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Carsten Schürmann, Ahmed Talaat

Towards a European Peripherality Index
Final Report

Report for
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of the European Commission

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Institut für Raumplanung
Fakultät Raumplanung, Universität Dortmund
D-44221 Dortmund
Tel. 0231-7552291, Fax 0231-7554788

IRPUD

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This Final Report on peripherality and the development of the *European Peripherality Index* (E.P.I.) software would not have been possible without the following contributions:

Chapter 2 of this Final Report discussing theoretical concepts of accessibility and peripherality is based on previous work performed at IRPUD in the EU project *Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements* (SASI) commissioned by DG VII (Transport) of the European Commission as part of the 4th RTD Framework Programme and in the Working Group 'Geographical Position' of the Study Programme for European Spatial Planning (SPESP) organised by DG XVI.

The definition of the centroids used for the accessibility calculations (Section 3.2.2) and the compilation of the socio-economic database described in Section 3.2.3 were contributed by Andrew Copus, Rural Policy Group, Scottish Agricultural College (SAC), Aberdeen.

1. Introduction

1.1 Problem Statement

Article 2 of the Maastricht Treaty states as the goals of the European Union the promotion of harmonious and balanced economic development, stable, non-inflationary and sustainable growth, convergence of economic performance, high levels of employment and social security, improvement of the quality of life and economic and social coherence and solidarity between the member states. A prominent role for the achievement of these goals play the envisaged trans-European networks in the fields of transport, communications and energy (TEN). The trans-European transport networks are to link landlocked and peripheral areas with the central areas of the Community. The identification of those peripheral regions, whose accessibility and transport infrastructure systems are to be improved, is becoming of great political importance. This is underlined by the European Commission's *Cohesion Report* (1997) which emphasises that "regions should ensure that policy success is measurable, that results are regularly monitored, and that the public and political authorities are regularly informed of progress." For measuring and monitoring the success of policies, the development of an easy-to-use peripherality indicator is indispensable.

1.2 Objectives of the Peripherality Study

The purpose of this study is to undertake, for the fifteen member states of the European Union and the twelve candidate countries, the calculation of an index of peripherality of the 'potential' type (sometimes also called 'gravity-model' type). The economic potential of a country or region is the total of destinations in all regions weighted by a function of distance from the origin region. In effect, it is assumed that the potential for economic activity at any location is a function both of its proximity to other economic centres and of its economic size or 'mass'. The analogy with the law of gravity is explicit in that the influence of each economic centre on any other centre is assumed to be proportional to its volume of economic activity and inversely proportional to a function of the distance between them. The economic potential of a given location is found by summing the influence on it of all other centres in the system.

1.3 Contents of this Report

The following Chapter 2 discusses theoretical concepts of accessibility based on previous work performed at IRPUD for the EU project *Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements* (SASI) (Schürmann et al., 1997) commissioned by DG VII (Transport) of the European Commission as part of the 4th RTD Framework Programme and in the Working Group 'Geographical Position' of the Study Programme for European Spatial Planning (SPESP) organised by DG XVI (Wegener et al., 2000).

Chapter 3 describes the accessibility concept implemented for the peripherality study, presents the geodatabase necessary to perform the study, explains the output indicators developed with respect to methodological issues and their relevance for measuring peripherality, and concludes with information how the model system is implemented in the geographical information system (GIS) ArcInfo.

The next Chapter 4 presents the results of the peripherality study. After the discussion of travel time matrices for passenger traffic and freight transport, different peripherality indices developed are presented with respect to spatial patterns, policy relevance, temporal dynamics and correlation between them.

Chapter 5 gives recommendations on the explanatory power and the choice and use of peripherality indicators. In addition, the advantages and weaknesses of the software system are addresses as well as future work to improve the model system.

Alongside this Final Report, a User Manual provides detailed information on the software environment developed, the hardware requirements, installation and use of the macros and database and the possibilities to update the database and modify default parameters. The accompanying CD ROM contains the geodatabase assembled as well as the macros themselves, the final report and the User Manual and all figures and output data as electronic files.

2. Accessibility and Peripherality

A peripheral region is defined as a region with low accessibility. However, in addition to accessibility, many other criteria are used to delineate centres and peripheries in regional research. Notwithstanding this qualification, accessibility is clearly a key criterion of geographical peripherality and also of major importance in defining economic peripherality. Therefore in this section first basic concepts of accessibility are discussed.

2.1 Basic Accessibility Indicators

Accessibility is the main 'product' of a transport system. It determines the locational advantage of a region relative to all regions (including itself). Indicators of accessibility measure the benefits households and firms in a region enjoy from the existence and use of the transport infrastructure relevant for their region.

Accessibility indicators can be defined to reflect both within-region transport infrastructure and infrastructure outside the region which affect the region.

Simple accessibility indicators consider only intraregional transport infrastructure expressed by such measures as total length of motorways, number of railway stations (e.g. Biehl, 1986; 1991) or travel time to the nearest nodes of interregional networks (e.g. Lutter et al., 1993). While this kind of indicator may contain valuable information about the region itself, they fail to recognise the network character of transport infrastructure linking parts of the region with each other and the region with other regions.

More complex accessibility indicators take account of the connectivity of transport networks by distinguishing between the network itself, i.e. its nodes and links, and the 'activities' (such as work, shop or leisure) or 'opportunities' (such as markets or jobs) that can be reached by it (cf. Bökemann, 1982). In general terms, accessibility then 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:

$$A_i = \sum_j \mathrm{g}(W_j)\ \mathrm{f}(c_{ij}) \tag{1}$$

where A_i is the accessibility of region i, W_j is the activity W to be reached in region j, and c_{ij} is the generalised cost of reaching region j from region i. The functions $\mathrm{g}(W_j)$ and $\mathrm{f}(c_{ij})$ 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 accumulated total of the activities reachable at 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 and introduced into regional science by Stewart (1947). According to the law of gravitation the attraction of a distant body is equal to its mass weighted by a decreasing function of its distance. Here the attractors are the activities or opportunities in regions j (including region i itself), and the distance term is the impedance c_{ij}.

The interpretation here is that the greater the number of attractive destinations in regions j is and the more accessible regions j are from region i, the greater is the accessibility of region 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 regions j and the more easily they can visit region i, the greater is the accessibility of region i. Because of the symmetry of most transport connections, destination-oriented and origin-oriented accessibility tend to be highly correlated.

Different types of accessibility indicators can be constructed by specifying different forms of functions $g(W_j)$ and $f(c_{ij})$. Table 2-1 shows the three most frequently applied combinations of $g(W_j)$ and $f(c_{ij})$, where W_{min} and c_{max} are constants and a and b parameters:

Table 2-1. Typology of accessibility indices

Type of accessibility	Activity function $g(W_j)$	Impedance function $f(c_{ij})$
Travel cost Accumulated travel cost to a set of activities	$W_j \mid 1 \text{ if } W_j \geq W_{\min}$ $0 \text{ if } W_j < W_{\min}$	c_{ij}
Daily accessibility Accumulated activities in a given travel time	W_j	$1 \text{ if } c_{ij} \leq c_{\max}$ $0 \text{ if } c_{ij} > c_{\max}$
Potential Accumulated activities weighted by a function of travel cost	W_j^a	$\exp(-b\, c_{ij})$

Travel cost

This indicator is based on the assumption that not all possible destinations are relevant for the accessibility of a region but only a specified set. This set may, for instance, consist of all cities over a certain size or attraction W_{min}. The indicator measures the accumulated generalised travel costs to the set of destinations. In the simplest case no distinction is made between larger and smaller destinations, i.e. all destinations in the set get equal weight irrespective of their size and all other destinations are weighted zero (the activity function is rectangular). In many applications, however, destinations are weighted by size (the activity function is linear). The impedance function is always linear, i.e. does not take into account that more distant destinations are visited less frequently.

$$A_i = \sum_j \mathrm{g}(W_j)\, c_{ij} \quad \text{with } \mathrm{g}(W_j) = \begin{cases} W_j \mid 1 \text{ if } W_j \geq W_{\min} \\ 0 \text{ if } W_j < W_{\min} \end{cases} \tag{2}$$

To make the index easier to compare, the accumulated generalised cost so generated is frequently divided by the number of destinations or the total of attractions $\mathrm{g}(W_j)$, respectively. The indicator then represents the average travel cost to the set of destinations:

$$A_i = \frac{\sum_j \mathrm{g}(W_j)\, c_{ij}}{\sum_j \mathrm{g}(W_j)} \quad \text{with } \mathrm{g}(W_j) = \begin{cases} W_j \mid 1 \text{ if } W_j \geq W_{\min} \\ 0 \text{ if } W_j < W_{\min} \end{cases} \tag{3}$$

In both cases the indicator expresses a *disutility*, i.e. the lower its value the higher the accessibility.

Travel cost indicators are popular because they are easy to interpret, in particular if they are expressed in familiar units such as average travel cost or travel time. Their common disadvantage is that they lack a behavioural foundation because they ignore that more distant destinations are visited less frequently and that therefore their values depend heavily on the selected set of destination, i.e. the arbitrary cut-off point of the W_j included.

Daily accessibility

This indicator is based on the notion of a fixed budget for travel, generally in terms of a maximum time interval in which a destination has to be reached to be of interest. The rationale of this accessibility indicator is derived from the case of a business traveller who wishes to travel to a certain city, conduct business there and return home in the evening (Törnqvist, 1970). Maximum travel times of between three and five hours one-way are used. Because of its association with a one-day business trip this type of accessibility is often called 'daily accessibility'.

$$A_i = \sum_j W_j\, \mathrm{f}(c_{ij}) \quad \text{with } \mathrm{f}(c_{ij}) = \begin{cases} 1 \text{ if } c_{ij} \leq c_{\max} \\ 0 \text{ if } c_{ij} > c_{\max} \end{cases} \tag{4}$$

where $c_{\max}$ is the travel time limit. The daily accessibility indicator is equivalent to a potential accessibility (see below) with a linear activity function and a rectangular impedance function, i.e. within the selected travel time limit destinations are weighted only by size, whereas beyond that limit no destinations are considered at all.

Daily accessibility indicators, like the travel time indicators above, have the advantage of being expressed in easy to understand terms, e.g. the number of people one can reach in a given number of hours. However, they also share their disadvantage that they heavily depend on the arbitrarily selected maximum travel time beyond which destinations are no more considered.

Potential accessibility

This indicator is based on the assumption that the attraction of a destination increases with size *and* declines with distance or travel time or cost. Therefore both size and distance of destinations are taken into account. The size of the destination is usually represented by regional population or some economic indicator such as total regional GDP or total regional income. The activity function may be linear or non-linear. Occasionally the attraction term W_j is weighted by an exponent a greater than one to take account of agglomeration effects, i.e. the fact that larger facilities may be disproportionally more attractive than smaller ones. One example is the attractiveness of large shopping centres which attract more customers than several smaller ones that together match the large centre in size. The impedance function is non-linear. Generally a negative exponential function is used in which a large parameter b indicates that nearby destinations are given greater weight than remote ones.

$$A_i = \sum_j W_j^a \exp(-b\, c_{ij}) \qquad (5)$$

Earlier versions of the potential accessibility used an inverse power function reminiscent of Newton's gravity model:

$$A_i = \sum_j \frac{W_j}{c_{ij}^a} \qquad (6)$$

This form was proposed by Hansen as early as 1959 and is therefore called 'Hansen' accessibility. Later improvements led to the empirically similar but behaviourally derived negative exponential function used above (Wilson, 1967).

Potential accessibility indicators are superior to travel time accessibility indicators and daily accessibility indicators in that they are founded on sound behavioural principles of stochastic utility maximisation. Their disadvantage is that they contain parameters that need to be calibrated and that their values cannot be easily interpreted in familiar units such as travel time or number of people. Therefore potential indicators are frequently expressed in percent of average accessibility of all regions or, if changes of accessibility are studied, in percent of average accessibility of all regions in the base year of the comparison.

2.2 Multimodal and Intermodal Accessibility

From the above three basic accessibility indicators, an almost unlimited variety of derivative indicators can be developed (cf. Ruppert, 1975). The most important ones are multimodal, intermodal and interoperable accessibility. In all three cases the equations given above remain valid; what changes is the way transport cost c_{ij} is calculated.

Multimodal accessibility

All three types of accessibility indicator can be calculated for any mode. On a European scale, accessibility indicators for road, rail and air are most frequently calculated. In most studies accessibility indicators were calculated for passenger travel only; only few studies calculating freight accessibility indicators are known.

Differences between modes are usually expressed by using different 'generalised' cost functions. A frequently used generalised cost function is:

$$c_{ijm} = v_m t_{ijm} + c_m d_{ijm} + u_m k_{ijm} \qquad (7)$$

where t_{ijm}, d_{ijm} and k_{ijm} are travel time, travel distance and convenience of travel from location i to destinations j by mode m, respectively, and v_m, c_m and u_m are value of time, cost per kilometre and inconvenience of mode m, respectively. In addition, there may be a fixed travel cost component as well as cost components taking account of network access at either end of a trip, waiting and transfer times at stations, waiting times at borders or congestion in metropolitan areas.

Modal accessibility indicators may be presented separately in order to demonstrate differences in accessibility between modes. Or they 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, which in general will be air for distant destinations and road or rail for short- or medium-distance destinations, and to ignore the remaining modes. Another way is to calculate an aggregate accessibility measure combining the information contained in the three modal accessibility indicators by replacing the generalised cost c_{ij} by the 'composite' generalised cost

$$\bar{c}_{ij} = -\frac{1}{\lambda} \sum_m \exp(-\lambda \; c_{ijm}) \qquad (8)$$

where c_{ijm} is the generalised cost of travel by mode m between i and j and λ is the sensitivity to travel cost (Williams, 1977). 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 daily accessibility exist.

Intermodal accessibility

A further refinement is to calculate *intermodal* accessibility. Intermodal accessibility indicators take account of intermodal trips involving two or more modes. Intermodal accessibility indicators are potentially most relevant for logistic chains in freight traffic with different possible combinations of freight modes and terminals 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.

The calculation of intermodal accessibility indicators requires, of course, the capability of minimum path search in a multimodal network. The intermodal generalised cost function consequently contains further components to take account of intermodal waiting and transfer times, cost and inconvenience.

Intermodality is also an issue when calculating *intraregional* accessibility. Most accessibility studies so far have concentrated on the accessibility of cities, i.e. network nodes which are assumed to represent the whole metropolitan area or region. This presents several problems:

- Accessibility indicators calculated for network nodes only 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.

- Also the quality of the interconnections between the high-speed interregional and the low-speed intraregional transport networks cannot be taken account of. Yet the ease of getting from home or office to the nearest station of the high-speed rail network or the next international airport may be more important for a location than the speed of the long-distance connection from there.

- In addition the estimation of access times from locations within the region to the regional centroid as well as of travel times between activities within the region itself ('self-potential'), which greatly influence the accessibility of a region, increases in difficulty with spatial aggregation.

Calculating intraregional accessibility indicators is not straightforward as it requires high-resolution data on the spatial distribution of activities in the region. If also the quality of the intraregional transport network and its connection with the long-distance interregional networks are to be assessed, detailed information on the intraregional road and public transport networks and the transfer possibilities at railway stations and airports are required.

Difficulties in travel or goods transport across network boundaries, e.g. between different railway systems, can be taken into account by assigning extra costs or waiting times to border nodes or border links when calculating accessibility indicators.

2.3 Accessibility Indicators Used in Other Studies

There is a large variety of approaches to measuring accessibility in the geographic and economic literature. Below a few examples of accessibility indicators calculated for the EU territory are referred to. More information is contained in Wegener et al. (2000).

Travel cost

Total or average travel time to a specified set of destinations has received increasing recognition as accessibility indicator in recent studies because of its straightforward interpretability. In 1993 the Bundesforschungsanstalt für Landeskunde und Raumordnung (BfLR) (Lutter et al., 1993) in a study for DG XVI of the European Commission calculated accessibility of NUTS-3 regions in the formerly twelve member countries of the European Community (EUR12) as average travel time by fastest mode (road, rail, air) to 194 economic centres. The selection of centres was based on RECLUS (1989) and Zumkeller and Herry (1992). Similar accessibility indicators were developed for the reunited Germany by Eckey and Horn (1992) and Lutter et al. (1992).

Gutiérrez and Urbano (1996) calculated average travel time by road and rail from about 4,000 nodes of a multimodal European transport network to 94 agglomerations with a population of more than 300,000 with and without planned infrastructure improvements. Road travel times included road and car ferry travel times modified by a link-type specific coefficient and a penalty for crossing nodes representing congested population centres (maximum 30 minutes for Paris). Rail travel times included time-table travel time plus road access time and penalties for changes between road and rail (60 minutes), rail and ferry (180 minutes) and change of rail gauge between Spain and France (30 minutes).

A road freight accessibility index expressing total road transport cost to a market of size M is the FreR(M) index used in the UTS study (Chatelus and Ulied, 1995). The indicator accumulates road transport cost to NUTS-2 regions in EUR15 plus Norway and Switzerland multiplied with regional population. Road transport cost include cost of the driver's time, cost per kilometre and a fixed cost component. Average travel time to selected destinations was also proposed as accessibility indicator for the EUNET study (INRETS, 1997).

Daily accessibility

As indicated above, the concept of daily accessibility is due to Törnqvist who as early as 1970 developed the notion of 'contact networks' hypothesising that the number of interactions with other cities by visits such as business trips would be a good indicator of the position of a city in the urban hierarchy (Cederlund et al., 1991). In the accessibility study of the BfLR for DG XVI mentioned above (Lutter et al., 1993) daily accessibility was calculated in terms of the number of people that can be reached in three hours by the fastest mode. Modes considered included road, rail and air with and without planned infrastructure investments (new motorways, high-speed rail lines and more frequent flight connections).

Also three hours was the time limit set for the CON(T) accessibility indicator used in the UTS study (Chatelus and Ulied, 1995). The indicator accumulated population of NUTS-2 regions of EUR15 plus Norway and Switzerland reachable within three hours by any combination of car, rail and air with transfers times between modes explicitly considered. In the same study the FreR(T) index, a freight accessibility indicator expressing the size of the market that can be reached in T days was developed. The indicator accumulates the population that can be reached in one, two or three days by the fastest connection using road, rail or combined traffic with driving time restrictions observed.

Potential accessibility

The most popular type of accessibility indicator found in the literature continues to be potential accessibility.

Keeble et al. (1982; 1988) analysed the centrality of economic centres in Europe using a gravity potential (see Section 3.1) with regional GDP as destination activity; the resulting centrality contours are shown in Figure 2-1. The figure clearly shows two central areas of high accessibility in Europe: one between London and northern Italy and one between Paris and Berlin.

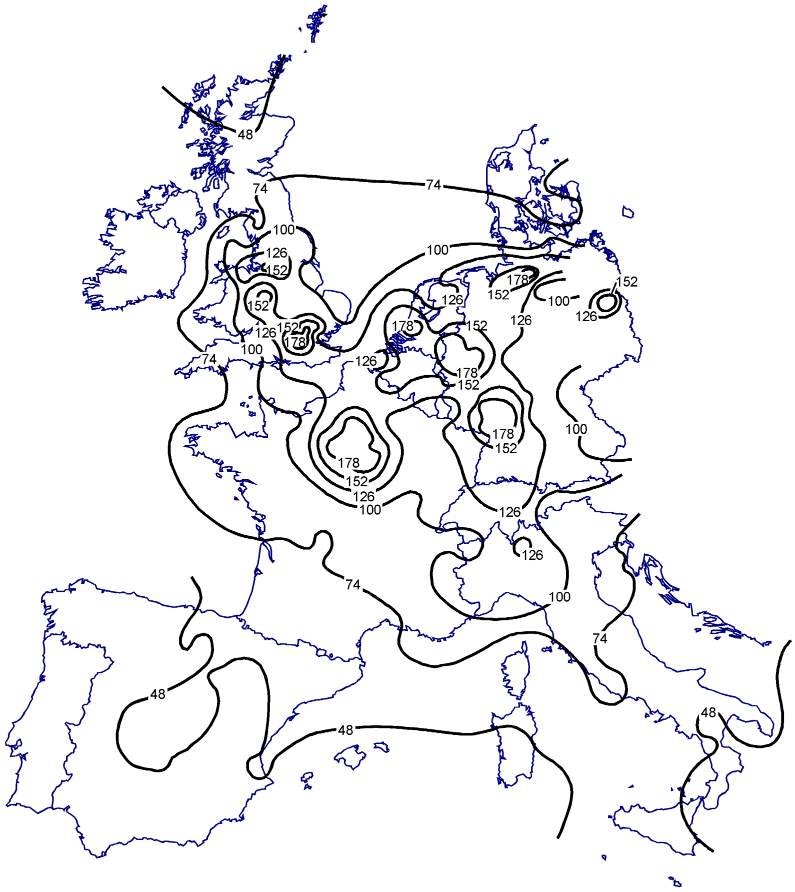

Figure 2-1. Economic potential in Europe (Keeble et al., 1988).

Bruinsma and Rietveld (1992) calculated potential accessibility of European cities with respect to population.

In studies for the Highlands and Islands European Partnership and for DG XVI of the European Commission, Copus (1997; 1998; 1999) developed 'peripherality indicators' for NUTS-2 and NUTS-3 regions based on road-based potential measures. Figure 2-2 shows the economic potential using GDP as the destination variable and Figure 2-3 the peripherality index derived from it as the inverse standardised to the interval between zero (most central) and one hundred (most peripheral).

