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SASI Model Description

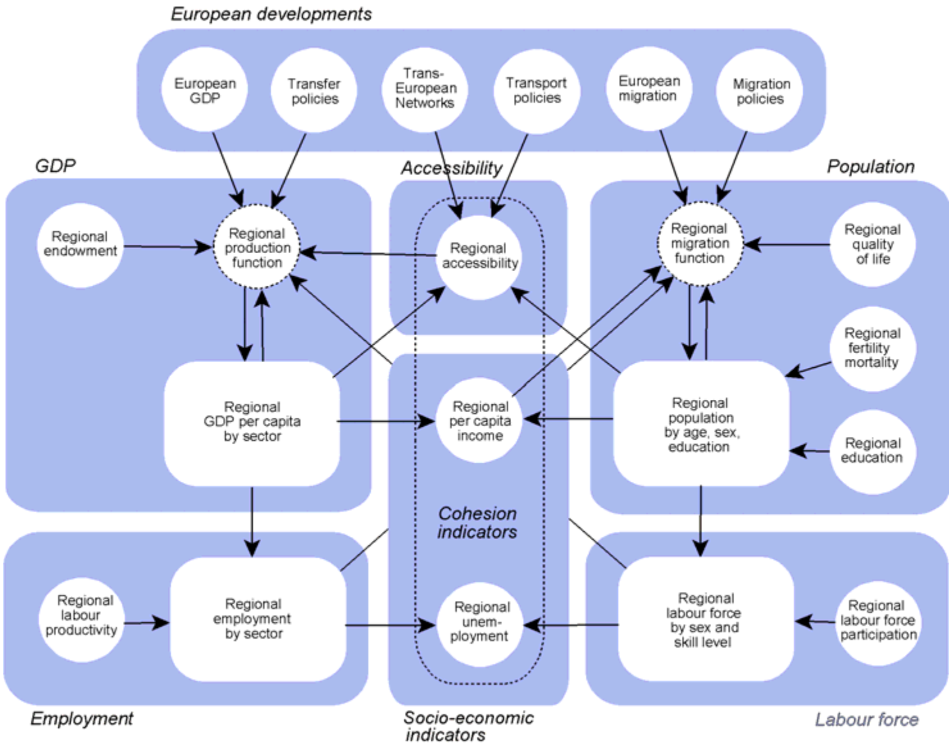

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Table of Contents

1. Introduction

The regional economic model SASI was developed at the Institute of Spatial Planning of the University of Dortmund since 1996 in co-operation with the Technical University of Vienna in the EU project SASI (Spatial and Socio-economic Impacts of Transport Investments and Transport System Improvements). A description of the first version of the model is Wegener and Bökemann (1998). The model has since been applied in several projects for the EU and national and regional authorities, such as

- IASON: Spatial Economic Effects of Transport Investments and Policies (2001-2003)
- ESPON 1.1.1: Polycentric Development (2002-2005)
- ESPON 2.1.1: Territorial Impacts of EU Transport and TEN Policies (2002-2005)
- ESPON 1.1.3: EU Enlargement (2003-2006)
- AlpenCorS: Modelling Regional Development in Alpen Corridor South (2004-2005)
- Impacts of Internalisation of External Costs of Transport in Saxony (2004-2005)
- STEPS: Scenarios for the Transport System and Energy Supply (2004-2006)
- SETI: Strategic Evaluation on Transport Investment Priorities 2007-2013 (2005-2006)
- Ex-ante Evaluation of the TEN-T Multi-Annual Programme 2007-2013 (2007)

The SASI model has been continuously further developed in the course of the projects. Most recent developments include the modelling of generative effects of transport infrastructure investments and the inclusion of the West Balkan countries into the study area.

This working paper describes the present version of the SASI model.

2. Theoretical Approach

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 (Jochimsen, 1966). However, the relationship between transport infrastructure and economic development seems to be more complex than this simple model. 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, such as some regions in the new EU member states.

So it is not surprising that it has been difficult to empirically verify the impact of transport infrastructure on regional development. 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 still 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).

There exists a broad spectrum of theoretical approaches to explain the impacts of transport infrastructure investments on regional socio-economic development. Originating from different scientific disciplines and intellectual traditions, these approaches presently coexist, even though they are partially in contradiction (cf. Linnecker, 1997):

- National growth approaches model multiplier effects of public investment in which public investment has either positive or negative (crowding-out) influence on private investment, here the effects of transport infrastructure investment on private investment and productivity. In general only national economies are studied and regional effects are ignored. Pioneered by Aschauer (1989; 1993) such studies use time-series analyses and growth model structures to link public infrastructure expenditures to movements in private sector productivity. An increase in public investment raises the marginal product of private capital and provides an incentive for a higher rate of private capital accumulation and labour productivity growth. Critics of these approaches argue that there may be better infrastructure strategies than new construction and that policy measures aimed at increasing private investment directly rather than via public investment will have greater impact on national competitiveness.

- Regional growth approaches rest on the neo-classical growth model which states that regional growth in GDP per capita is a function of regional endowment factors including public capital such as transport infrastructure, and that, based on the assumption of diminishing returns to capital, regions with similar factors should experience converging per-capita incomes over time. The suggestion is that, as long as transport infrastructure is unevenly distributed among regions, transport infrastructure investments in regions with poor infrastructure endowment will accelerate the convergence process, whereas once the level of infrastructure provision becomes uniform across regions, they cease to be important. Critics of regional growth models built on the central assumption of diminishing returns to capital argue that they cannot distinguish between this and other possible mechanisms generating convergence such as migration of labour from poor to rich regions or technological flows from rich to poor regions.

- Production function approaches model economic activity in a region as a function of production factors. The classical production factors are capital, labour and land. In modern production function approaches, among other location factors, infrastructure is added as a public input used by firms within the region (Jochimsen, 1966; Buhr, 1975). The assumption behind this expanded production function is that regions with higher levels of infrastructure provision will have higher output levels and that in regions with cheap and abundant transport infrastructure more transport-intensive goods will be produced. The main problem of regional production functions is that their econometric estimation tends to confound rather than clarify the complex causal relationships and substitution effects between production factors. This holds equally for production function approaches including measures of regional transport infrastructure endowment. In addition the latter suffer from the fact that they disregard the network quality of transport infrastructure, i.e. treat a kilometre of motorway or railway the same everywhere, irrespective of where they lead to.

- Accessibility approaches attempt to respond to the latter criticism by substituting more complex accessibility indicators for the simple infrastructure endowment in the regional production function. Accessibility indicators can be any of the indicators discussed in Schürmann et al. (1997), but in most cases are some form of population or economic potential. In that respect they are the operationalisation of the concept of 'economic potential' which is based on the assumption that regions with better access to markets have a higher probability of being economically successful. Pioneering examples of empirical potential studies for Europe are Keeble et al. (1982; 1988). Today approaches relying only on accessibility or potential measures have been replaced by the hybrid approaches were accessibility is but one of several explanatory factors of regional economic growth, including 'soft' location factors. Also the accessibility indicators used have become much more diversified by type, industry and mode (see Schürmann et al., 1997). The SASI model is a model of this type incorporating accessibility as one explanatory variable among other explanatory factors

- Regional input-output approaches model interregional and inter-industry linkages using the Leontief (1966) multiregional input-output framework. These models estimate inter-industry/interregional trade flows as a function of transport cost and a fixed matrix of technical inter-industry input-output coefficients. Final demand in each region is exogenous. Regional supply, however, is elastic, so the models can be used to forecast regional economic development. One example of an operational multiregional input-output models is the MEPLAN regional economic model (Echenique, 2004)

- Trade integration approaches model interregional trade flows as a function of interregional transport and regional product prices. Peschel (1981) and Bröcker and Peschel (1988) estimated a trade model for several European countries as a doubly-constrained spatial interaction model with fixed supply and demand in each region to assess the impact of reduced tariff barriers and border delays between European countries through European integration. Their model could have been used to forecast the impacts of transport infrastructure improvements on interregional trade flows. If the origin constraint of fixed regional supply were relaxed, the model could have been used also for predicting regional economic development. Krugman (1991), Krugman and Venables (1995) and Fujita at al. (1999) extended this simple model of trade flows by the introduction of economies of scale and labour mobility. Examples of this type of model are the so-called computable general equilibrium (CGE) models (Bröcker, 2004). The CGEurope model (Bröcker et al., 2005) is a model of this type.

3. Model Structure

The SASI model is a recursive simulation model of socio-economic development of regions in Europe subject to exogenous assumptions about the economic and demographic development of the European Union as a whole and transport infrastructure investments and transport system improvements, in particular of the trans-European transport networks (TEN-T).

The SASI model differs from other approaches to model the impacts of transport on regional development by modelling not only production (the demand side of regional labour markets) but also population (the supply side of regional labour markets). A second distinct feature is its dynamic network database maintained by RRG Spatial Planning and Geoinformation based on a 'strategic' subset of highly detailed pan-European road, rail and air networks including major historical network changes as far back as 1981 and forecasting expected network changes according to the most recent EU documents on the future evolution of the trans-European transport networks.

The spatial dimension of the model is established by the subdivision of the European Union, Norway and Switzerland and the Western Balkan countries in 1,330 regions and by connecting these by road, rail and air networks. For each region the model forecasts the development of accessibility and GDP per capita. In addition cohesion indicators expressing the impact of transport infrastructure investments and transport system improvements on the convergence (or divergence) of socio-economic development in the regions of the European Union are calculated.

Figure 1 visualises the structure of the SASI model.

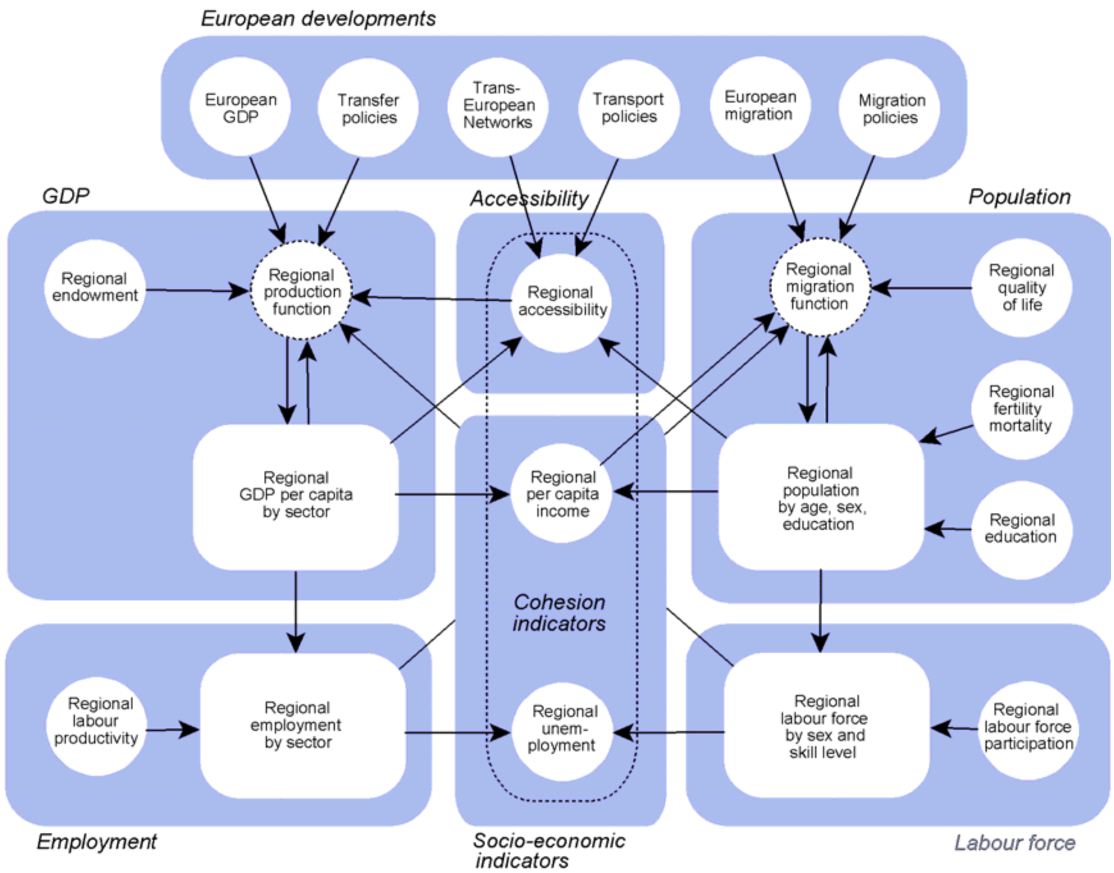

Figure 1. The structure of the SASI model

The temporal dimension of the model is established by dividing time into periods of one year duration. By modelling relatively short time periods both short- and long-term lagged impacts can be taken into account. In each simulation year the seven submodels of the SASI model are processed in a recursive way, i.e. sequentially one after another. This implies that within one simulation period no equilibrium between model variables is established; in other words, all endogenous effects in the model are lagged by one or more years.

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

Figure 2 shows the sequence of the seven submodels:

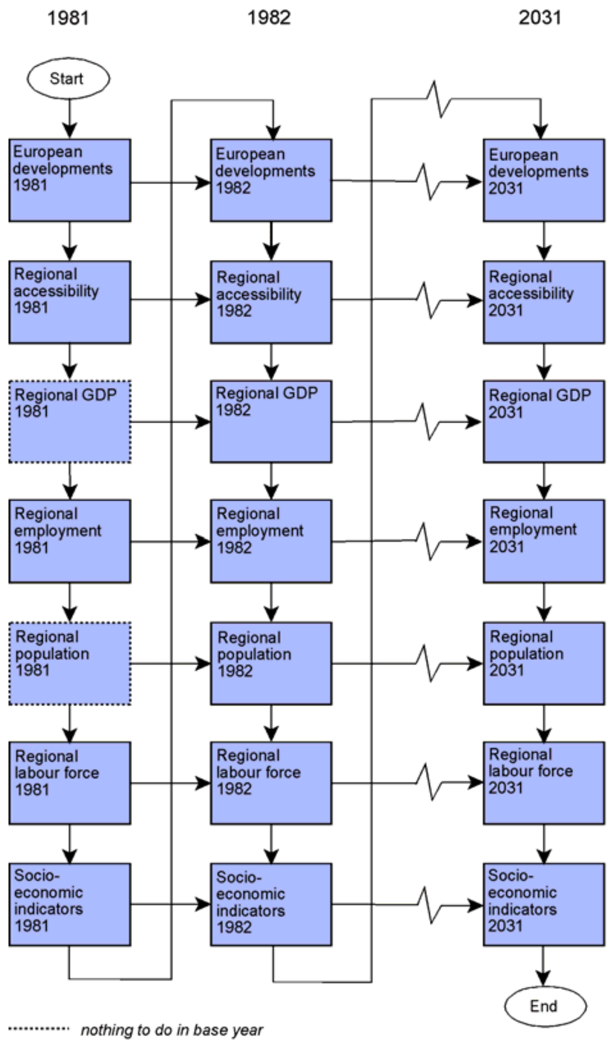

Figure 2. The sequence of submodels

The seven submodels of the SASI model European Developments, Regional Accessibility, Regional GDP, Regional Employment, Regional Population, Regional Labour Force and Socio-Economic Indicators are described below.

3.1 European Developments

The European Developments submodel is not a 'submodel' in the narrow sense because it simply prepares exogenous assumptions about the wider economic and policy framework of the simulations and makes sure that external developments and trends are considered.

For each simulation period the simulation model requires the following assumptions about European developments:

(1) Assumptions about the performance of the European economy as a whole. The performance of the European economy is represented by observed values of sectoral GDP for the study area as a whole for past years and forecasts for the future years until 2031. All GDP values are entered in Euro of 2006.

(2) Assumptions about net migration across Europe's borders. European migration trends are represented by observed annual net migration of the study area as a whole for past years and forecasts for future years until 2031.

These two groups of assumptions serve as constraints to ensure that the regional forecasts of economic development and population remain consistent with external developments not modelled in the Reference Scenario. To keep the total economic development exogenous in all scenarios would mean that the model would be prevented from making forecasts about the general increase in production through transport infrastructure investments (generative effects). However, its parameters are estimated in a way that makes it capable of doing that. Therefore the constraints are only applied to the Reference Scenario; by applying the adjustment factors of the Reference Scenario also to the policy scenarios, the changes in generative effects induced by the policies are forecast.

(3) Assumptions about transfer payments by the European Union via the Structural Funds and the Common Agricultural Policy or by national governments to support specific regions. European and national transfer payments are taken into account by annual transfers (in Euro of 2006) received by the regions in the European Union during the past and forecasts for future years until 2031.

(4) