were harmonised, the results are highly comparable across the different regions. However, because the indicators were calculated with seven different accessibility models, some with a detailed representation of public transport networks, some with a more abstract representation, some with raster based approaches, some with centroids of LAU-2 regions, differences in accessibility might also be traced back to differences in spatial resolution, parameters or country-specific definitions of destinations. But notwithstanding this small reservation, the strict case study approach might be used as a model for other territorially oriented case study projects.
- **Transport network data.** The different accessibility models, even at the European level, worked with partly different transport network data which are not easily to obtain and to maintain. In consequence, harmonised databases should be developed based on user needs assessment for accessibility modelling in Europe. In this framework, it has to be assessed how public transport networks can be more easily integrated based on up-to-date sources.

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