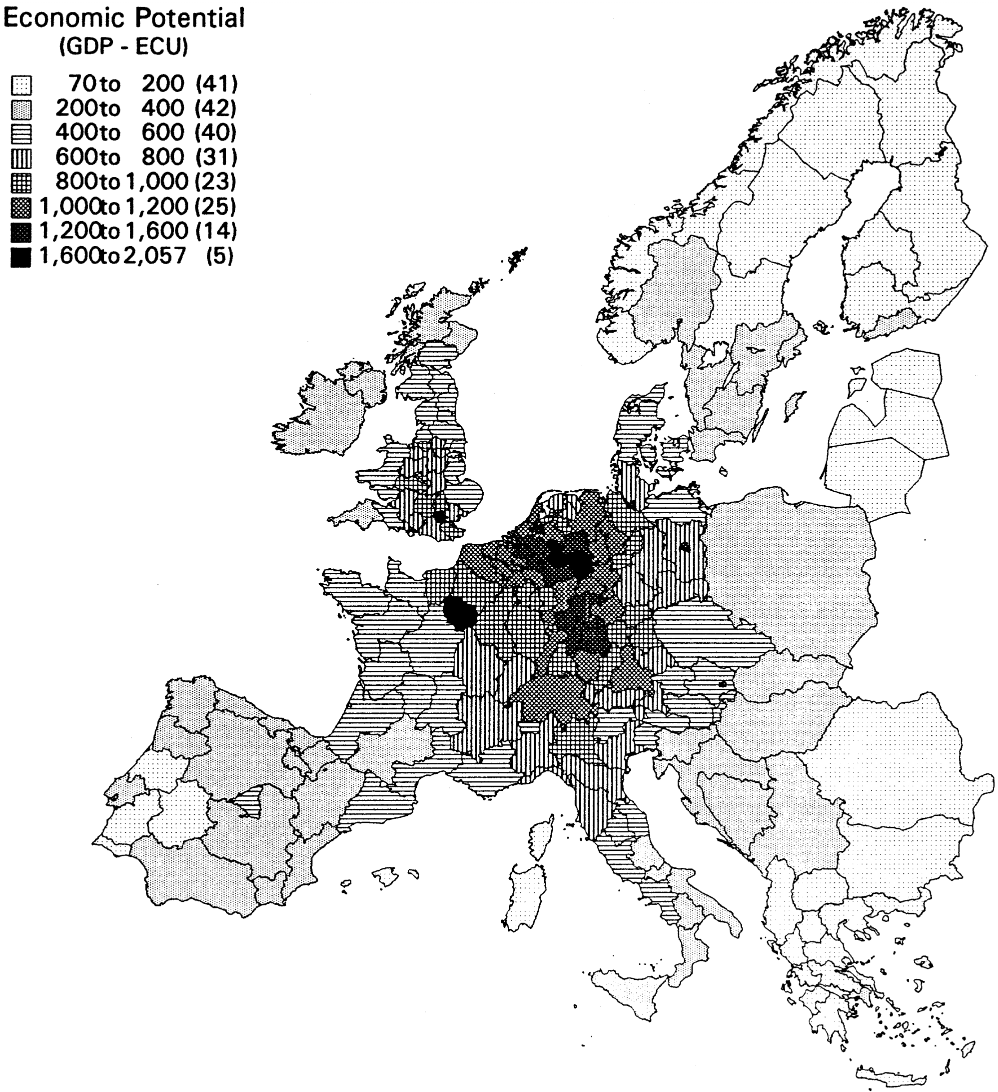

Figure 2-2. Economic potential in 1994 (Copus, 1997).

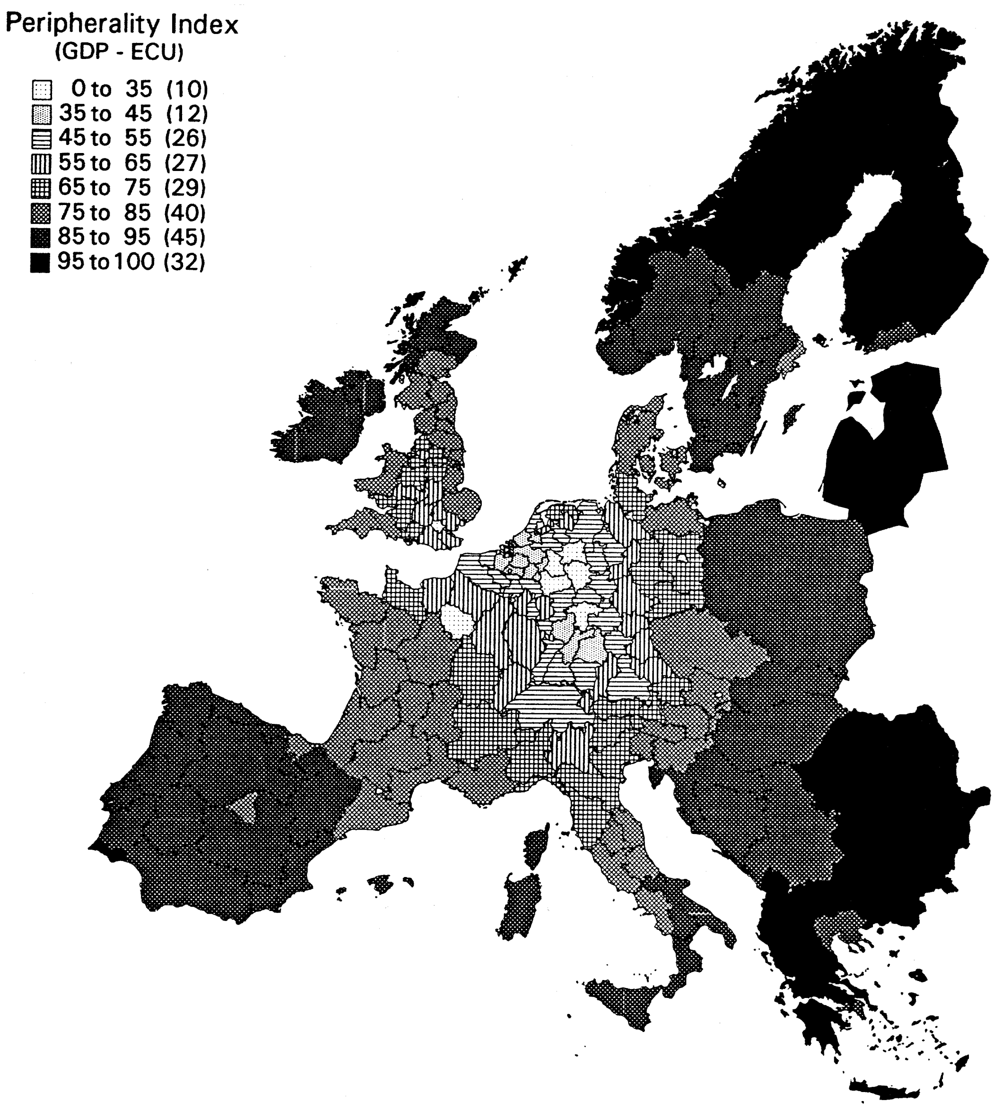

Figure 2-3. Peripherality index 1994 (Copus, 1997).

The final example (Figure 2-4) shows three-dimensional accessibility surfaces of potential rail accessibility in Europe in the year 1996 constructed by Spiekermann and Wegener (Spiekermann and Wegener, 1994; 1996; Schürmann et al., 1997; Vickerman et al., 1999). Figure 2-5 shows absolute growth in accessibility until 2010 due to the high-speed rail TEN Outline Plan. It can be seen that potential indicators tend to predict that the already highly accessible central regions will benefit most from the TEN programme, i.e. predict divergence in accessibility rather than convergence.

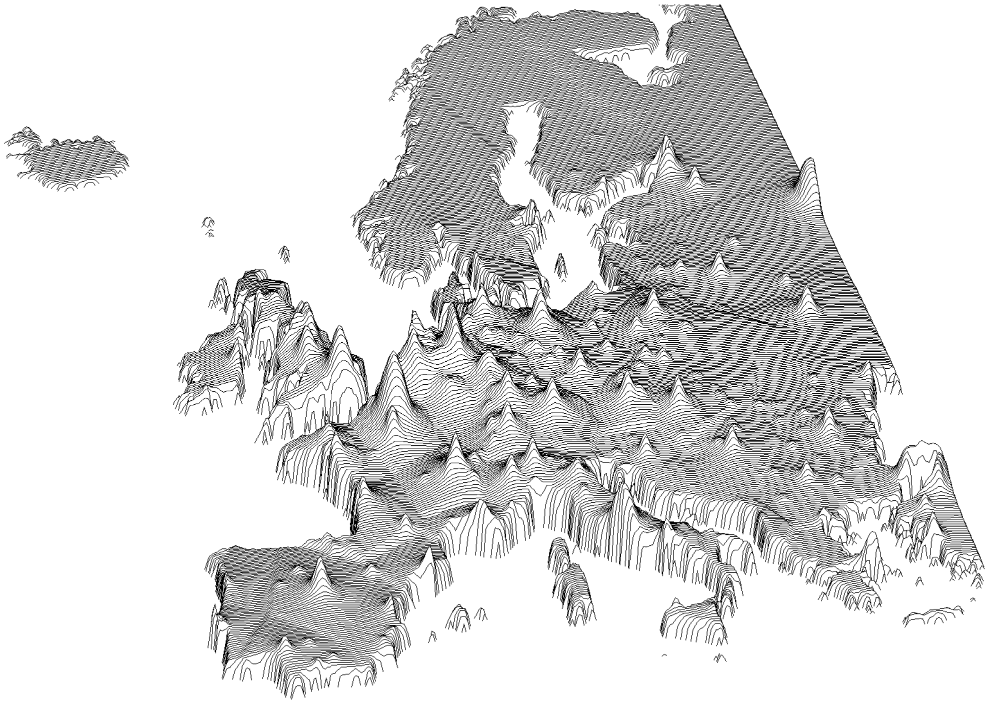

Figure 2-4. Accessibility potential in 1996 by rail (Spiekermann and Wegener, 1994).

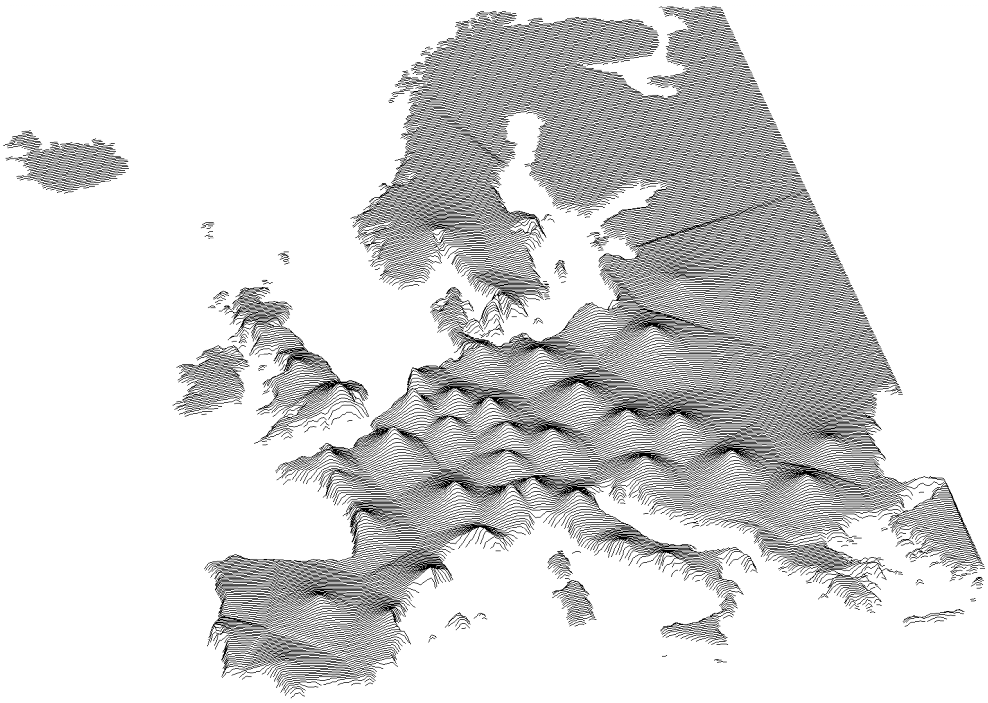

Figure 2-5. Absolute growth in accessibility until 2010 by rail (Spiekermann and Wegener, 1994).

2.4 Accessibility, Cohesion and Peripherality

The important role of transport infrastructure for regional development is one of the fundamental principles of regional economics. In its most simplified form it 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 and isolated regions (see Linneker, 1997).

The two-way interaction between regional economic development and interregional transport is illustrated by Figure 2-6. The relationship between regional development and transport can be seen as a self-reinforcing positive feedback loop in which regional economic growth creates more traffic and, vice versa, transport opportunities generate regional economic growth, with congestion and factor prices acting as equilibrating negative feedbacks:

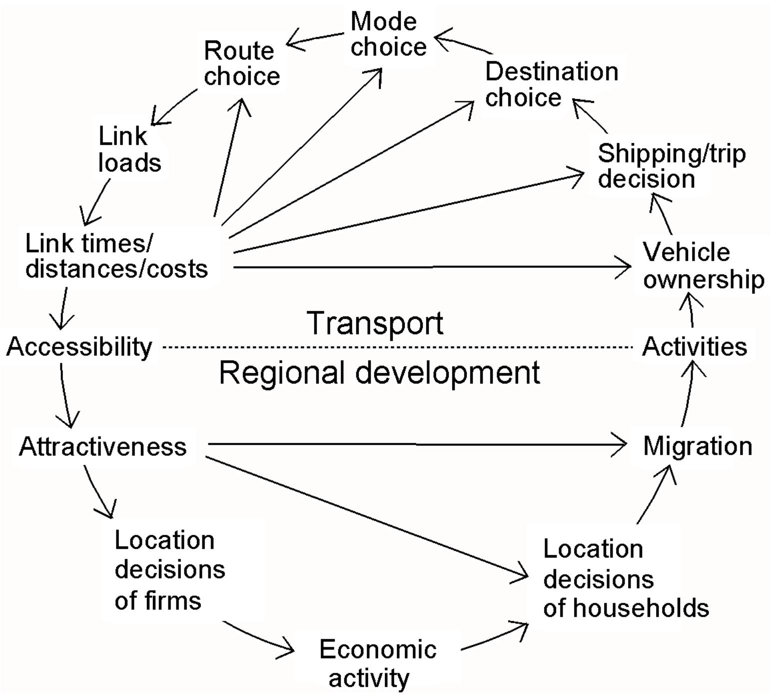

Figure 2-6. Transport and regional development.

(1) The spatial distribution of economic activity and population gives rise to shipments of goods and movements of travellers between the regions.

(2) Shippers and traveller make use of the existing transport infrastructure by a sequence of decisions about vehicle ownership, trips to make (or not to make), choice of destination, choice of mode(s) and choice of route(s).

(3) These decisions lead to congestion in parts of the networks which result in increases in transport and travel costs and times which in turn affect the transport decisions of shippers and travellers.

(4) Transport and travel costs in the (congested) networks are location factors co-determining the attractiveness of regions for investors and households.

(5) Investors decide on the location or relocation of capital and firm locations, this leads to changes in employment opportunities in the regions.

(6) Households make migration decisions as a function of employment opportunities, this leads to changes in regional population.

According to SACTRA (1998) a list of important regional effects of transport investment effects has to include the following aspects: Transport investment may broaden the access of employers to qualified labour, expand market areas, attract inward investment, improve the image of a region, unlock suitable development sites and induce further economic activity and further employment. However, there may be also negative impacts: The net effect on employment and regional activities depends on the balance between export promotion and import substitution for local production. Transport improvement may have displacement effects in other regions. Marginal changes in the quality of an already good infrastructure system are less likely to have significant effects. Transport investments may reduce the demand for transport resources (e.g. drivers and vehicles) by improving the productivity of the transport sector. And finally, labour market characteristics have to be considered.

The discussion about the importance of infrastructure capital for economic growth was revived at the end of the 1980s by the so-called public-capital hypothesis. Pioneered by Aschauer (1989), the hypothesis states that increases in public capital, i.e. public investments, will have either positive or negative (crowding-out) influence on private investment and productivity. One part of economic capital is directly linked to the transport sector. Public infrastructure capital is a part of the whole capital stock, so increases in public infrastructure will generate private investment.

Empirical Problems

The impact of transport infrastructure on regional 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 (e.g. Biehl, 1986; 1991; Keeble et al., 1982, 1988). However, this correlation may merely reflect historical agglomeration processes rather than causal relationships effective today (cf. Bröcker and Peschel, 1988). 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. The conclusion is that transport improvements have strong impacts on regional development only where they result in removing a *bottleneck* (Blum, 1982; Biehl, 1986; 1991; Fürst et al., 2000a, 2000b).

While there is uncertainty about the magnitude of the impact of transport infrastructure on regional development, there is even less agreement on its direction. It is debated whether transport infrastructure contributes to regional polarisation or decentralisation. Some analysts argue that regional development policies based on the creation of infrastructure in lagging regions have not succeeded in reducing regional disparities in Europe (Vickerman, 1991a), whereas others point out that it has yet to be ascertained that the reduction of barriers between regions has disadvantaged peripheral regions (Bröcker and Peschel, 1988). 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, for instance, 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 (Vickerman, 1991b; Bundesminister für Verkehr, 1996).

While these two effects may partly cancel each other out, one factor unambiguously increases existing differences in transport infrastructure. New transport infrastructure tends to be built not between core and periphery but within and between core regions, because this is where transport demand is highest (Vickerman, 1991a). It can therefore be assumed that the trans-European networks will largely benefit the core regions of Europe.

New developments

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 (see Masser et al., 1992). Several trends combine to reinforce the tendency to diminish the impacts of transport infrastructure on 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 goods transports and person trips, however, they may also increase 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 environment, i.e. quality of life, and factors related to access to information and specialised high-level services and to 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 may 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).

Both above tendencies are being accelerated by the increasing integration of national economies by the Single European Market, the ongoing process of normalisation between western and eastern Europe and the globalisation of the world economy.

The conclusion is that 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. However, 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 Scandinavian countries. To make things even more difficult, some of the economically fastest growing regions are among the most peripheral ones.

Cohesion

Article 2 of the Maastricht Treaty stated as the goals of the European Union the promotion of harmonious and balanced economic development, stable, non-inflationary and sustainable growth, convergence of economic performance, high levels of employment and social security, improvement of the quality of life and economic and social coherence and solidarity between the member states.

A prominent role for the achievement of these goals play the trans-European networks in the fields of transport, communications and energy (TEN). Already Article 129b of the Maastricht Treaty linked the TEN to the objectives of Article 7a (free traffic of goods, persons, services and capital) and Article 130a (promotion of economic and social cohesion). In particular the trans-European transport networks were to link landlocked and peripheral areas with the central areas of the Union. These objectives were confirmed in the European Spatial Development Perspective (ESDP 1999, 14). The trans-European transport networks (TETN) are the most relevant in spatial development policy and in financial terms. The TETN absorb more than 80 % of the total TEN budget. A large part of the investments in TETN is currently concentrated on high-speed railway lines, often connecting major conurbations. Cities close to high-speed transport stops and with a comparatively poor connection until now are likely to benefit most from these investments. In addition, in areas with a high volume of long-distance road traffic, high-speed lines may offer an incentive to shift increasing shares of traffic to the railways, thus helping to relieve road congestion and improve the environment. Indeed, rising traffic levels, in particular on road and air net-works, are threatening the competitiveness of some central areas in the EU. A multitude of different initiatives are also required in long-distance traffic, in particular by increasing the shift to rail, inland water-ways and coastal and maritime transport.

Also the Structural Funds, in particular the European Regional Development Fund (ERDF), follow the objective of economic and social cohesion (as measured by traditional macroeconomic indicators). The First Report on Economic and Social Cohesion concluded that disparities between Member States have tended to decrease, but that at the same time regional concentration of economic activities is increasing. This is related to the lack of mechanisms for spatial co-ordination. The latter could substantially contribute to a more balanced distribution of economic activities. For this reason, increasingly, spatial typologies are being used to frame the interventions of the Funds (for example, urban areas), in addition to traditional subsidising (ESDP, 1999, 16).

Peripherality

In the ESDP document, improvements in accessibility are given a high priority as a policy target: "Good accessibility of European regions improves not only their competitive position but also the competitiveness of Europe as a whole." (ESDP 1999, 69) "The creation of several dynamic zones of global economic integration, well distributed throughout the EU territory and comprising a network of internationally accessible metropolitan regions and their linked hinterland (towns, cities and rural areas of varying sizes), will play a key role in improving spatial balance in Europe" (ESDP, 1999, 20). However, it is admitted that "it is not possible to achieve the same degree of accessibility between all regions of the EU" (ESDP, 1999, 36).

This goal-setting reflects the assertion that improvements in accessibility have positive implications for regional (economic) development. Unfortunately, there is no unicausal and straightforward link between these two phenomena, and thus the question remains *a priori* open: upgrading a region's accessibility provides actors in that particular region with improved possibilities to reach destinations outside, but at the same time, they meet increasing competition from outside. The net effect on regional development remains an empirical issue.

Accessibility indicators can be used to analyse peripherality in several ways: regions can be classified into central and peripheral regions, impacts of different policy measures such as transport investments can be evaluated, or impacts of accessibility on regional development can be analysed.

3. Peripherality Analysis

3.1 Concept

Fundamentally, a peripherality indicator can be interpreted as an inverse function of accessibility, i.e. the higher the accessibility, the less peripheral a region is located and *vice versa*. As outlined in Chapter 2, a wide range of accessibility indicators are applied in other studies. For theoretical reasons, the concept of potential accessibility was chosen here since it seems most promising for calculating peripherality indicators.

In this study travel time matrices are calculated separately for passenger traffic and freight transport. These travel time matrices are used to calculate regional accessibility indicators, which are then converted to peripherality indicators. Travel time matrices and peripherality indicators for cars represent the perspective of service firms and consumers, namely how many opportunities, such as clients, markets or tourist facilities can be reached from a firm´s location. Travel time matrices and peripherality indicators for lorries, i.e. for goods transport, can be interpreted from the perspective of producers on (potential) markets as the answer to the question which location has the highest market potential.

Peripherality indicators are calculated for each origin region by adding up the mass of each destination region weighted by a function of distance from the origin region. Usually, the mass is measured in terms of gross domestic product (GDP). In this study, also GDP in Purchasing Power Standards (PPS), employment and population are used as mass terms. Distance is measured as the average travel time from one region to every other region in the form of a matrix. The regions are represented by their 'centroids', i.e. their main urban centres.

All calculations of peripherality indicators are based on level 3 of the Nomenclature of Territorial Units for Statistics (NUTS) and are then be aggregated to levels 2, 1 and 0 of the NUTS for the EU member states (Eurostat, 1999a) and equivalent geographical units as identified by Eurostat for the candidate and EFTA countries (Eurostat, 1999b) by averaging over NUTS-3 regions weighted by NUTS-3 region population.

Since speed limits for cars and trucks differ and statutory drivers' resting periods affect freight transport, travel time matrices and peripherality indicators for passenger and freight road transport are calculated separately. Travel time matrices take account of different road types, national speed limits for cars and lorries, speed constraints in urban and mountainous areas, sea journeys, border delays and, in the case of freight transport, statutory drivers' resting periods. Speed limits and congestion in urban areas are estimated as a function of population density at NUTS-3 level. It is assumed that the higher the population density, the slower will be the speeds. Road gradients are estimated by overlaying the road network with a digital terrain model (DTM).

The result of the calculations are travel time matrices between all regions and peripherality indicators for all regions for cars and lorries. Two ways of standardisation of peripherality indicators are offered:

(i) standardisation to the interval between 0 and 100, with 0 representing the most central and 100 the most peripheral region, and
(ii) standardisation on the average of all regions (again weighted by population), where high values indicate central and small values peripheral regions.

All calculations are performed with the geographical information system ArcInfo.

3.2 Geodatabase

The database compiled for this study comprises the following geodata:

- a coverage of region boundaries of Europe which subdivide the EU member states and candidate and EFTA countries into geographical units at the NUTS-3 level,
- a road network coverage of Europe containing a ‘strategic network’ connecting the centroids of the NUTS-3 regions with each other,
- socio-economic data on total and employed population and gross domestic product expressed both in Euro and in Purchasing Power Standards (PPS) used as the mass terms in the accessibility calculations,
- a European digital terrain model (DTM) to derive information on slope gradients on roads,
- additional parameter and data stored in ASCII files and ArcInfo tables on border delays and speed limits.

3.2.1 Regions

The basis for all calculations are the NUTS-3 regions of the system of regions defined by Eurostat (1999a) for the fifteen member states of the European Union and equivalent regions defined by Eurostat (1999b) for the accession and EFTA countries. Figure 3-1 shows the system of regions. Travel time matrices and peripherality indices are then aggregated to NUTS-2, NUTS-1 and NUTS-0 levels.

Standardisation of the accessibility indicators to peripherality indices is done separately for the following three groups of countries (Figure 3-2):

(1) the existing fifteen member states of the European Union;
(2) Group (1) plus the following candidate countries: Estonia, Poland, Czech Republic, Hungary and Slovenia,
(3) Group (2) and the remaining candidate countries, viz. Latvia, Lithuania, Slovakia, Romania, Bulgaria, Cyprus and Malta.

Although the remaining European countries are included as origins and destinations in the travel time matrices and accessibility indicators are calculated for them, no peripherality indicators are derived for them.

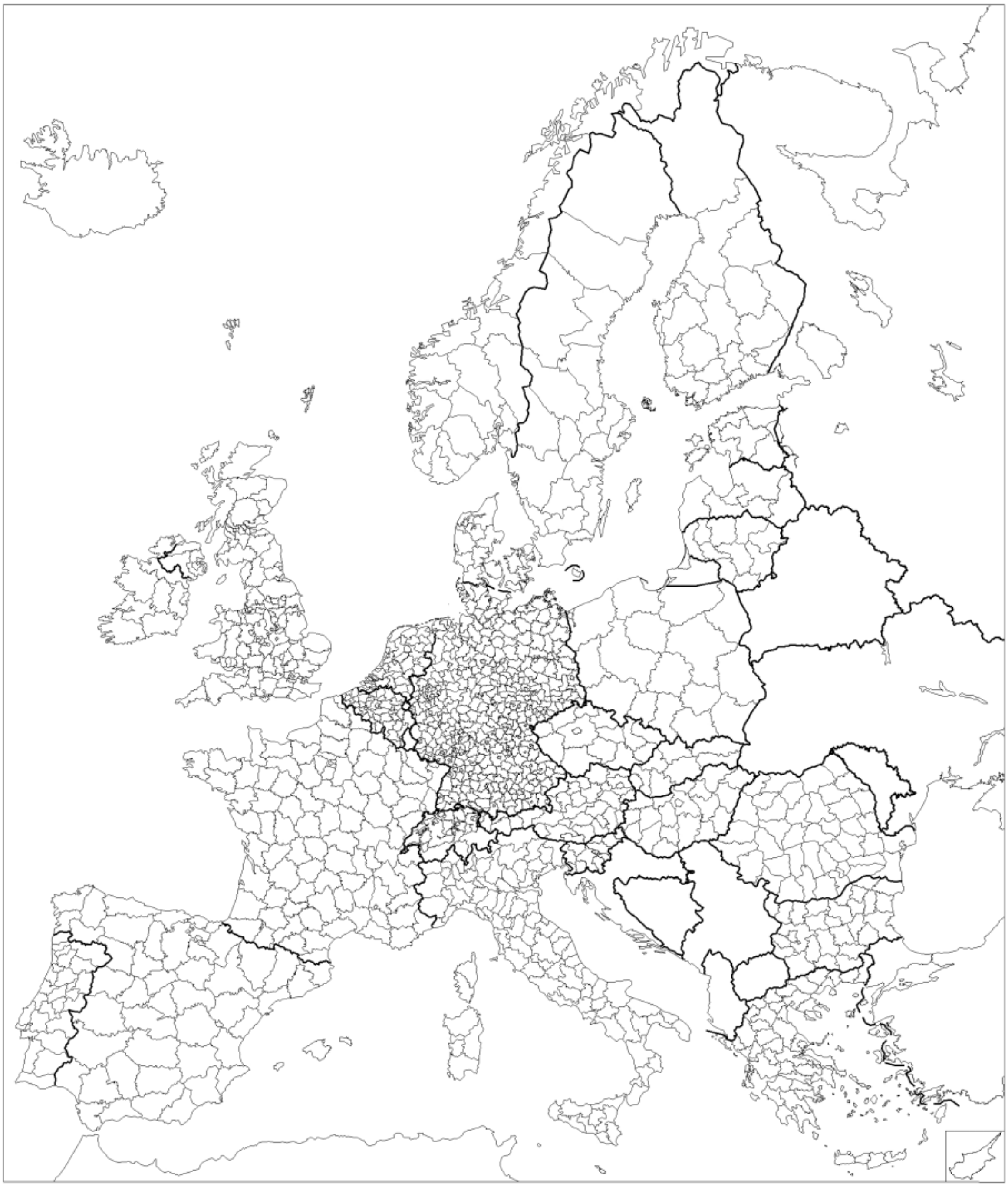

Figure 3-1. The system of regions.

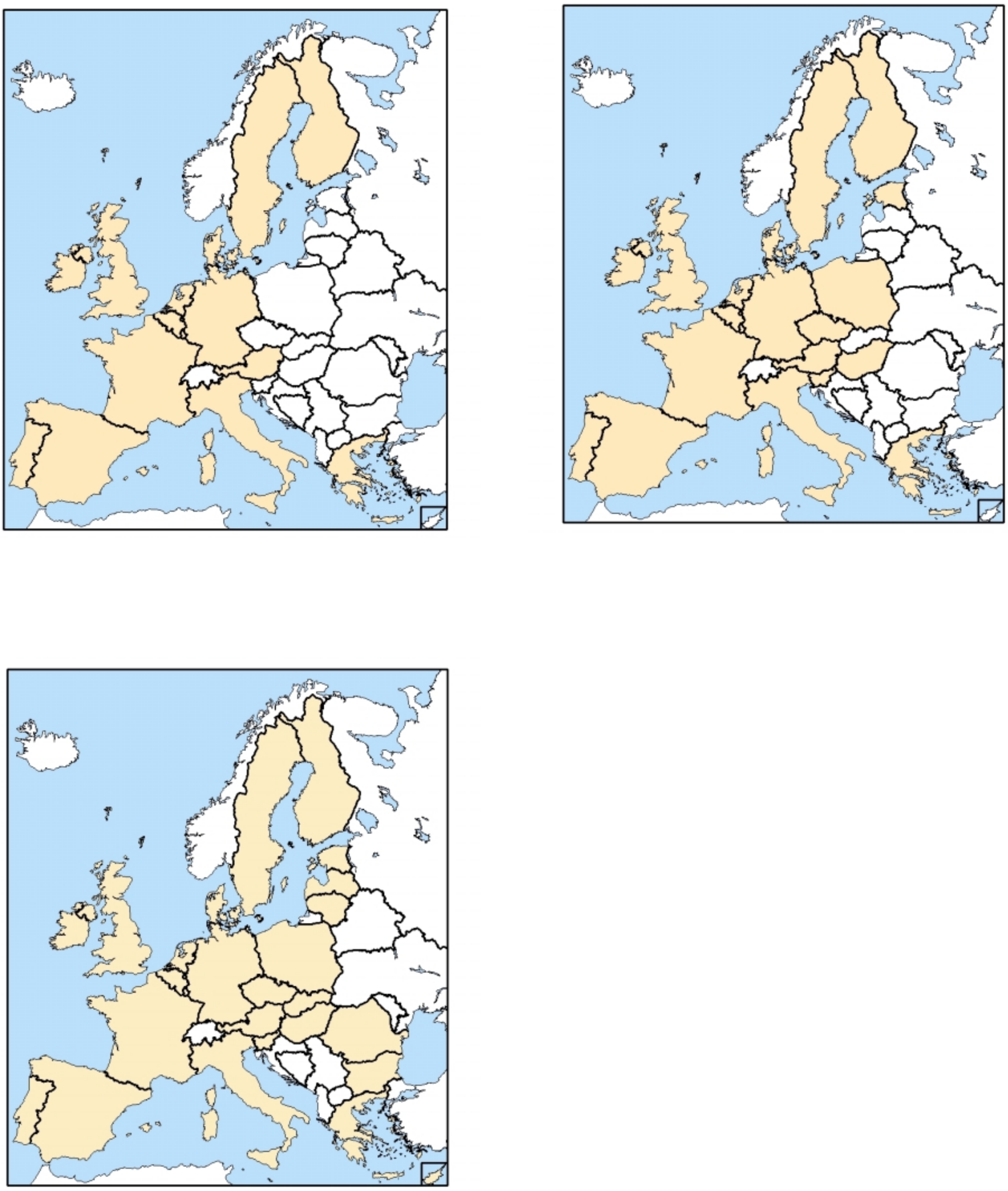

Figure 3-2. Groups of countries used for standardisation: EU (top left), EU and 5 candidate countries (top right), EU and 12 candidate countries (bottom left).

3.2.2 Road Network

To perform accessibility analysis for Europe, a so-called 'strategic' European road network based on the IRPUD European road network database was developed. The strategic road network is a subset of the overall IRPUD road database comprising the trans-European road links specified in Decision 1692/96/EC of the European Parliament and of the Council (European Communities, 1996), the TINA networks as identified by the TINA Secretariat (1999), the Helsinki Corridors as well as selected additional links in eastern Europe and other links to guarantee connectivity of regions and centroids (IRPUD, 1999). The coverage contains access links to/from NUTS-3 region centroids. The definition of the centroids is based on an evaluation of the Eurostat STEU database (GISCO, 2000) and on previous work performed at IRPUD.

All information necessary to calculate link travel times for passenger and freight transport are assigned to links, i.e. information on road types, country codes, urban and mountainous speed constraints and national car and lorry speed limits.

Figure 3-3 shows the strategic road network used for the study by link types.

3.2.3 Socio-Economic Data

For all NUTS-3 regions data on total population, employment as well as on gross domestic product (GDP) expressed in both Euro and Purchasing Power Standards (PPS), were compiled and incorporated into the GIS database.

The data were mainly compiled from different tables of the *New Chronos Database* (Eurostat, 1997). To fill some gaps of that database, for some countries a number of additional (national) sources had to be used. This will be explained below for each data category.

Population

Figure 3-4 shows population density based on the distribution of population and the size of the regions. Population figures for the EU member states for 1997 are based on Table *d3pop* of the *New Chronos Database* (Eurostat, 1997). Figures for the candidate countries were calculated from GDP and GDP per capita data in Table *xe_gdp* of the *New Chronos Database* (Eurostat, 1997), as these were more complete than Table *xdpop*. For the remaining countries, a number of additional sources were used (Bundesamt für Statistik, 2000; Eurostat, 1997; 1999b; 2000; Statistics Norway, 1999; UN, 1999; World Bank, 1997).

Population density was used to simulate traffic volumes and congestion in urban areas, i.e. it was assumed that if the population density exceeds a certain threshold, the speeds travelled by cars and lorries on roads will decrease.

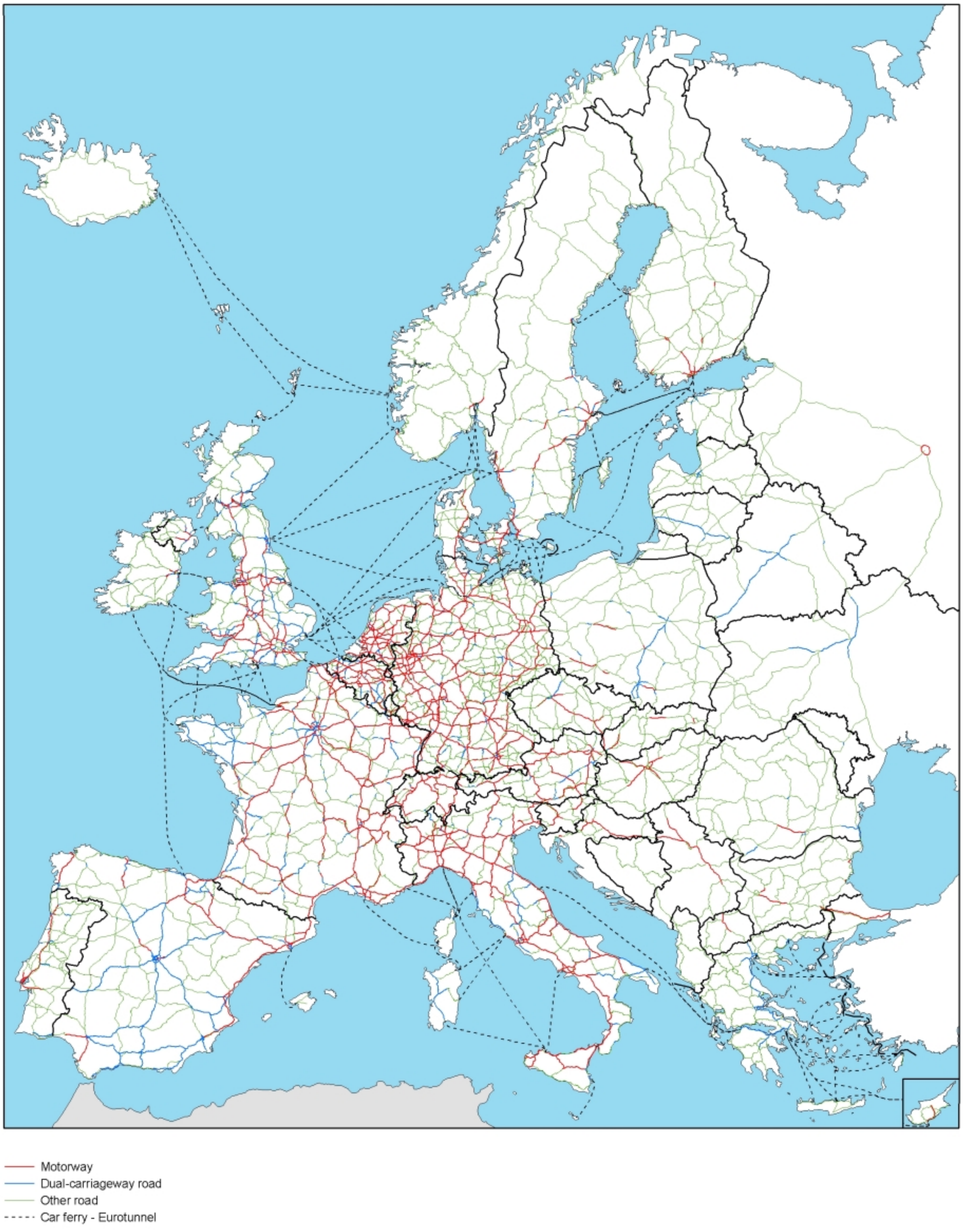

Figure 3-3. The strategic road network.

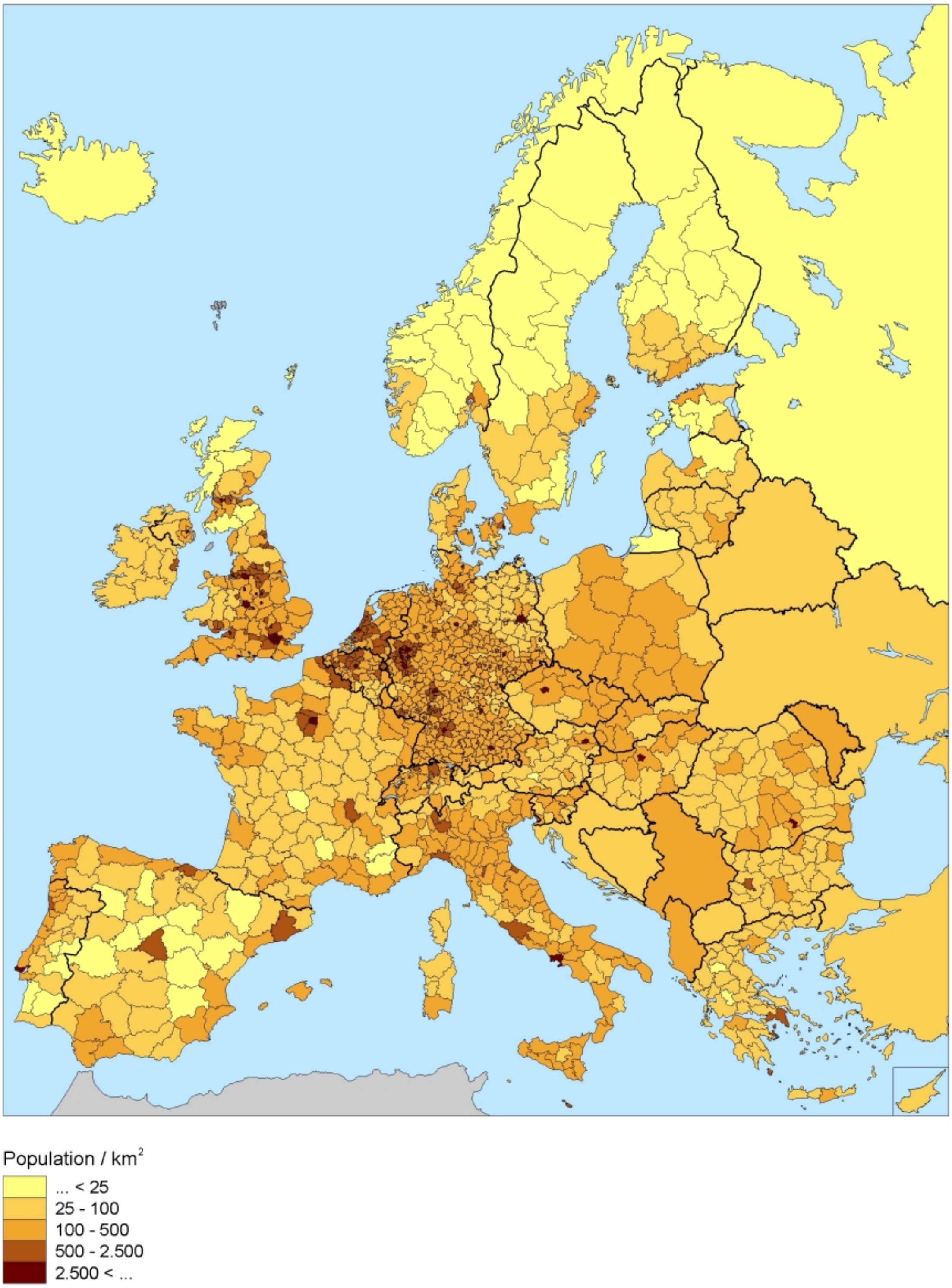

Figure 3-4. Population density of NUTS-3 regions.

Employment

Data for employment for EU member states for 1998 were also taken from the *New Chronos Database*, Table *un3wpop* (Eurostat, 1998). Data for NUTS-3 regions within NUTS-1 region 'DED' (Sachsen) were estimated in proportion to their share of employment of the larger region. Data for NUTS-3 region data in Greece were estimated in proportion to their population share. Data on employment for the candidate countries are taken from the *New Chronos Dartabase*, Table *xlfemp.* Since data for Bulgaria are not available at all, it was assumed that 45 percent of the population is employed. For the Czech Republic, Hungary, Romania and Slovakia, NUTS-2 region data were apportioned to NUTS-3 regions according to their population shares. For Slovenia, NUTS 0 data were apportioned in the same way.

Data for the other countries were taken from Bundesamt für Statistik (2000), Eurostat (1996), Statistics Norway (1999) and World Bank (1997). For a number of countries data on employment were not available at all, so certain assumptions had to be made: For Cyprus, Albania, Makedonia, Moldova and Turkiye, employment was estimated assuming that the employment/workforce ratio is the same as for Greece. For Liechtenstein the ratio of Switzerland, for Bosna I Hercegovina and Yugoslavia that of Croatia, for Belarus, Ukraina and Russia that of Poland and for Malta that of Italy was used.

Figure 3-5 shows employment expressed as jobs per capita.

Gross domestic product (GDP)

Data on gross domestic product in Euro (Figure 3-6) for EU member states and for the candidate countries were taken from Tables *e3gdp95* and *xe_gdp* of the *New Chronos Database* (Eurostat, 1998). For Italy data of NUTS-2 regions were allocated to NUTS-3 regions according their to population shares. National figures for Cyprus and Malta were taken from Table *Pvd3a* of the *New Chronos Database* (Eurostat, 1998). Data for Norway were estimated from 1994 Norwegian currency figures in Statistics Norway (1999). Data for Switzerland were derived from Bundesamt für Statistik (2000), whereas figures for Lichtenstein were estimated on the assumption that the GDP per capita is the same as for Switzerland. Data for Iceland were based on OECD (2000). Data for Croatia were taken from World Bank (1997), and for the remaining external countries latest data for 1996 were taken from UN (1999).

Similar to GDP in Euro, data on GDP in PPS (Figure 3-7) for EU member states, the candidate countries and Cyprus and Malta were taken from the *New Chronos Database* (Eurostat, 1998). Again GDP values for Italian NUTS-2 regions were broken down to NUTS-3 regions in proportion to their population shares. Data for Switzerland were compiled from Bundesamt für Statistik (2000) and Eurostat (2000). Data for Iceland were taken from Eurostat (1996), and data for Norway were adjusted from GDP in Euro figures from Eurostat (2000). Data for Liechtenstein were estimated from GDP in Euro on the assumption that GDP per capita is the same as in Switzerland. Data for Croatia were estimated from GDP in Euro assuming that the ration GDP in Euro v. GDP in PPS is the same as in Slovenia. Data for Albania, Bosna I Hercegovina, Makedonia, Moldova, Turkiye and Yugoslavia were estimated from GDP in Euro on the assumption that GDP per capita is the same as in Greece. Similar estimations were made for Belarus, Russia and Ukraina, assuming that GDP per capita is the same as in Poland.

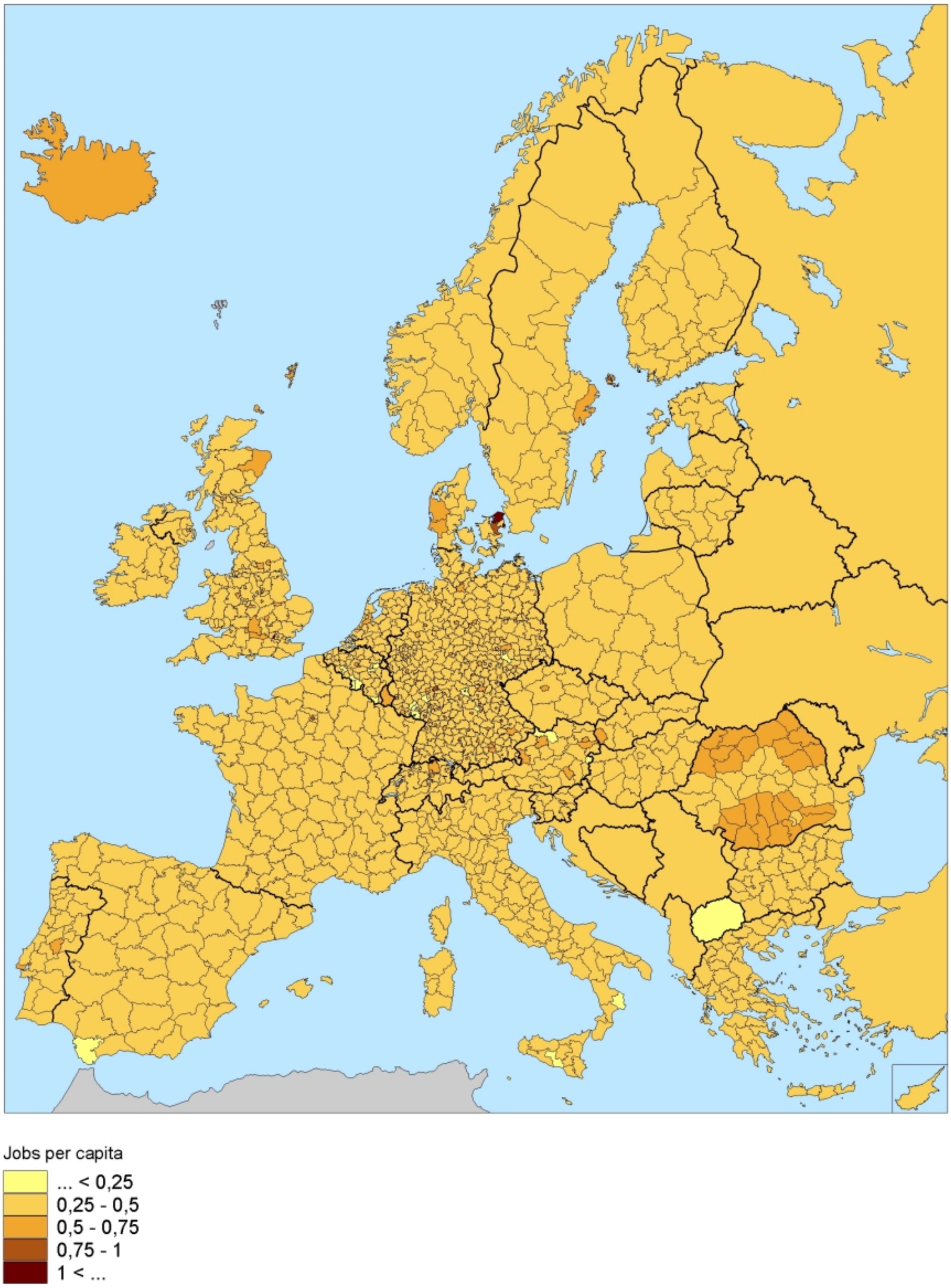

Figure 3-5. Jobs per capita.

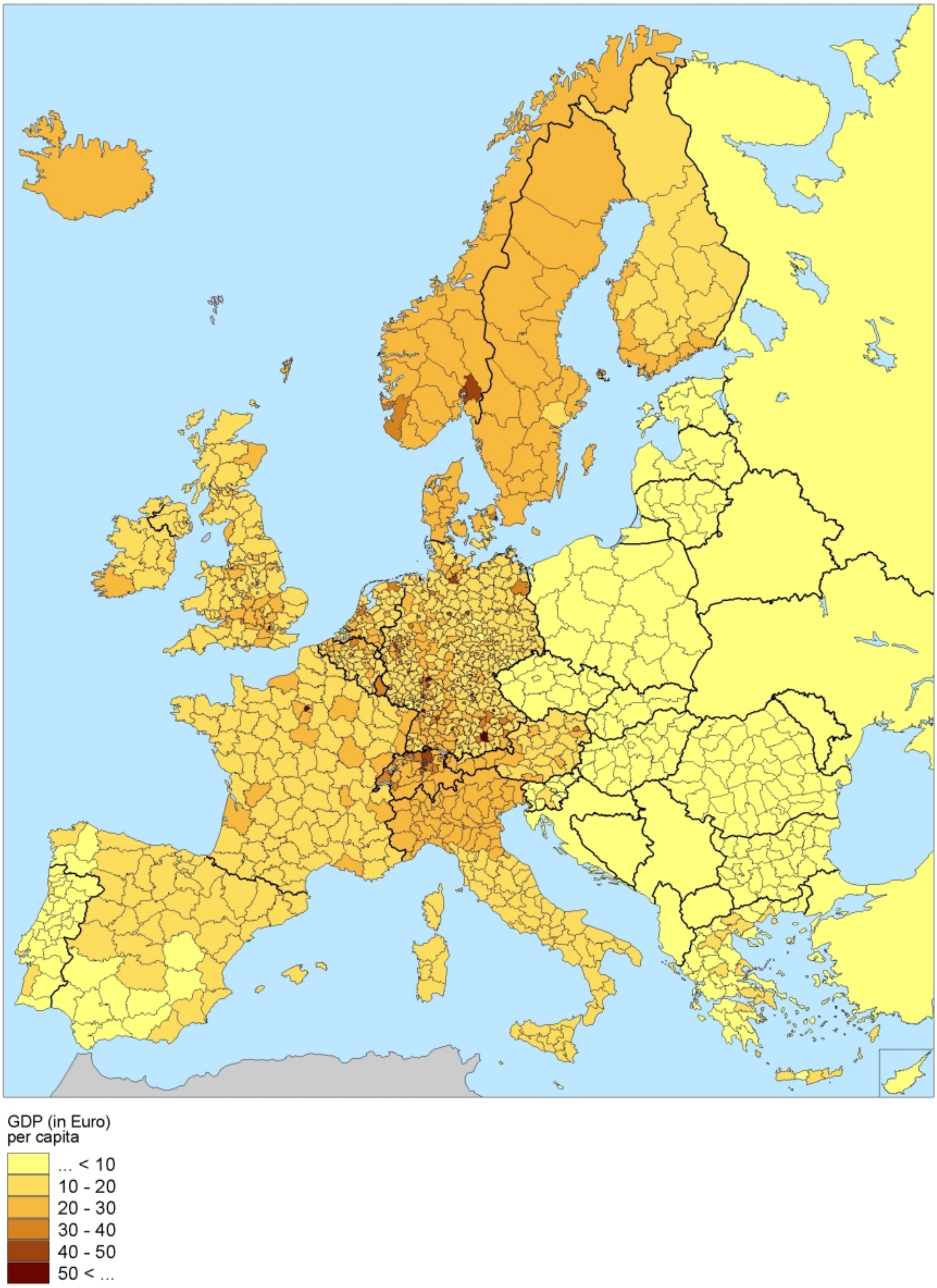

Figure 3-6. Gross domestic product per capita (in Euro).

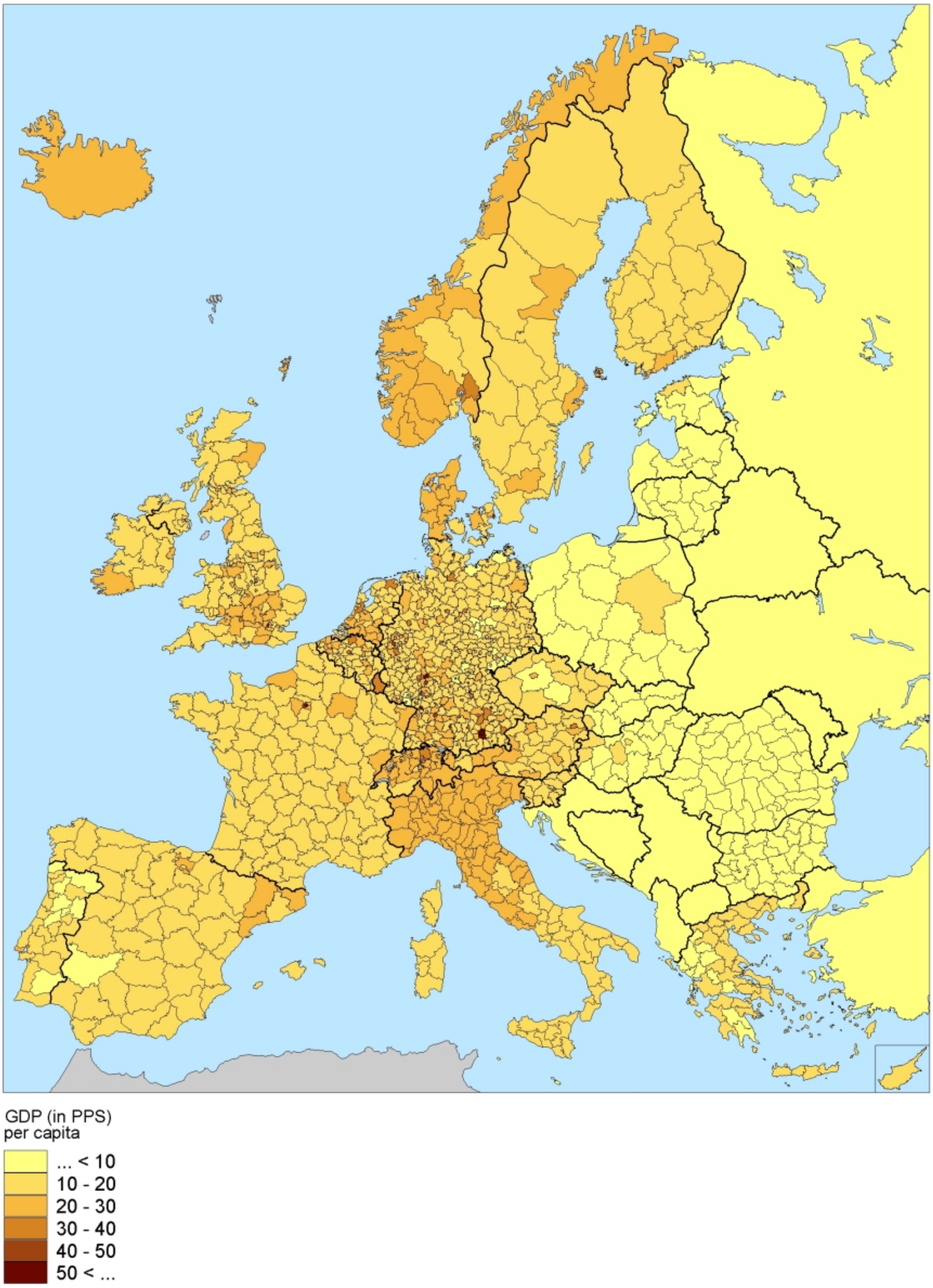

Figure 3-7. Gross domestic product per capita (in PPS).

Since in all tables of the *New Chronos Database* the Bulgarian regions Buchuresti (RO081) and Ilfov (RO082) are combined, estimates had to be made to subdivide the numbers to the two regions. Population figures for the two regions were estimated by using the population of Bucuresti from the Eurostat STEU database and estimating the population of Ilfov as the residual of the RO08 total. All other variables were allocated from RO08 to the two cities according to their population shares.

3.2.4 Digital Terrain Model

The relief of a territory plays an important role for modelling travel times. On a flat ground higher speeds and so shorter travel times can be achieved than in hilly or mountainous regions. Therefore a detailed European digital terrain model (DTM) is necessary to simulate road gradients. However, high-resolution DTM are associated with exorbitant storage requirements and long processing times. For this study a compromise was made using the GTOP30 pan-European digital terrain model provided by U.S. Geological Survey (2000) with a scale of 1:3,000,000. In the INTERNAT project funded by the European Commission under the Transport RTD Programme (Mens en Ruimte N.V. et al., 2000), that DTM proved to be appropriate for modelling road gradients at a Europe-wide scale.

Even in this scale the DTM comprises several million points representing elevation above sea level for the whole of Europe. This volume of data cannot be handled by the software developed in this study with defendable effort. Therefore, the elevation points were pre-processed by converting them into a raster-based relief surface representing the standard deviation of the elevation of all points falling into a raster cell of 10 by 10 square kilometres. The standard deviation can be interpreted as the relief energy in each cell. The higher the deviation, the greater will be the road gradients and the lower the speeds. Figure 3-8 displays the standard deviations of elevation of raster cells.

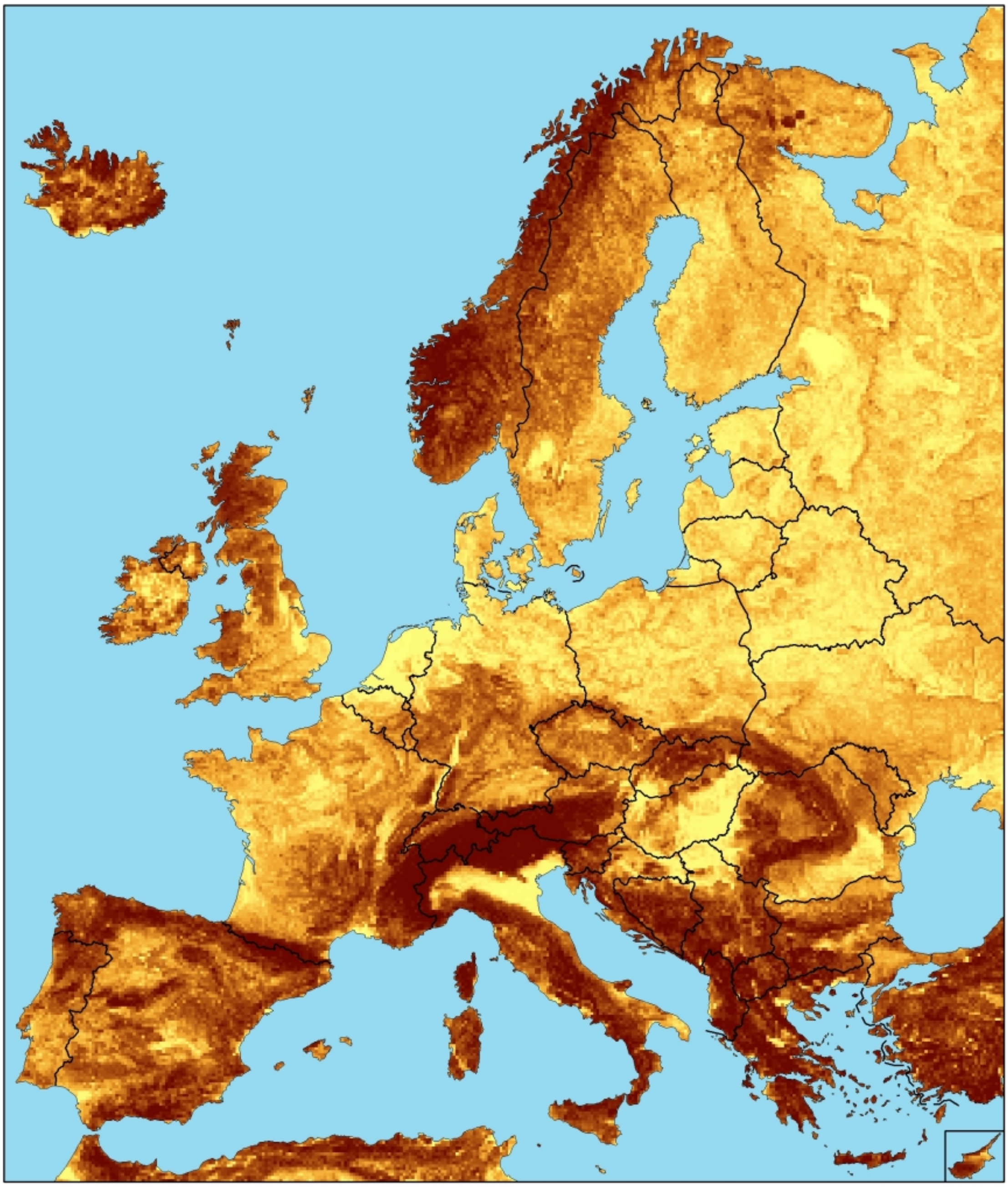

Figure 3-8. Digital terrain model of Europe.

3.2.5 Other Parameters

The spatial distribution of activities and the location and quality of the road network described in the previous section are the main determinations of accessibility, and hence peripherality. Additionally, a number of parameters were taken into account to give more realistic results. These parameters address theoretical considerations (e.g. the parameter β in the equation of the potential accessibility), political and practical issues, such as border waiting times or delays at ferry ports, or regulatory systems, such as the statutory rest periods of lorry drivers.

Betas for accessibility calculations

As shown in Table 2-1 (Section 2.1), the choice of the parameter expressing sensitivity to spatial impedance, β, plays a prominent role in calculating potential accessibility. Based on previous work of Schürmann et al. (1997) and Fürst et al. (1999) for the SASI project, β of .007 for cars and .003 for lorries seem appropriate for European accessibility studies. Figure 3-9 shows the resulting impedance curves for the chosen β. The impedance curve for lorries is flatter since it can be assumed that goods transport is less sensitive to travel time than passenger travel. These curves must be interpreted as follows: The more distant (in hours of travel time) a destination is away from the origin region, the less it contributes to the accessibility of the origin region. For example, a destination four lorry driving hours away from an origin region contributes only 50 percent to its accessibility for goods transport. A detailed discussion of impedance curves and their impact on accessibility is contained in Schürmann et al. (1997).

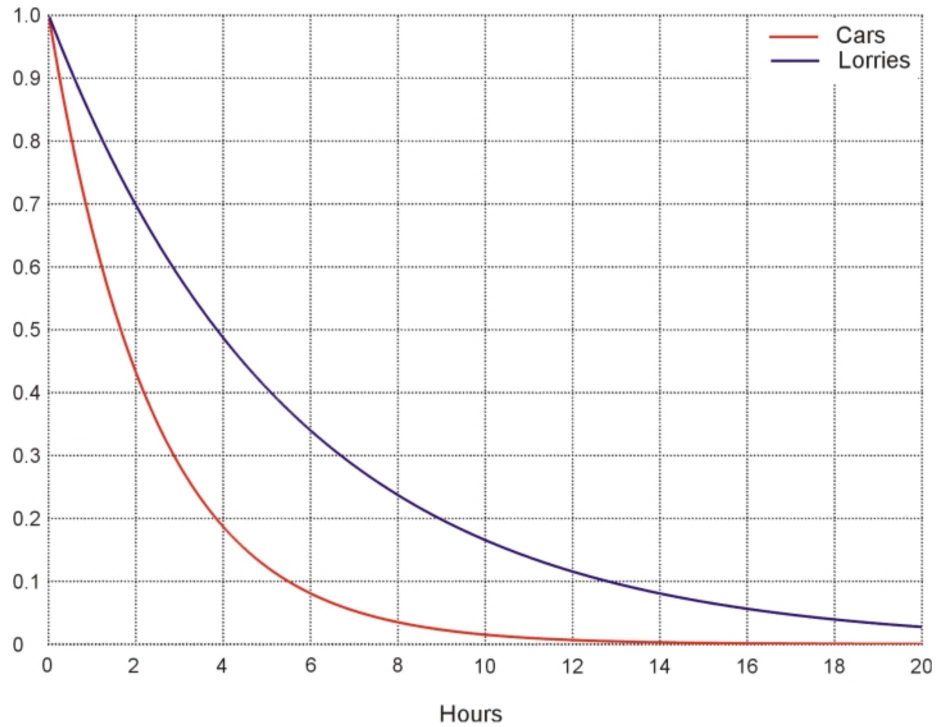

Figure 3-9. Calibration of parameter β of potential accessibility.

Border delays

In the past, waiting time at border crossings were a major concern especially for freight transport, but to some extent also for passenger trips. Long waiting times of 30 minutes or more were not unusual even between EU member states. In the process of European integration and the forming of the European Union, one of the main tasks was the removal of border controls between the member states to ease the movement of freight and people as laid down in the Schengen Agreement. However, waiting times at borders between the EU and east European countries and between these countries are still a major problem which heavily affects road travel times and so regional accessibilities.

The remaining minimal border delays between EU member states are based on plausible assumptions. Border delays for eastern Europe were compiled from IRU (1998) as the average waiting times in July 1998. Because this source gives the waiting times for lorries and heavy trucks only, it is assumed that waiting times for passenger cars are one fourth of lorry waiting times. A similar approach was also incorporated into the SASI model by Fürst et al. (1999).

In detail, the waiting times implemented in the study are based on the following assumptions:

- It is assumed that waiting times between adjacent countries are the same at each checkpoint, regardless of type of road (motorways, other roads) or the location of the checkpoint.

- If ferry connections or the Eurotunnel are used to travel from one country to another, no additional border waiting times are added, since customs clearance is part of the ferry disembarking and so is already included in the time penalty added for ferry ports.

- Armed conflicts are taken into account (former Yugoslavia).

- Waiting times are differentiated by trip direction, because especially between EU member states and non-EU countries inbound and outbound delays are significantly different.

Table 3-1 presents examples of assumptions on waiting times at border crossings.

Table 3-1. Examples of waiting times at border crossings.

Countries	Waiting times (min)	
	Car	Lorry
AT-DE	5	5
BA-HR	25	100
DE-PL	110	440
PL-DE	90	360
DE-BE	5	10

The waiting times are implemented into the software in a way that they can be manually adjusted to fit specific needs or to simulate certain policy options. Please refer to the User Manual (Schürmann and Talaat, 2000) for further details regarding adjustments of border delays.

Delays at ferry ports and the Eurotunnel

Similar to border delays at checkpoints, also (dis-)embarkation movements at ferry ports cause delays. Usually one has to arrive a certain time before embarkation. If the ferry connection is leading abroad, also customs clearance will be involved.

Since no comprehensive source comprising all waiting times is available, plausible assumptions were made for embarkation waiting times. It is assumed, that there will be a delay for cars of about 50 minutes and for lorries of about 70 minutes at every port. Because of lack of information, no differentiation is made between different ports nor between embarking and disembarking. Based on Eurotunnel (2000), delays of 30 minutes for cars and 50 minutes for lorries are used for the boarding stations of the Eurotunnel.

All these parameters can be manually adjusted in the software (see Schürmann and Talaat, 2000).

Internal average trip length

When calculating accessibility of the potential type, a major concern is how to handle the 'self-potential' of the origin region, i.e. the contribution of the origin region's own activities to its accessibility.

The most elegant solution to modelling the self-potential is to switch from a region-based approach to a raster-based approach (see Spiekermann and Wegener, 2000), in which accessibility is not modelled for regions but for small raster cells. However, this solution is not feasible in this study.

Therefore, intraregional trips are assumed to be of 10 km length on average. This represents the average trip length in many agglomerations. It is assumed that on intraregional trips cars travel with an average speed of 50 km/h and lorries with an average speed of 30 km/h. The β of .007 for cars and .003 for lorries are also used.

Speed limits

Travel time calculations highly depend on the speed limits valid for different road categories. Since these limits differ between countries and between vehicle types, country-specific national speed limits differentiated by vehicle type are considered.

Speed limits for cars were compiled from ADAC (2000) and UBA (1998), whereas speed limits for lorries are based on IRU (2000).

Differentiation by the motor power of vehicles (e.g. for Italy or Romania) or for dry or wet road pavements (e.g. in France) are not taken into account. If there are different regulations for express roads and regular roads, the speed limits for regular roads are used for roads with only one lane per direction and speed limits for express roads for multi-lane roads which are no motorways. This ensures maximum differences between motorways and other roads.

Where regulations in some countries differentiate between light (between 3.5 and 12 tonnes) and heavy trucks (more than 7.5 or in some countries more than 12 tonnes), the speed limits for heavy trucks are used.

Table 3-2 presents some examples of national speed limits for different road categories used in the study.

Table 3-2. Examples of national speed limits (km/h).

Country	Cars				Lorries / Trucks			
	Motorways	Express Ways	Outside built-up areas[1]	Roads in built-up areas	Motorways	Express ways	Outside built-up areass[1]	Roads in built-up areas
AT	130	100	100	50	80	70	70	50
BE	120	90	90	50	90	90	60	50
FR[2]	130	90	90	50	90	80	60	50
HU	120	100	80	50	80	70	70	50
IT[2]	130	90	90	60	80	80	70	50
PL	110	80	80	50	70	70	70	60
PT	120	100	90	50	80	70	70	50

[1] *one lane per direction; no expressways.*
[2] *Speed limits for lorries refer to heavy trucks with more than 12 tonnes.*

Statutory rest periods for drivers

A major concern for calculating accessibilities for freight transport are the regulatory rest periods of lorry drivers. From a modelling point of view, incorporating these rest periods is difficult since Community legislation gives only a general framework which is filled by national regulations. Moreover, even this framework allows a number of exceptions and special regulations with respect to splitting rest periods, differences between employed and independent lorry drivers or the number of drivers per vehicle. It is not possible to include every detail of national regulations into the model.

A way of incorporating the most important principles of statutory rest periods of drivers was developed based on European Communities (1985, 1-7). According to Section 5 ('Breaks and resting periods'), Article 7, a lorry driver shall observe a break of at least 45 minutes after four-and-a-half hours' driving. Additionally, according to Section 4 ('Driving periods'), Article 6 states that the daily driving period should not exceed nine hours, after which the driver shall have a daily rest period of at least 11 consecutive hours (Section 5). Moreover, if the vehicle is transported on a ferryboat or a train (e.g. in the Eurotunnel), time spend on the ferryboat or train can be acknowledged as rest time (Section 5, Article 9).

These basic regulations are introduced into the model by calculating the pure travel time for freight transport from an origin to a destination region, adding time penalties of 45 minutes after each four-and-a-half hours of driving and of 11 hours daily rest period after nine hours of driving. Travel times on ferries are subtracted and not taken into account.

3.3 Output Indicators

The model developed is capable of calculating a large number of different output indicators. The range of indicators available is explained below.

- *Spatial aggregation*. Every calculation is done for NUTS-3 regions, and indicator values for higher-level regions are derived by aggregating results of NUTS-3 regions to NUTS-2, NUTS-1 and NUTS-0 regions.

- *Modes*. All indicators are calculated separately for cars and lorries.

- *Mass terms*. All indicators are calculated for four different mass terms (or destination activities): population, employment, GDP in Euro, GDP in PPS.

- *Type of indicator*. All peripherality indices are derivates of potential accessibility. Two different types of peripherality indices are defined:

  - Peripherality Index 1 (PI1): The region with the highest potential accessibility, i.e. the most central region, is defined to have a peripherality index of zero. The region with the lowest potential accessibility, i.e. the most remote region, is defined to have a peripherality index of one hundred. The peripherality index of all other regions is a linear interpolation between zero and one hundred proportional to their potential accessibility. The higher the peripherality index, the higher the peripherality.

  - Peripherality Index 2 (PI2): The average potential accessibility of all regions weighted by regional population is defined to be one hundred. The peripherality index of all regions is calculated as potential accessibility expressed in percent of average accessibility. The higher the peripherality index, the lower the peripherality. Peripherality Index 2 is therefore in fact a standardised accessibility indicator.

- *Spatial scope of standardisation*. Standardisation is done for the three different territories covered: EU member states only, EU plus five candidates and EU plus twelve candidates. This implies that the values of the regional peripherality indices differ depending on the territory covered.

Based on the above classification (4 NUTS levels, 2 modes, 4 mass terms, 2 types of indicators, 3 territories), 4 x 2 x 4 x 2 x 3 = 192 possible output indicators can be calculated and mapped. Table 3-3 summarises the 192 possible output indicators . The numbers in the table are consecutive numbers used for identifying the resulting maps and output files (see Schürmann and Talaat, 2000).

Table 3-3. Available output.

Mode	NUTS level	Standardisation	EU member states				EU plus 5 candidates				EU plus 12 candidates			
			Population	Employ-ment	GDP	GDP in PPS	Population	Employ-ment	GDP	GDP in PPS	Population	Employ-ment	GDP	GDP in PPS
Car	0	PI1	1	2	3	4	9	10	11	12	17	18	19	20
		PI2	5	6	7	8	13	14	15	16	21	22	23	24
	1	PI1	25	26	27	28	33	34	35	36	41	42	43	44
		PI2	29	30	31	32	37	38	39	40	45	46	47	48
	2	PI1	49	50	51	52	57	58	59	60	65	66	67	68
		PI2	53	54	55	56	61	62	63	64	69	70	71	72
	3	PI1	73	74	75	76	81	82	83	84	89	90	91	92
		PI2	77	78	79	80	85	86	87	88	93	94	95	96
Lorry	0	PI1	97	98	99	100	105	106	107	108	113	114	115	116
		PI2	101	102	103	104	109	110	111	112	117	118	119	120
	1	PI1	121	122	123	124	129	130	131	132	137	138	139	140
		PI2	125	126	127	128	133	134	135	136	141	142	143	144
	2	PI1	145	146	147	148	153	154	155	156	161	162	163	164
		PI2	149	150	151	152	157	158	159	160	165	166	167	168
	3	PI1	169	170	171	172	177	178	179	180	185	186	187	188
		PI2	173	174	175	176	181	182	183	184	189	190	191	192

3.4 Implementation in ArcInfo

The model to calculate peripherality indices is incorporated into the geographical information system ArcInfo. The geodatabase and parameters required to run the system are stored as ArcInfo coverages and INFO tables and ASCII files.

The model system itself consists of three core components: the **`INITIAL`** macro, the **`CALCUL`** macro and the **`PLOT`** macro. The **`INITIAL`** macro defines global variables and parameters and initialises ASCII input files. The **`CALCUL`** macro calculates the indicators presented in Table 3-3, stores them in output coverages and INFO tables and exports them into ASCII files. The **`PLOT`** macro is used to produce output maps showing the resulting peripherality indices.

In addition, a number of add-ons were developed to support certain tasks for updating the geodatabase or to perform error checking. As a principle, updates of the database or changes of the parameters can be achieved by editing the input coverages and parameter files. It is not necessary to edit the code of the macros itself to change default settings. The User Manual (Schürmann and Talaat, 2000) gives a comprehensive description of the model system, explains how to run the system and how to edit the database and suggests how to handle errors.

4 Peripherality Indices

This chapter presents the main results of the study obtained with the system described above. First, the overall outcome, i.e. the classification of European regions in terms of their peripherality, is elaborated for the two most important peripherality indices. Then, the impact of modifying certain aspects of the indicators on the results are discussed. Then, an outlook is given on how transport investments might change the peripherality of regions in Europe.

The peripherality indices are presented in this chapter at the NUTS-2 and NUTS-3 levels in maps and also in diagrams at the NUTS-2 level.

4.1 Standard Peripherality Indices

Based on other studies and on theoretical considerations, peripherality with respect to population by car and peripherality with respect to GDP in Euro by lorry are proposed as standard peripherality indices.

The two indicators refer to different perspectives. Peripherality with respect to population by car represent the perspective of service firms and consumers with respect to how many opportunities such as clients, markets or tourist facilities can be reached. Peripherality to GDP by lorry represent the perspective of producers on potential markets.

In all cases Peripherality Index 2, i.e. potential accessibility in percent of average potential accessibility of the territory considered, is used. For the following discussion, it is important to keep in mind that this index of peripherality is in fact an accessibility indicator and that *higher* index values indicate more central and *lower* index values more peripheral regions.

Peripherality with respect to population

The peripherality index with respect to population is shown in Figure 4-1. Regions in Benelux countries, most of the regions in Germany and regions in northern France show accessibility above average, i.e. can be considered as the most central regions. Regions between the cities of Rotterdam and Antwerp, towards Rhine-Ruhr-Area and alongside the Rhine river in Germany are the most central ones. Additionally, regions in England, in particular around London, and in northern Italy nearby Madrid also show above-average accessibilities.

All other regions show accessibilities below-average, i.e. tend to be peripheral. The most peripheral regions are, as expected, located in Scandinavia and Scotland and on the Mediterranian Islands. Most regions in Spain, Italy and southern France yield peripherality indices between 25 and 100.

With very few exceptions in the Czech Republic and Poland, all regions in the candidate countries have below-average accessibility, i.e. are to be seen as peripheral. Other regions in the Czech Republic and Poland show index values near the average, i.e. they benefit from their relative closeness to German agglomerations, but also from their relatively high self-potential. Peripherality indices for Bulgaria and Romania are as low as in Spain. The Baltic countries are not that peripheral as the Scandinavian countries, but yield also relatively low index values. The further north they are located, the lower are their index values.

Peripherality with respect to GDP

The peripherality index with respect to GDP is illustrated in Figure 4-2. The overall spatial pattern is similar to the peripherality index with respect to population. However, the most central and most peripheral regions are much more pronounced. Regions in the European core show the highest accessibility and so are most central. These regions are located along the 'Blue Banana' in western Germany, Belgium, in the southern parts of the Netherlands, in northern France and southern England. A band of regions from the Po estuary towards Milano and Lyon up to the Channel coast show above-average accessibility. The differences between Spain and Portugal and between the southern and northern Scandinavian regions are, compared to Figure 4-1, more pronounced, i.e. among the peripheral regions there seems to be a clear distinction between peripheral, more peripheral and most peripheral regions. Regarding the most peripheral regions, also regions in the Baltic countries, in Romania and Bulgaria show index values of less than 10 due to their – compared to EU member states – still relatively poor economic performance.

Compared to the peripherality index with respect to population, regions directly located at the Channel benefit to a higher degree from the Eurotunnel. This indicates that from a consumer's perspective the Eurotunnel still has a barrier effect, whereas from a producer's perspective this barrier effect can be considered as much lower if existing at all. Nevertheless, the number of regions with accessibility values of more than 250 is significantly higher as for car; similarly, the number of regions with accessibility values of less than 10 is also significantly higher compared to Figure 4-1, since now also Romania and Bulgaria, all the Baltic regions and also regions in Portugal and Greece show up extremely low index values due to their poor economic performance. So it can be stated that peripherality with respect to GDP is more polarised than with respect to population by car.

Comparing both indices

The correlation diagram (Figure 4-3) confirms a high degree of similarity of both peripherality indices. Although the overall correlation seems clear, there are some small, but nevertheless important differences between both indices. In general, central regions in Benelux, Germany and France, but also in the UK show comparably higher values for peripherality with respect to GDP than with respect to population. On the other side, regions in the candidate countries have higher accessibility to population than to GDP. This is because most of the candidate countries have relatively poor economic performance but large populations which confirms the observation that peripherality index with respect to population seems less polarised than peripherality with respect to GDP. In other words, if peripherality with respect to GDP is used, central regions, if peripherality with respect to population is used the candidate countries appear less peripheral.

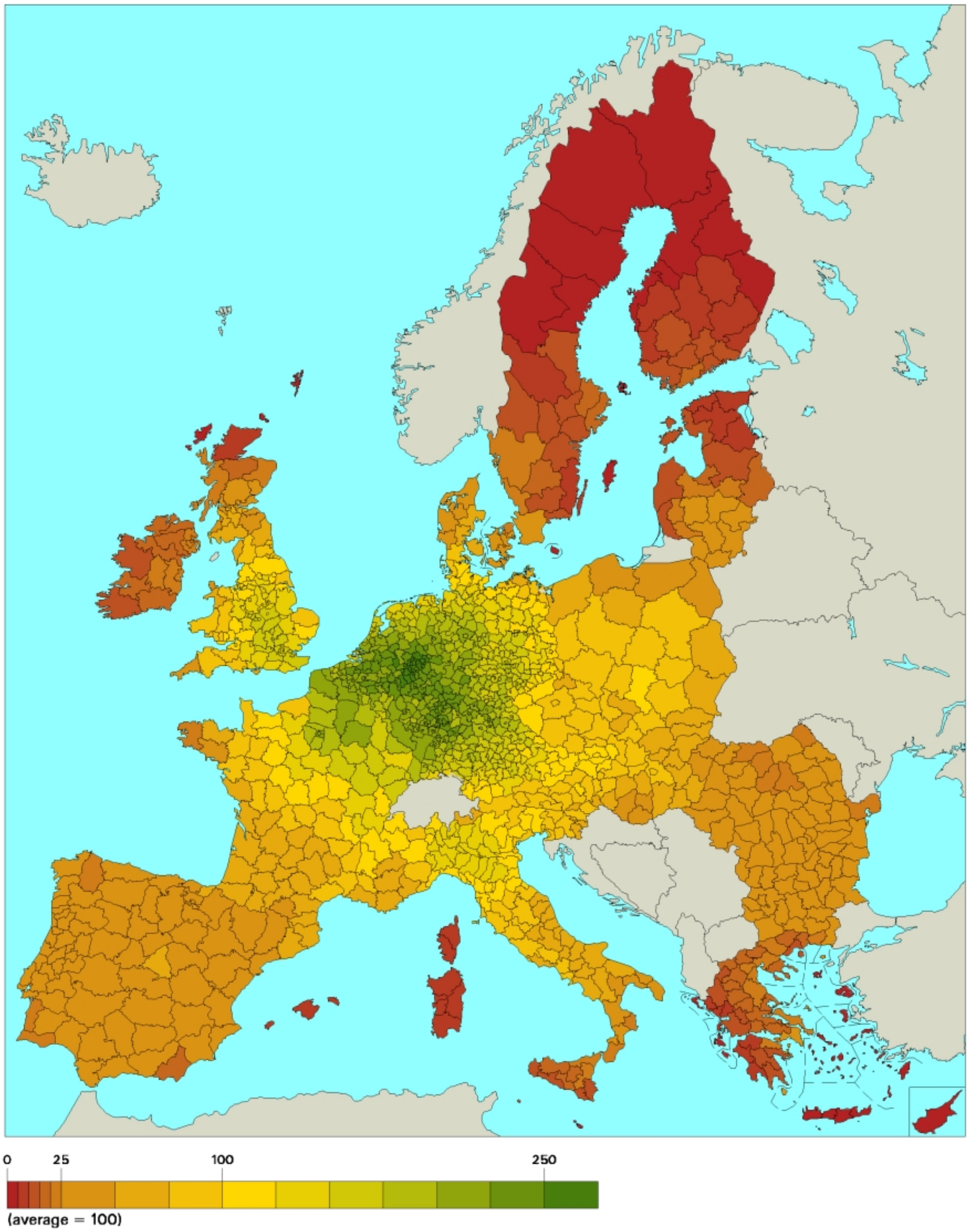

Figure 4-1. Peripherality with respect to population by car (NUTS 3).

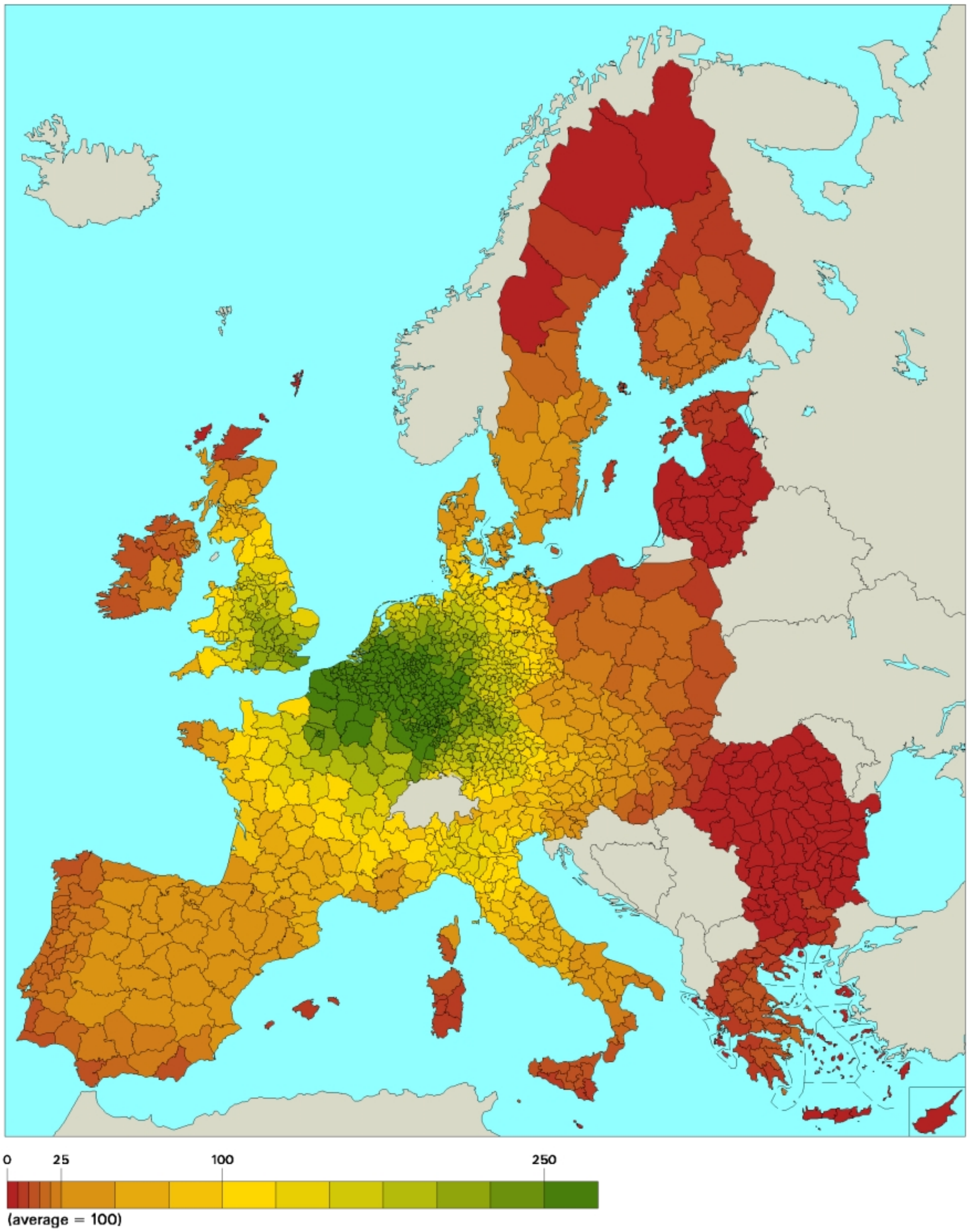

Figure 4-2. Peripherality with respect to GDP by lorry (NUTS 3).

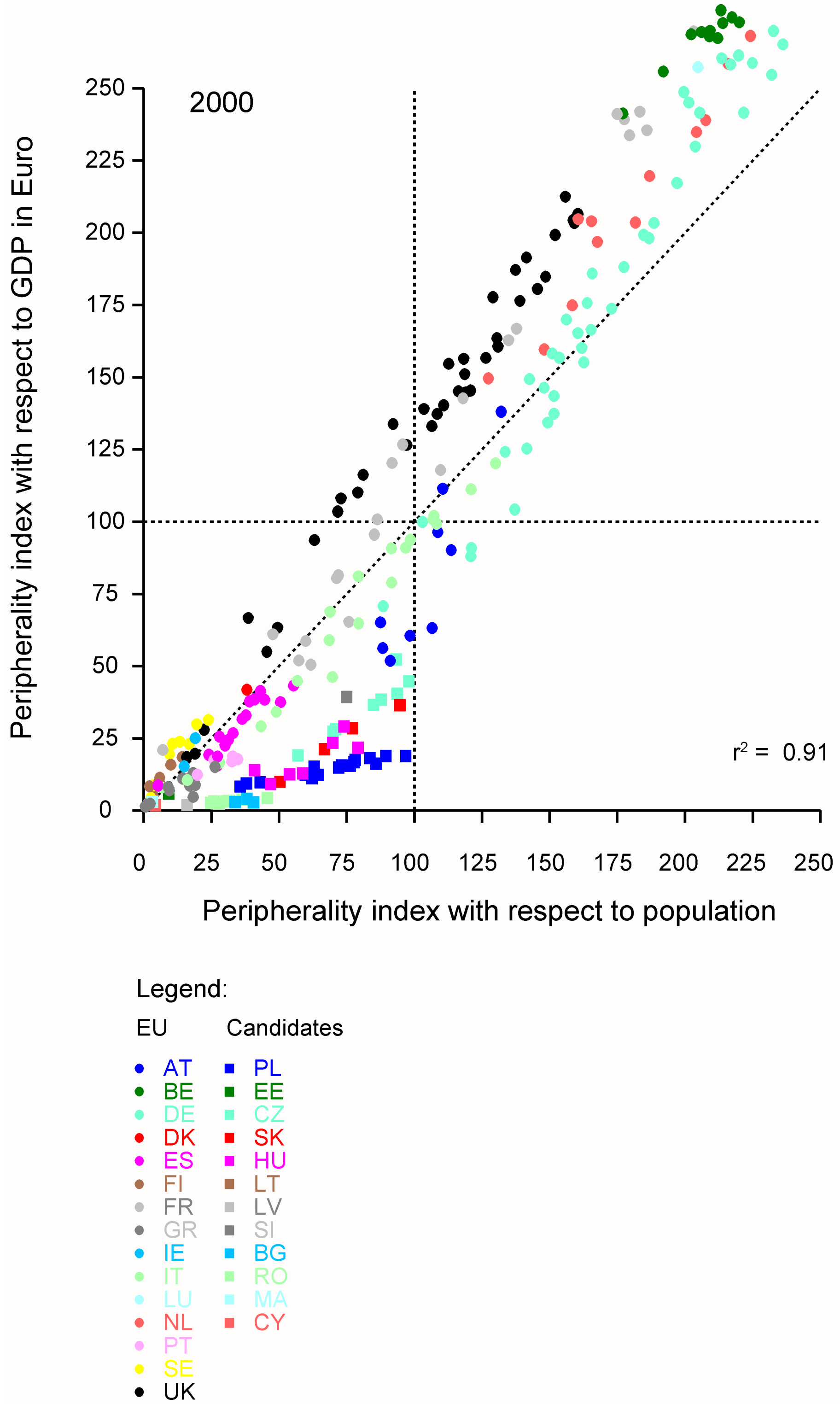

Figure 4-3. Peripherality with respect to population v. with respect to GDP (NUTS 2).

4.2 Discussion of Peripherality Indices

As indicated in Section 3.3, the model offers a large number of output indicators based on different combinations of different transport modes, standardisation methods, masses, territories covered and NUTS levels considered. It will be assessed now on the basis of the preliminary results outlined in the previous section, how index values behave when parameter settings change.

This assessment will be done for the five parameters separately. Since the overall spatial patterns seem to be very similar for all indices, the following discussion focuses on the differences and the way the peripherality index behaves when a certain kind of index is used. At the same time, this evaluation presents different output options and different types of indicators available in the model with respect to different combinations of the five parameters.

Modes

Two transport modes are available in the model: cars and lorries. To compare differences between modes, peripherality indices with respect to population and with respect to GDP (in PPS) for NUTS-2 level are calculated for NUTS-2 level regions (Figure 4-4).

Comparing peripherality indices with respect to GDP (in PPS) by car and lorry, only marginal difference can be observed. These differences mainly refer to regions around the Channel coast, i.e. some regions in Benelux, northern France and around London show better performance for lorries than for cars. This illustrates the fact that the Channel is still a barrier for passenger traffic but not to the same extent for freight transport because lorry drivers can use the ferry crossing as statutory rest period. For other regions, almost no differences can be seen. However, as stated already in Section 4.1, regions in the ‘Blue Banana’ yield highest indicator values, i.e. are most central, and regions in Scandinavia, Bulgaria, Romania and Greece are among the most peripheral ones.

This relatively high degree of similarity between peripherality by car and lorry is confirmed by a correlation analysis (Figure 4-5), which shows an even higher correlation than Figure 4-3. Regions in Belgium, the Netherlands, France and the UK show higher indicator values for lorries than for cars; for German regions and most regions in the candidate countries, the opposite is true.

Almost the same interpretation can be given for the periperality indices with respect to population (Figure 4-4 top). The spatial patterns for both indicators look very similar, even differences for regions around the Channel coast are less pronounced as for GDP since population is more evenly distributed across Europe than GDP.

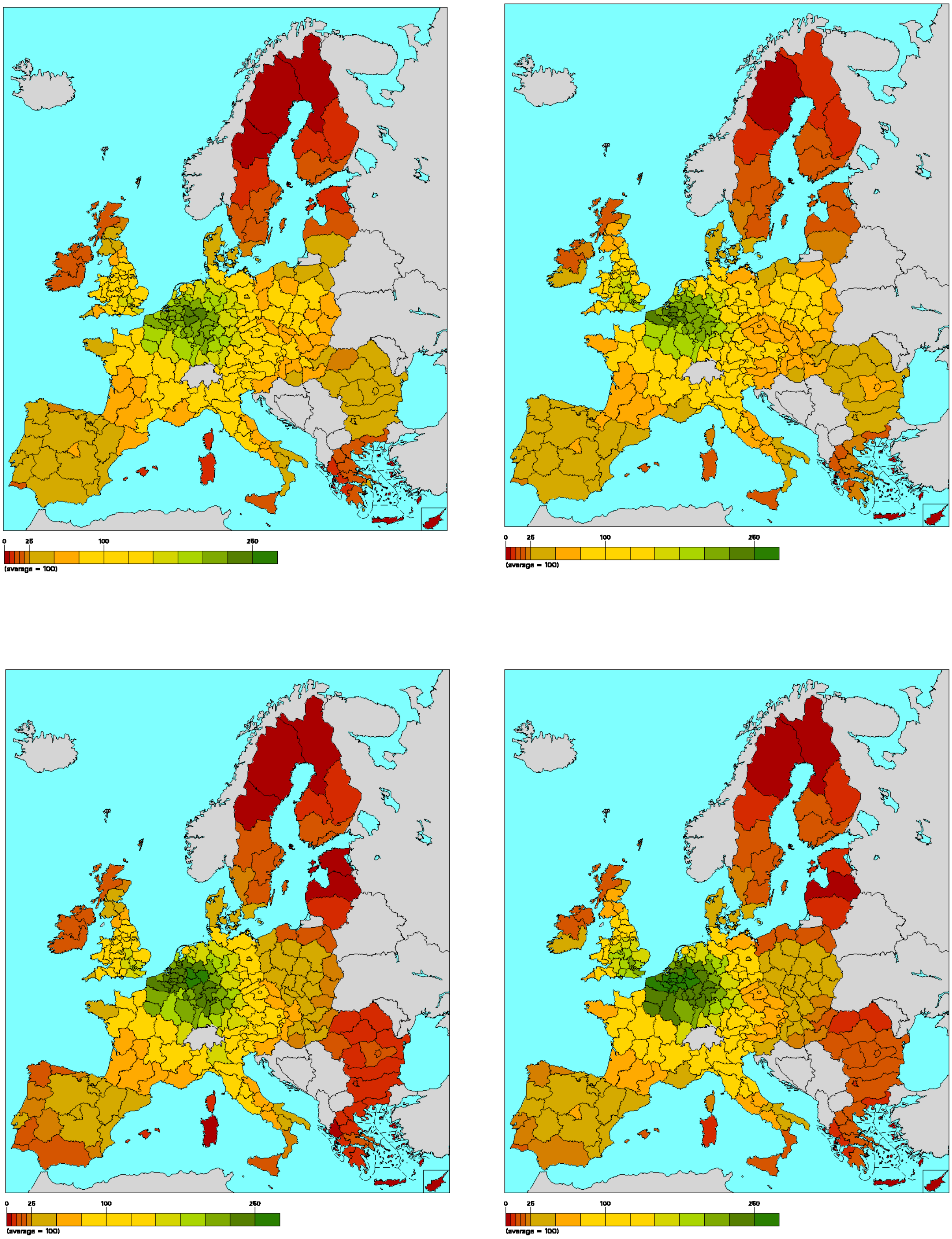

Figure 4-4. Peripherality (NUTS 2) with respect to population by car (top left) and lorry (top right); with respect to GDP in PPS by car (bottom left) and lorry (bottom right).

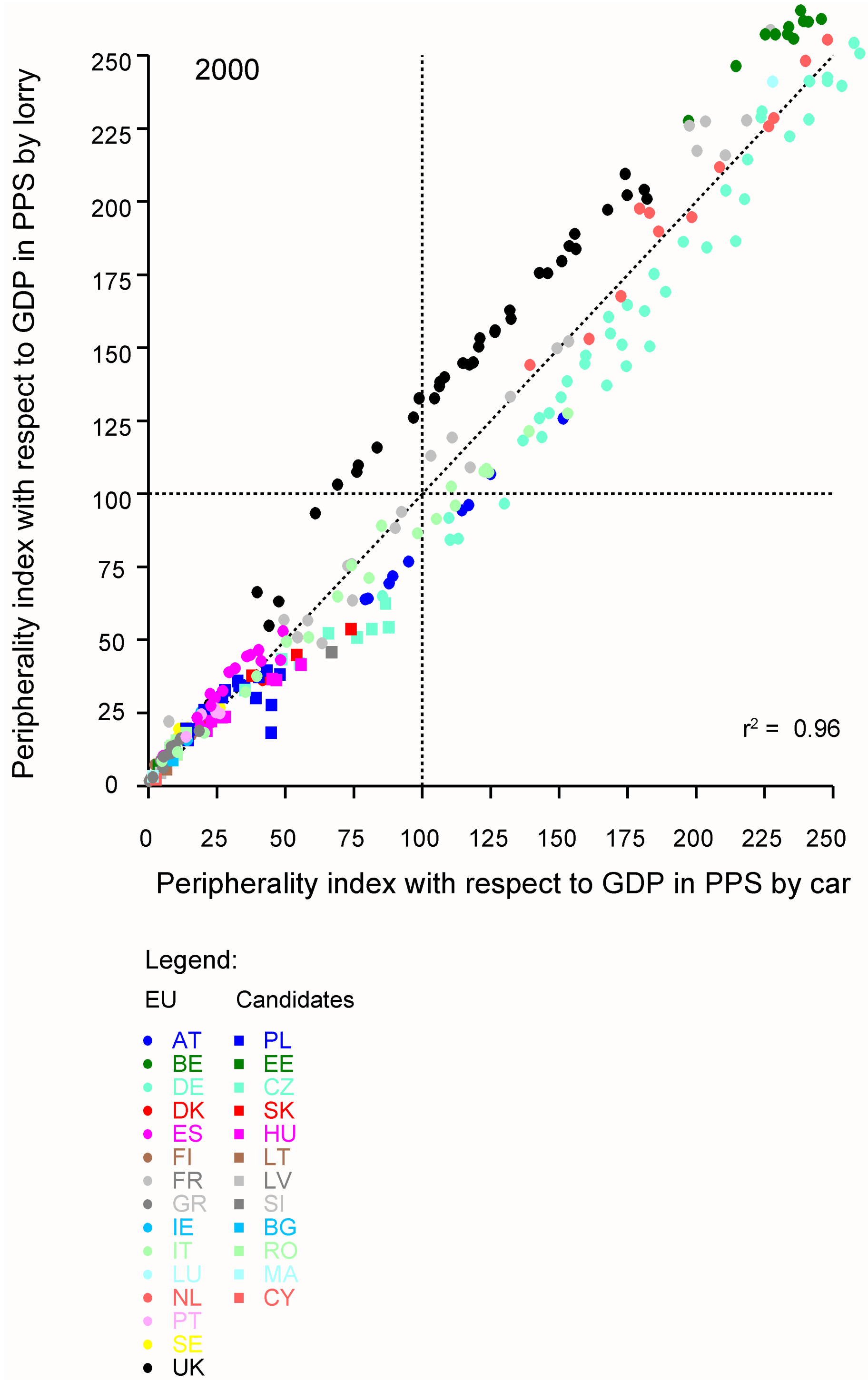

Figure 4-5. Peripherality with respect to GDP in PPS by car v. GDP in PPS by lorry (NUTS 2).

Types of indicator

Two different types of peripherality index are implemented:

- Peripherality Index 1 (PI1): The region with the highest potential accessibility, i.e. the most central region, is defined to have a peripherality index of zero. The region with the lowest potential accessibility, i.e. the most remote region, is defined to have a peripherality index of one hundred. The peripherality index of all other regions is a linear interpolation between zero and one hundred proportional to their potential accessibility. The higher the peripherality index, the higher the peripherality.

- Peripherality Index 2 (PI2): The average potential accessibility of all regions weighted by regional population is defined to be one hundred. The peripherality index of all regions is calculated as potential accessibility expressed in percent of average accessibility. The higher the peripherality index, the lower the peripherality. Peripherality Index 2 is therefore in fact a standardised accessibility indicator.

At the NUTS-2 level, there seem to be only very little differences in analytical power of both types of indicator (see Figure 4-6). Despite the different colour schemes used, the overall pattern of indicator distributions is very similar. Standardisation in the range of 0 to 100 (PI1) leads to slightly more differentiation among the peripheral regions (e.g. in Portugal), whereas standardisation on the European average (PI2) leads to slightly larger differences between the central regions. However, these differences seems negligible and so no fundamental rule should be derived from them.

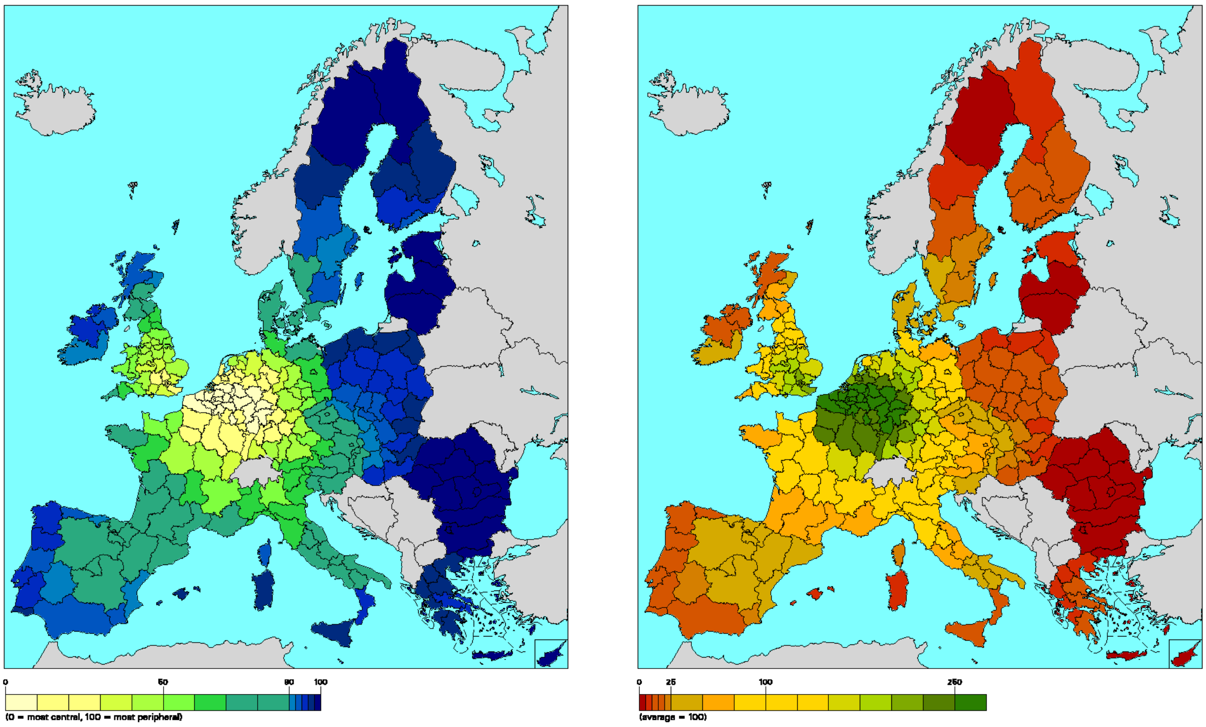

Figure 4-6. Peripherality with respect to GDP by lorry (NUTS 2): standardised between 0 and 100 (left) and on the European average (right).

Mass terms

Peripherality indices are calculated for four masses, i.e. destination activities: population, employment, GDP in Euro and GDP in PPS. Peripherality by lorry for NUTS-2 regions of EU member states is used to analyse the impact of the mass term on peripherality (Figure 4-7).

Taking peripherality with respect to population by lorry as the basis, regions in western Germany, Belgium, in northern France, in the southern parts of the Netherlands and – with slight deductions – regions surrounding London show the highest accessibility and can so be considered as the most central ones. Comparing this with accessibility to employment, only marginal differences can be found. On the one hand, there are more regions located in Belgium, northern France and western Germany showing accessibility values of more than 200 for population, on the other hand Mediterranean regions in Spain, Portugal, southern Italy and Greece yield slightly lower accessibility values for employment. Nevertheless, it is evident that the most peripheral regions are the regions in northern Scandinavia and on the Mediterranean islands, in particular the Greek islands.

Looking at GDP, the differences increase. Even for GDP in PPS, the central regions in Belgium, the Netherlands, northern France and western Germany as well as the peripheral regions in Scandinavia, southern Italy, Greece and Spain are much more peripheral than with respect to population. For periherality with respect to GDP in Euro these differences increase indicating that GDP in PPS is balancing out differences in GDP in Euro. In particular regions in Portugal and Greece become more peripheral. It can be stated that peripherality indices with respect to population and employment show slight cohesion effects, whereas indices with respect to GDP display a more polarised pattern. However, the range of indicator values is similar.

This can be confirmed by correlation analysis. Comparing peripherality with respect to population with peripherality with respect to GDP (Figure 4-8), it is obvious that all regions showing values above average for both indicators yield comparatively higher values with respect to GDP than for population. Conversely, regions showing values below average for both indicators, tend to have comparatively higher values with respect to population. This is due to the fact that although many people live in those regions, they are less productive in economic terms.

If the two peripherality indices with respect to GDP – GDP in Euro and GDP in PPS – are compared (Figure 4-9), the effects are evident: GDP in Euro benefits central regions and affects peripheral regions, whereas GDP in PPS benefits peripheral regions, in particular the candidate countries indicating the balancing effects of the PPS.

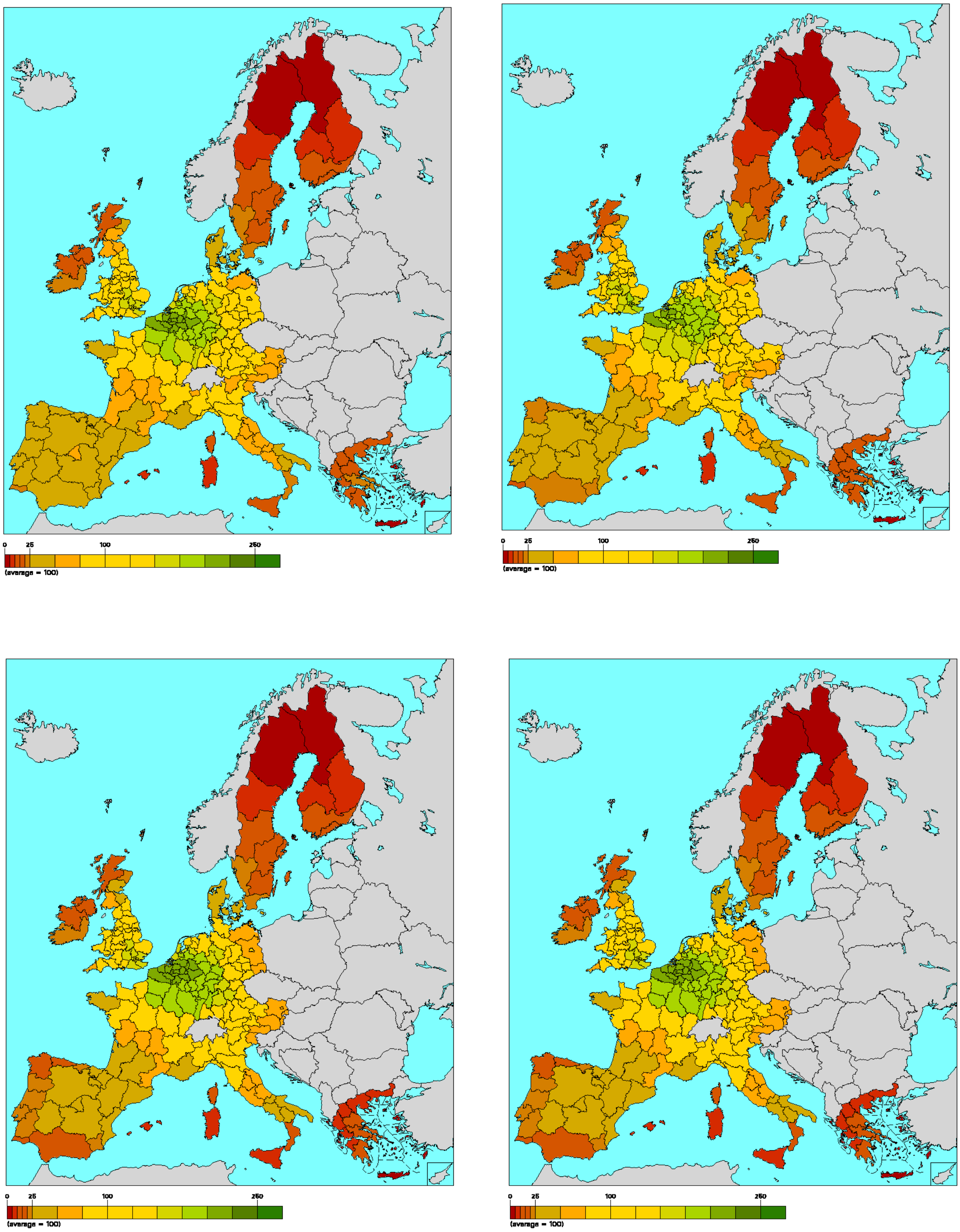

Figure 4-7. Peripherality indices by lorry (NUTS 2) with respect to population (top left), employment (top right), GDP in Euro (bottom left) and GDP in PPS (bottom right).

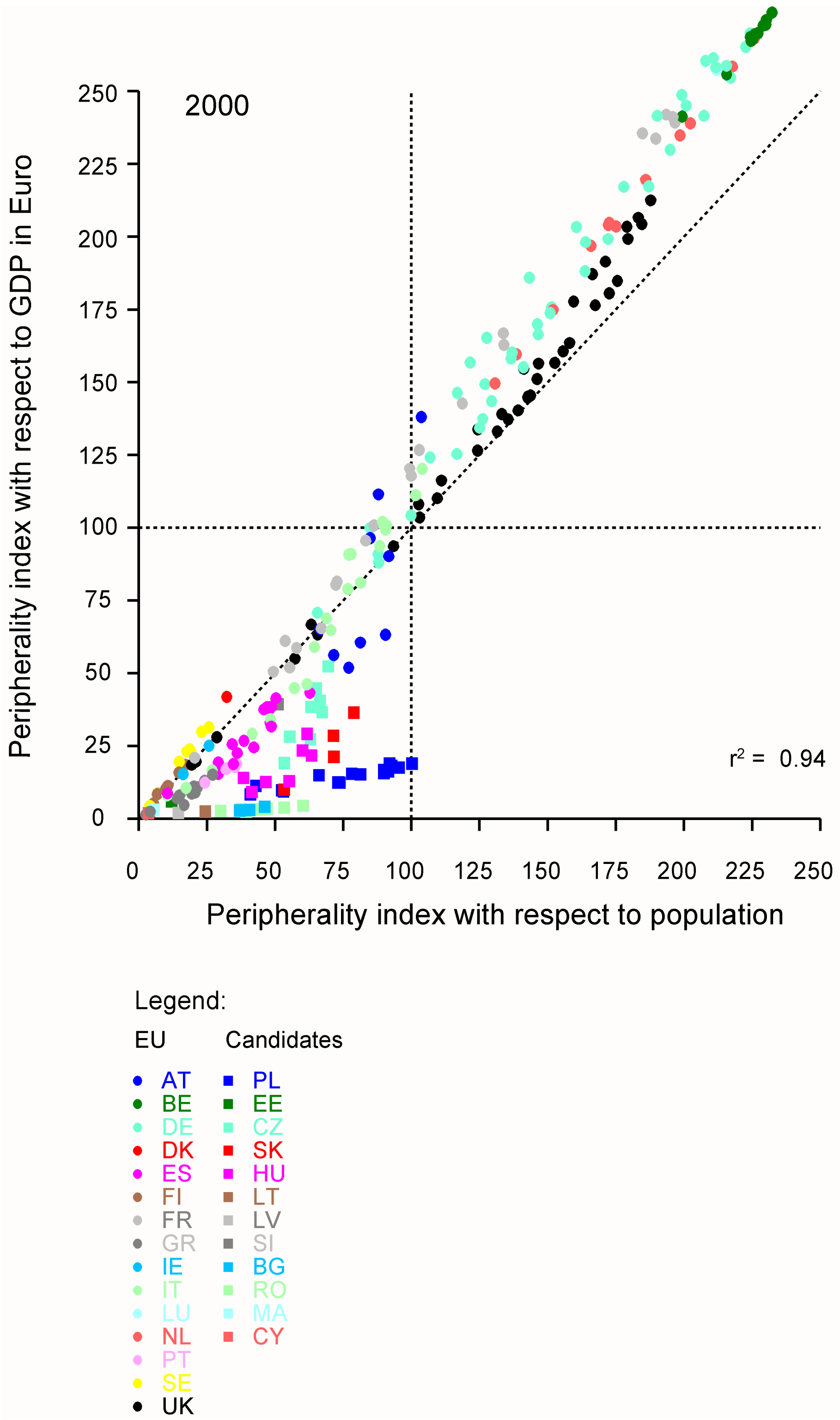

Figure 4-8. Peripherality index with respect to population by lorry v. with respect to GDP by lorry (NUTS 2).

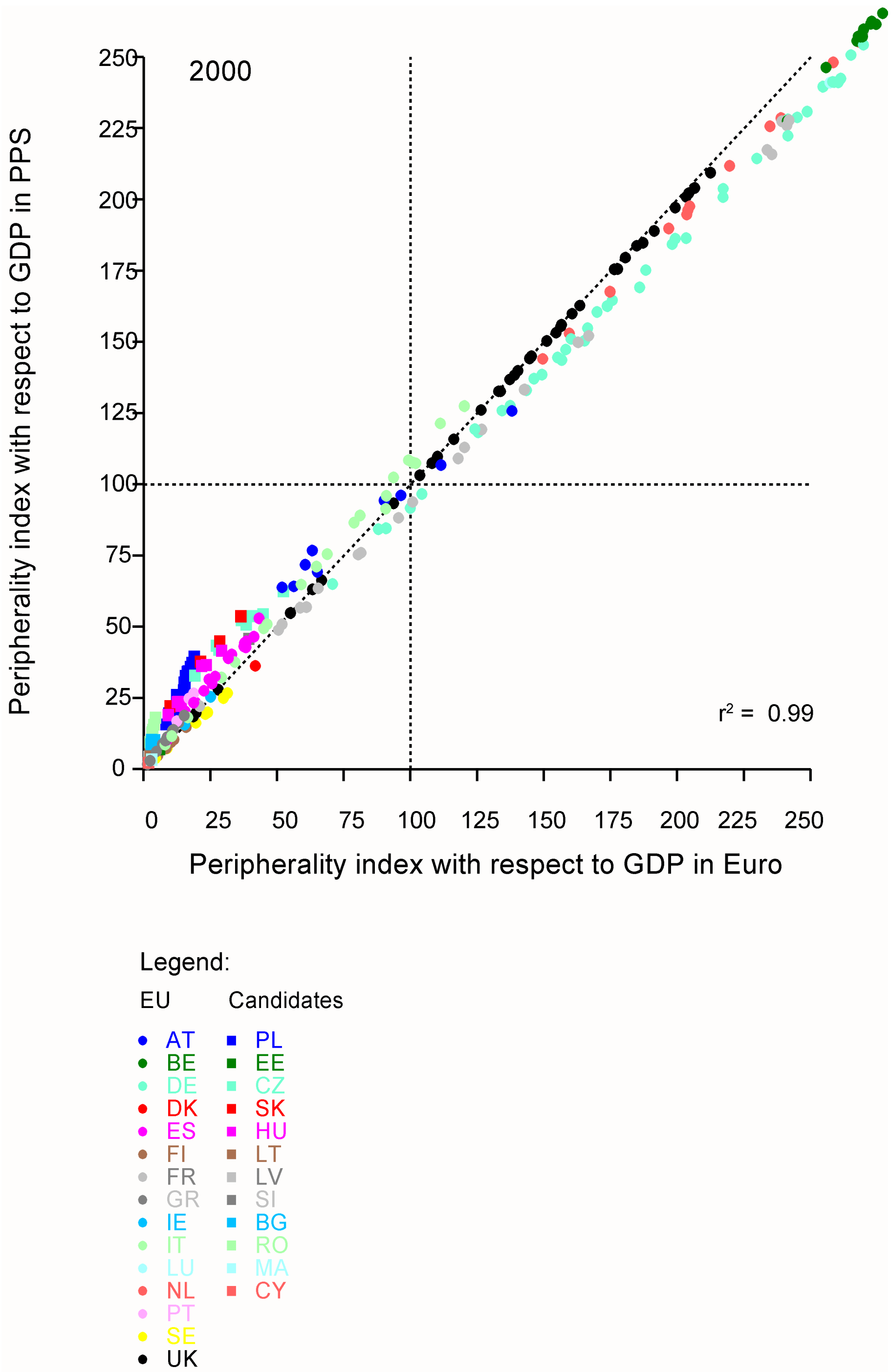

Figure 4-9. Peripherality index by lorry with respect to GDP in Euro v. with respect to GDP in PPS (NUTS 2).

Spatial scope

For both types of indicator the territory used for standardisation plays a prominent role for the level of peripherality. For example, when calculating averages it makes a difference whether only current EU member states or all candidate countries are considered. The underlying accessibilities were always calculated by considering all European countries. The changes will be illustrated for peripherality with respect to population by car (Figure 4-10).

If standardisation over all EU member states and all candidate countries is compared with standardisation over EU member states only, it is evident that the average calculated for the overall standardisation is lower than the average of the 15 EU member states. This results in greater differences in indicator values between the most central and the most peripheral regions. This particularly highlights the already central regions in western Germany, Belgium, the Netherlands and northern France. With other words, standardisation over the 15 EU member states leads to lower indicator values for the present EU regions (see also Figure 4-11), which results in a slightly less polarised distribution of peripherality index values, notwithstanding that there are still great disparities between the regions of some member states.

The principle illustrated in Figure 4-11 can been seen as a general rule. Based on the same accessibilities, the peripherality index mainly depends on the territory taken into account in the standardisation. If only EU member states are included, the indicators show lower values than for all EU and candidate countries, and the differences will be greater the more central a region is located. Moreover, calculations showed that these effects are stronger for lorries than for cars and are stronger for GDP than for population.

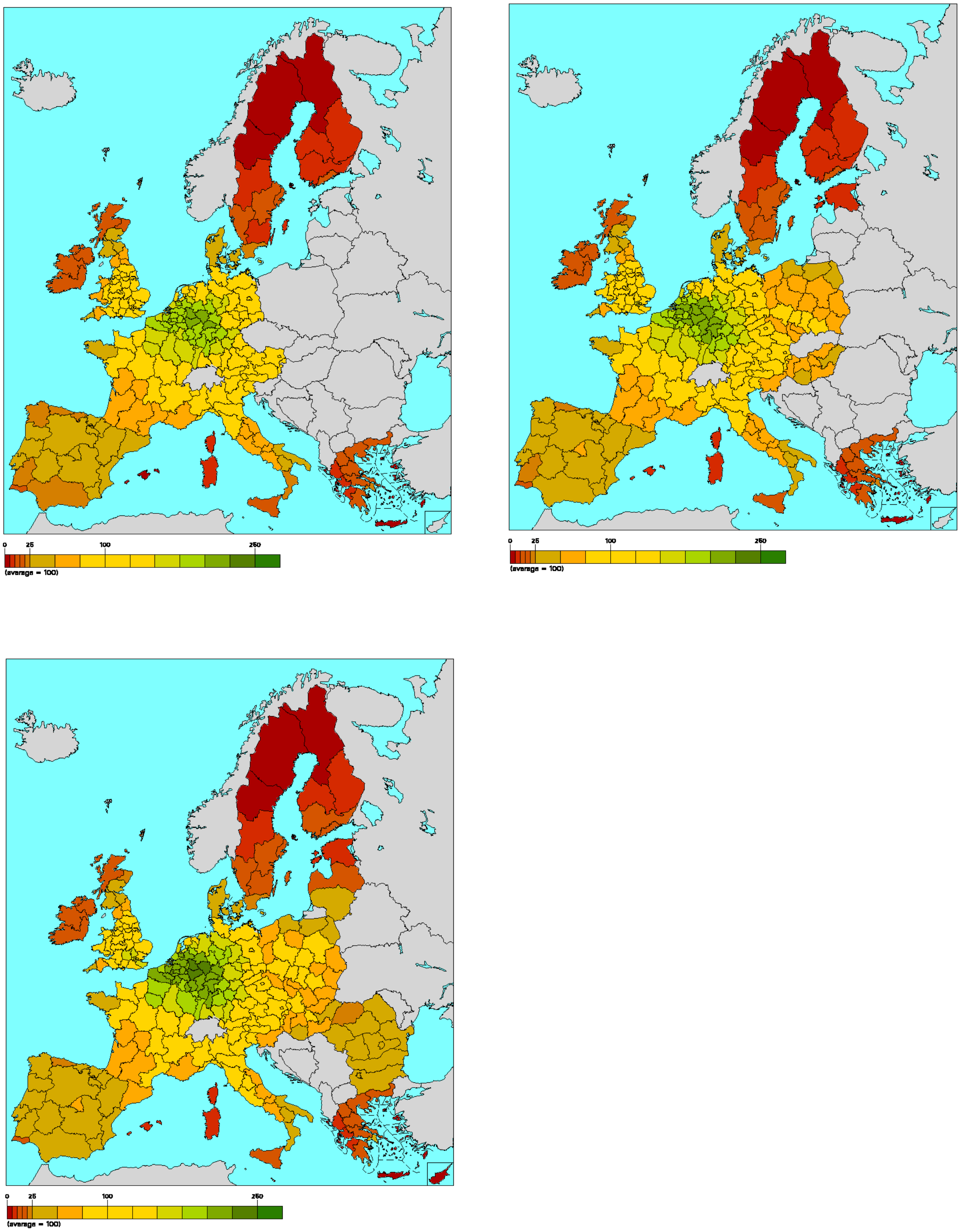

Figure 4-10. Peripherality with respect to population by car (NUTS 2) for EU member states only (top left), for EU and five candidate countries (top right) and for EU and all candidate countries (bottom left).

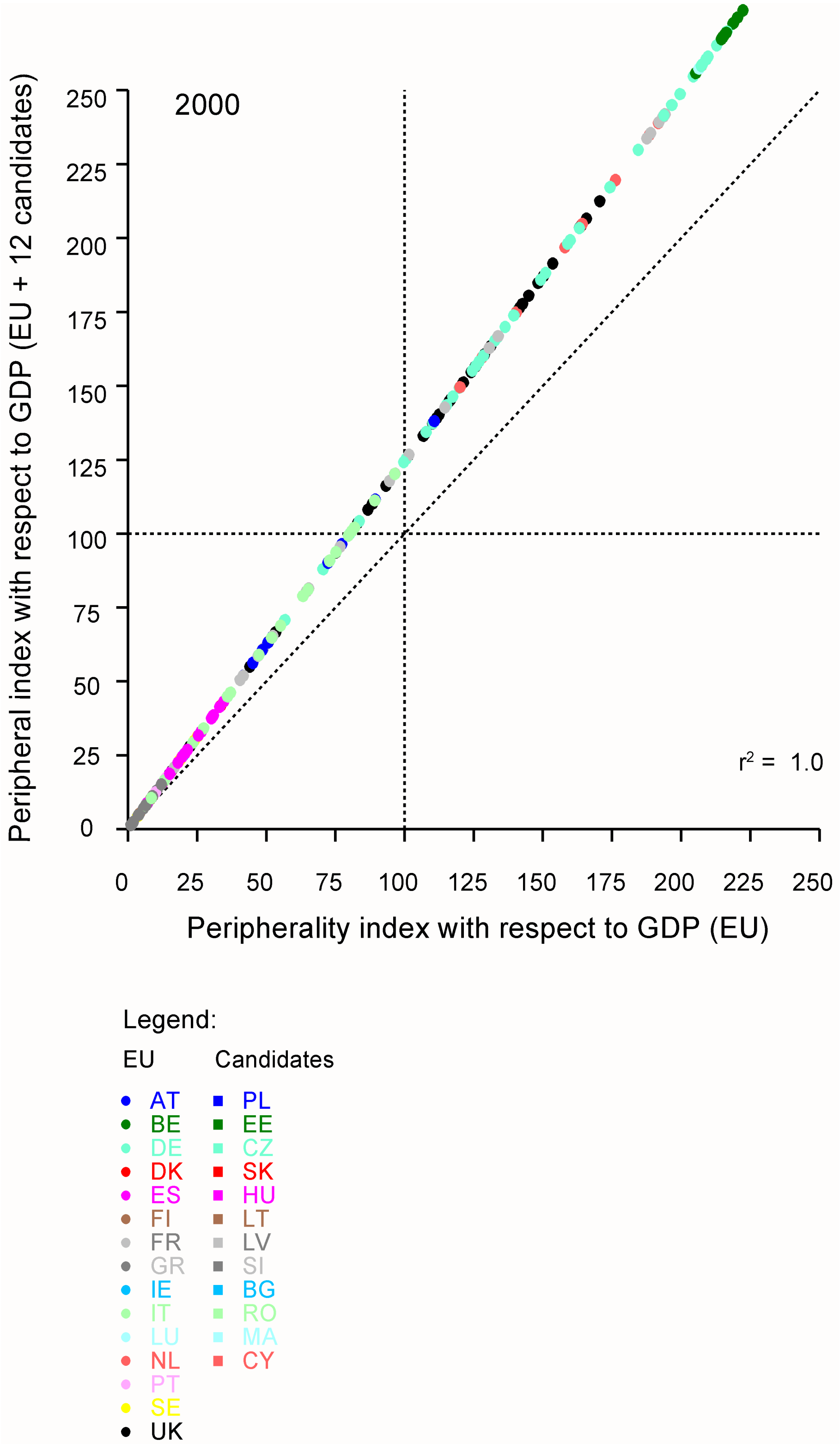

Figure 4-11. Peripherality with respect to GDP by lorry for EU member states v. EU plus 12 candidate countries.

Spatial resolution

The NUTS level considered also influences peripherality indices as Figure 4-12 shows.

If results at different NUTS levels are compared with, it can be stated that

(i) there is a loss in spatial differentiation between the NUTS-3 and NUTS-2 levels, in particular for those countries with relatively small NUTS-3 regions such as Germany, but also for many French or Italian regions which leads to the wrong assumption of a less polarised pattern of peripherality;

(ii) the most extreme maximum and minimum indicator values are balanced out and cut off, also suggesting a misleading picture of a more harmonised pattern of peripherality

However, if the NUTS-2 and NUTS-3 levels are compared, the spatial pattern at the NUTS-2 level hides the fact that not every NUTS-3 region in the geographical core of Europe belongs to the most central ones, but that there are regions in the core of Europe that are more peripheral compared to the surrounding agglomeration centres. For example, the positive effects of the TGV between Paris and Lyon can be observed at the NUTS-3 level, however, at the NUTS-2 level these effects disappear. Similar infrastructure effects observable at the NUTS-3 level such as the motorways along the Danish and Spanish east coasts are hidden at the NUTS-2 level.

At the NUTS-1 or even NUTS-0 levels, the loss of spatial differentiation is overwhelming so that these levels are unsuited as basis for peripherality calculations.

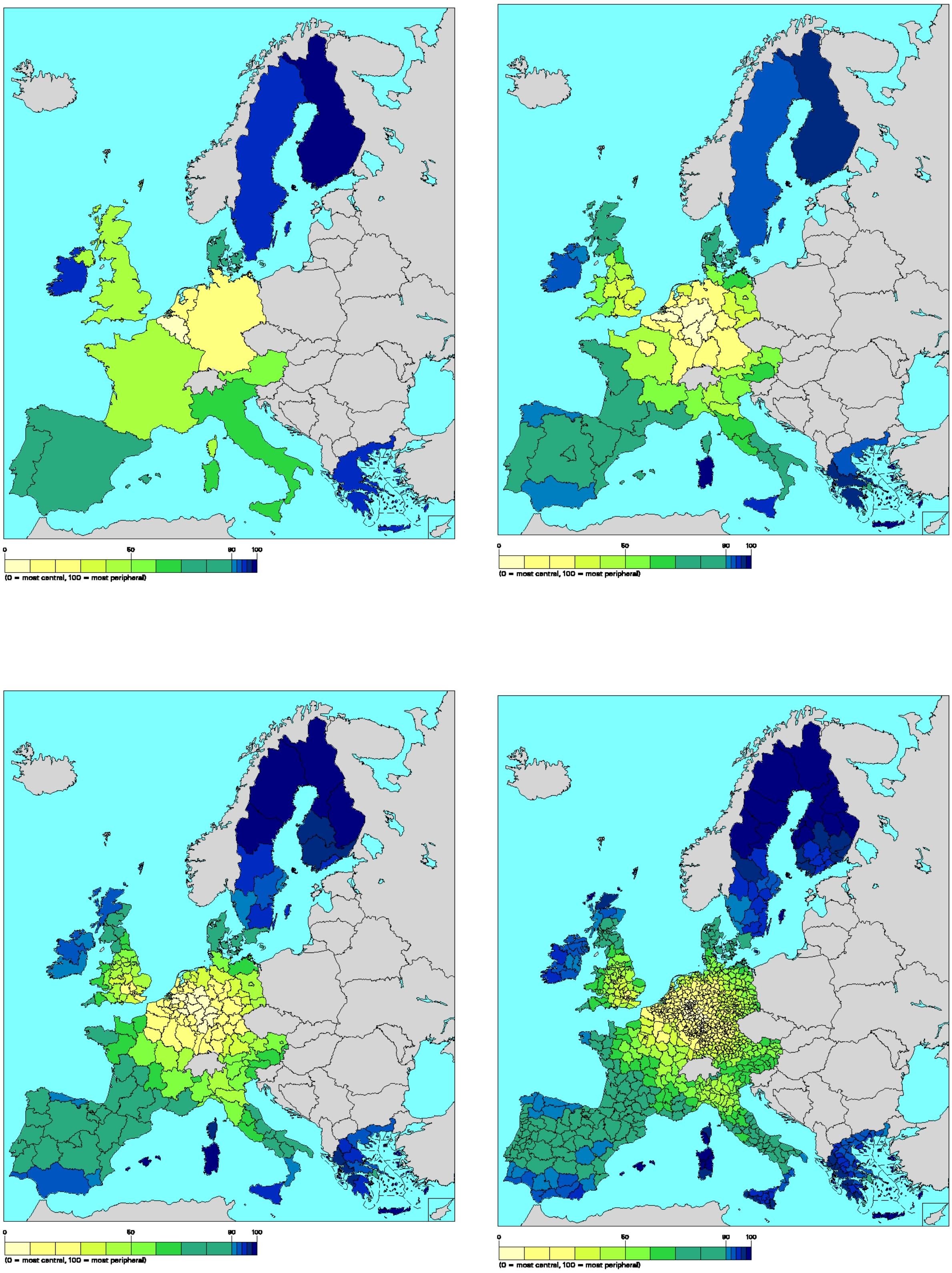

Figure 4-12. Peripherality with respect to employment by car for NUTS-0 (top left), NUTS-1 (top right), NUTS-2 (bottom left) and NUTS-3 regions (bottom right).

4.3 Dynamics

To demonstrate the policy relevance of peripherality indices, a future scenario has been defined and calculated with the model to evaluate whether the model is able to yield reasonable results for future situations.

The assumptions underlying this scenario are:

1. The target year for the scenario is 2016.
2. All candidate countries have become members of the European Union.
3. All road infrastructure projects and plans included in the TEN and TINA outline plans (European Communities, 1996; TINA Secretariat, 1999) are implemented.
4. As a consequence of the enlargement of the European Union, delays at borders to and between member states have been significantly reduced, and waiting times at borders to non-EU countries have also been reduced.
5. The socio-economic data as described in Section 3.2.3 have not been changed.

The scenario focuses on network changes and evaluates changes to peripherality indices through network infrastructure improvements, with population and GDP figures being kept constant.

Figure 4-13 and 4-14 illustrate some of the results for the 2016 scenario for passenger traffic and freight transport. The same standard peripherality indices are used as for the 2000 base scenario described in Section 4.1. The average used for standardisation is not the same as for the 2000 scenario but was newly calculated based on the 2016 accessibilities.

Peripherality with respect to population in 2016

The main differences between peripherality with respect to population by car in 2000 and 2016 are that regions in Poland and in the Czech Republic improve their relative position due to the huge infrastructure investments of the TINA programme. Additionally, these regions also benefit from the TEN projects implemented in eastern Germany. All these regions show accessibility values between 100 (Poland) and even 140 (Czech Republic). The other candidate countries do not improve their relative peripherality. However, also most of the peripheral regions in the EU member states do not reduce their peripherality, with the exception of the new German Länder, who improve their relative position.

Peripherality with respect to GDP in 2016

The same effects as for population can be observed for peripherality with respect to GDP in 2016. Regions in Poland, the Czech Republic, Slovakia and the new German Länder improve their relative position significantly. Also some regions in France, in Portugal and in southern Bulgaria show higher accessibility values in 2016 than in 2000 and improve their relative position.

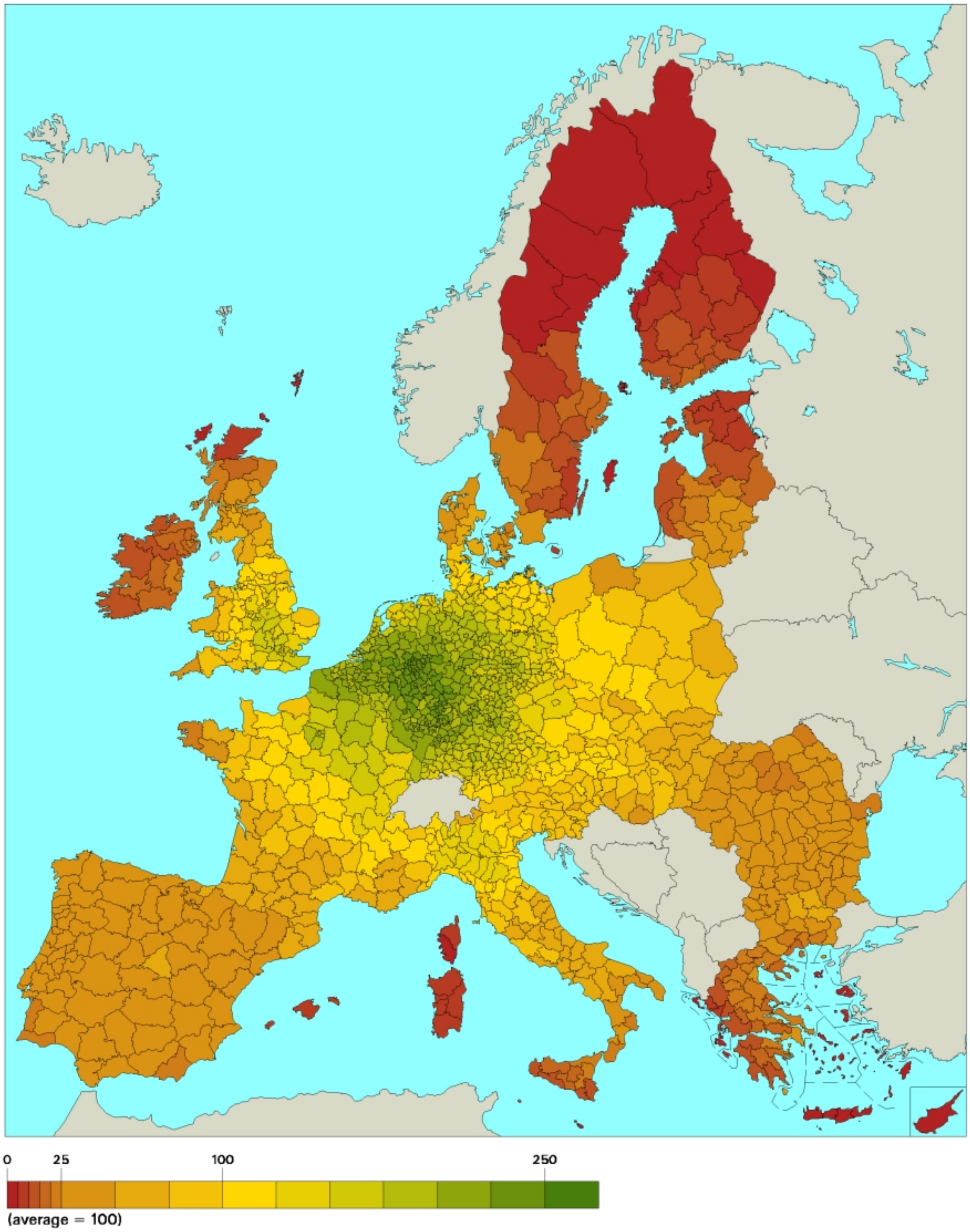

Figure 4-13. Peripherality with respect to population in 2016 (NUTS 3).

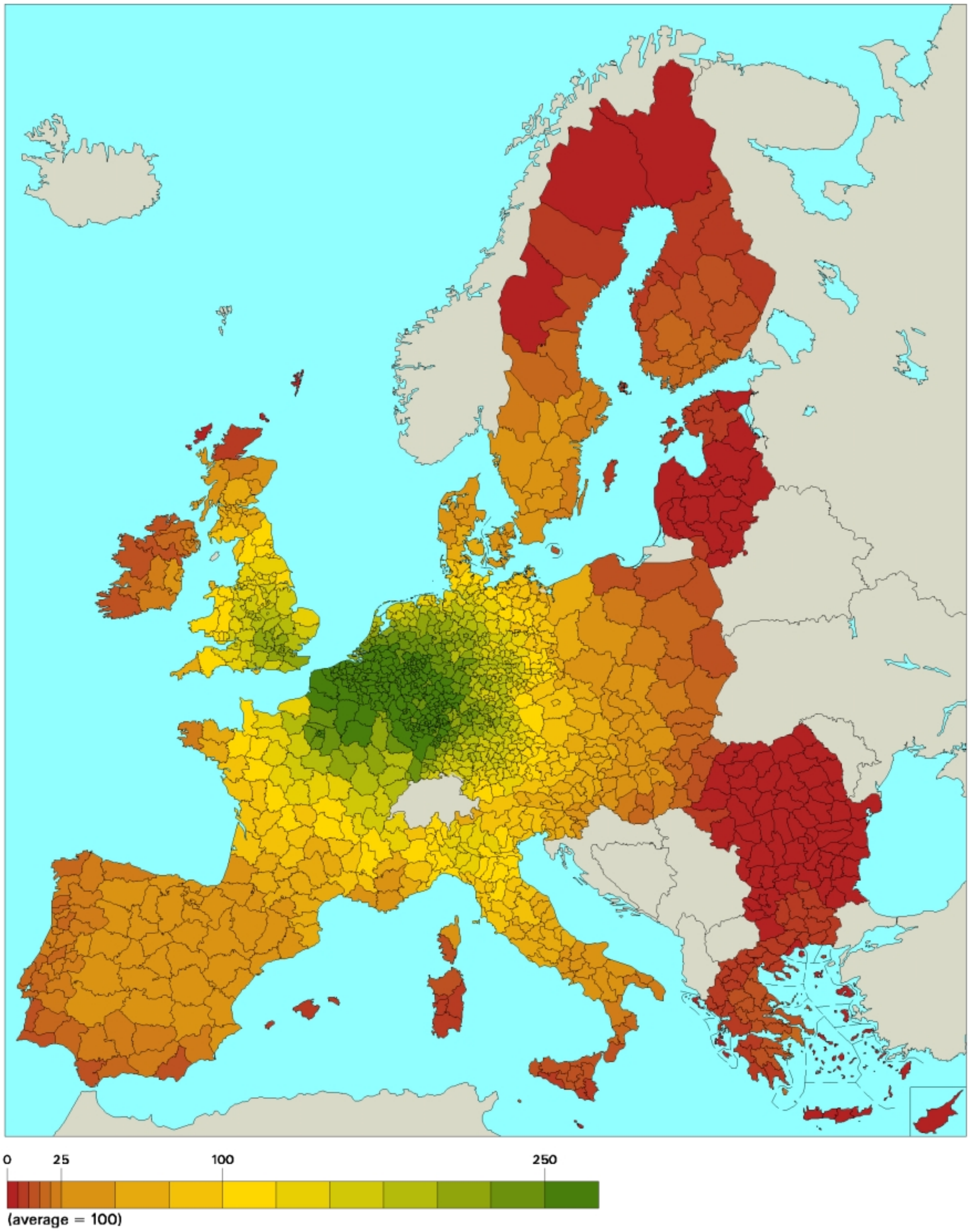

Figure 4-14. Peripherality with respect to GDP in 2016 (NUTS 3).

Comparing both indicators

If Figure 4-15 is compared with the same figure for 2000 (Figure 4-3), the correlation between peripherality with respect to population and with respect to GDP is lower which is due to the fact that regions in Poland and the Czech Republic improve their relative position and show above-average accessibility values with respect to population, whereas they do not improve their relative position with respect to GDP to the same extent. This is also shown in Figure 4-16, where peripherality with respect to population by car is compared. It is evident that Poland and the Czech Republic get the largest benefits from the infrastructure projects, whereas the other countries do not improve their relative position or even lose in relative terms (e.g. UK regions and regions in Benelux and Germany).

Since the overall range of peripherality in 2016 between the most central and the most peripheral regions for both modes does not change, it can be assumed that despite the ambitious investment programmes (TEN and TINA), the overall spatial patterns of peripherality are not reversed and that positive effects are limited to very few regions.

However, this first attempt at calculating peripherality indices for a future scenario is no substitute for a full discussion on how peripherality will change after the implementation of the TEN and TINA programmes.

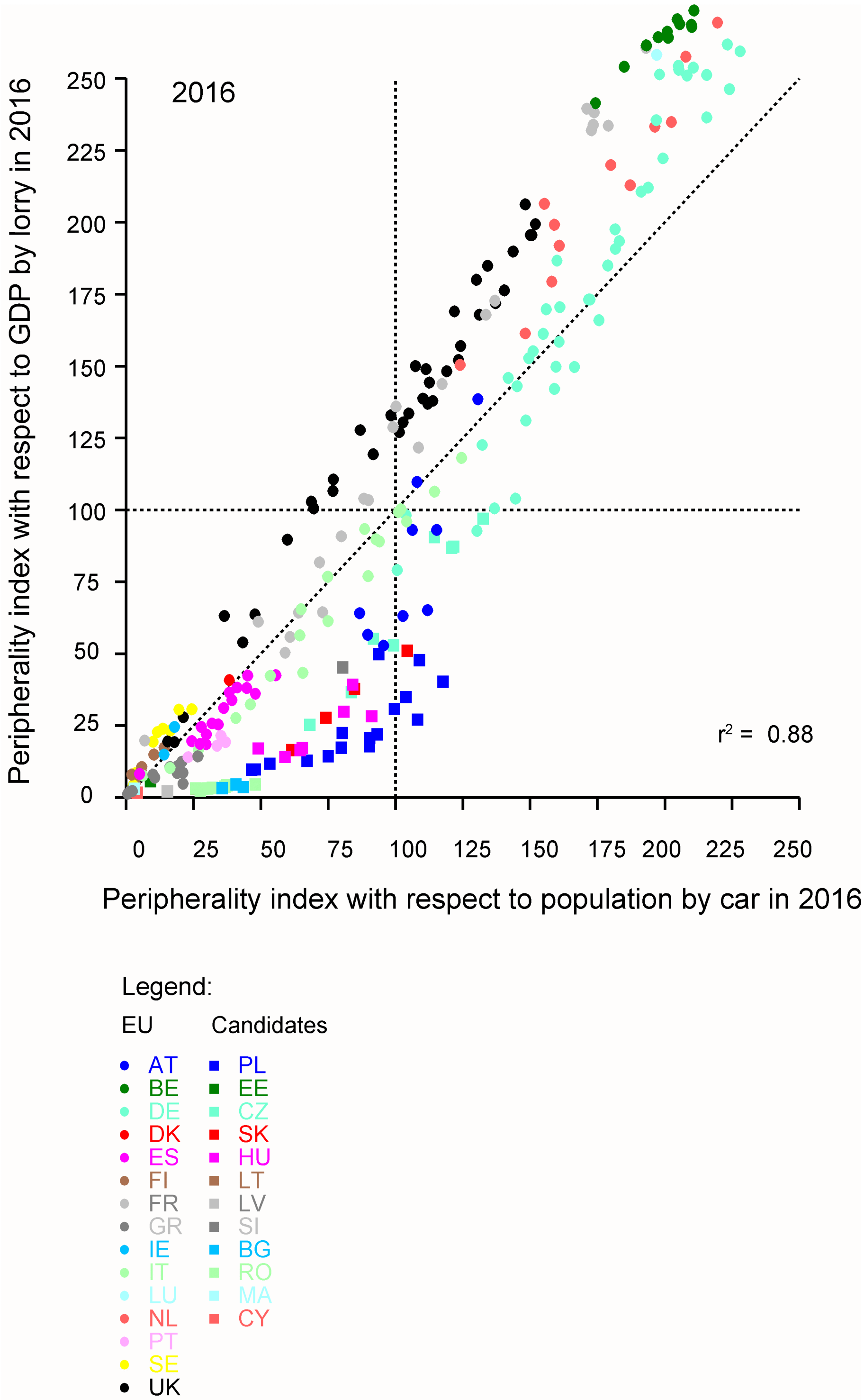

Figure 4-15. Peripherality with respect to population v. with respect to GDP in 2016 (NUTS 2).

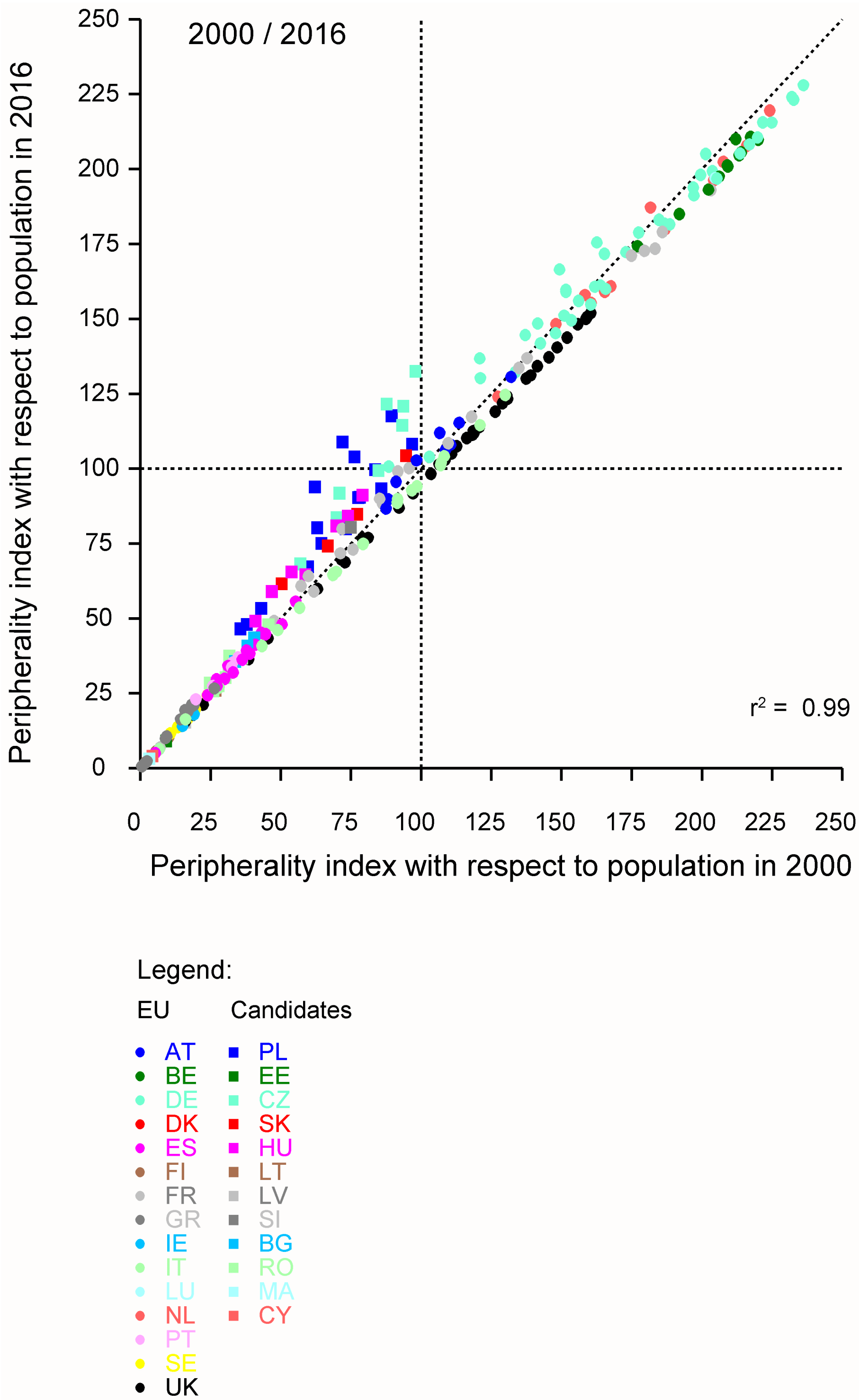

Figure 4-16. Peripherality with respect to population, 2000 v. 2016 (NUTS 2).

5 Conclusions

Evaluation of peripherality indices

The accessibility indicators and peripherality indices presented confirm previous accessibility calculations undertaken for the SASI and ESPON projects (Fürst et al., 2000a; 2000b; Wegener et al., 2000). In summary, for all kind of indicators, regions in western Germany, northern France, Belgium, the Netherlands, southern England and northern Italy show the highest accessibilities and can be considered the most central regions.

When NUTS-3 regions are considered, great differences in peripherality can be found between peripheral regions, for example in Scandinavia, in Greece and on the Iberian Peninsula. This indicates that the model is able to capture relatively small, but nevertheless important differences. When higher NUTS levels are considered, these details partly disappear.

It was shown that the system can also be applied to future scenarios yielding reasonable results.

Comparisons between different peripherality indices show that the choice of indicator has great influence on the results. The following conclusions can be drawn:

- The overall spatial patterns of all peripherality indices are very similar, so correlations between different indicators are rather high. This reflects the fact that, irrespective of the kind of peripherality index used, the distant geographical position of peripheral regions cannot be fully removed by transport infrastructure improvements.

- Peripherality with respect to population by car is less polarised than peripherality with respect to GDP by lorry.

- Peripherality with respect to lorry favours regions around the Channel coast, since for lorries the ‘barrier effect’ of the Channel Tunnel is much less than for cars.

- Candidate countries benefit more if peripherality with respect to population by car is used; conversely, central regions benefit more if peripherality with respect to GDP by lorry is used.

- The type of indicator has relatively little influence on the results. Standardisation between the minimum and maximum shows slightly more differentiation among peripheral regions, whereas standardisation on the European average shows slightly more polarisation between the central regions.

- GDP in PPS has slight balancing effects compared to GDP in Euro, but nevertheless peripherality with respect to both is more polarised than peripherality with respect to population or employment.

- The greater the territory used for standardisation is, i.e. the more candidate countries are taken into account, the lower will be the European average, and the more will regions in EU member states improve their relative position.

- The higher the NUTS level, the greater will be the loss in spatial differentiation. Studies based on the NUTS-3 level yield a great number of detail and differentiation between and within peripheral and central regions. This is particularly true for the relatively small German, French and Italian regions.

Theoretical considerations

Accessibility is the main product of a transport system. It determines the locational advantage of a region relative to all regions and so is a major factor for the social and economic development of a region. Since peripherality can be seen as an inverse function of accessibility, it indicates not only central or peripheral regions in a geographic sense, but gives also information on the quality of its links with the European core.

Peripherality can be evaluated by a number of different peripherality indices with respect to NUTS levels, modes, mass terms, types of indicator and spatial scope of standardisation. The software system developed offers the full range of combinations of these parameters, totalling 192 indicators. The general spatial patterns of peripherality are very similar across all these indicators, reflecting the fact that distant geographical location cannot be fully compensated by transport infrastructure. Each indicator emphasises certain aspects of peripherality. So, the choice of the type of peripherality index to be used becomes a matter of concern. Depending on the purpose of the study, a certain indicator type may be more appropriate than another type.

For calculating distance measures, i.e. average road travel times of passengers and goods, the model takes account of road types, speed limits for cars and lorries, congestion in urban regions and delays due to mountainous areas, national borders and maximum driving hours of lorry drivers. In this the system goes far beyond the way usually travel times are measured in accessibility studies. Moreover, peripherality indices are calculated for NUTS-0, NUTS-1, NUTS-2 and NUTS-3 regions based on a unified and disaggregate approach.

Beside these theoretical and conceptual considerations, the software implemented has the following strengths and weaknesses (see the User Manual for more detail):

Strengths

- The modular structure is flexible, expandable and offers a number of capabilities.
- The core macro calculates all peripherality indices in one model run.
- Output options are available to fit user needs with respect to contents, processing time and disc space availability.
- The number of user interactions is minimised.
- Additional tools support a wide range of specific tasks.
- The system is running under UNIX or Windows NT / Windows 2000.
- All input coverages and input files can be manually edited, adjusted or exchanged.

- There is a combination of windows-based menu operations designed for user-friendliness and command line executions designed for efficiency.
- Capabilities for designing scenarios are provided.

Weaknesses

Compared to these strengths, the software has only little weaknesses. One is the relatively long processing time of the core macro which is due to the fact that it calculates all 192 indicators in one run. Also the relatively large amount of disc space required for temporary coverages and for storing results might limit the applicability of the model. In the current version, the model considers only road traffic and neglects rail, air and inland waterways and so is not able to calculate intermodal accessibilities. Moreover, only accessibility of the potential type can be calculated, whereas daily accessibility or average travel costs are not taken into account.

Possible extensions

From a theoretical point of view, it would be of great interest to incorporate also the other modes, namely rail, air and inland waterways, into the system to enable calculations of intermodal accessibilities and peripherality indices. Also of interest would be the possibility to calculate daily accessibility or average travel costs. A more practical extension would be to incorporate a ‘scenario manager’ into the system which would allow generation, management and application of different scenarios.

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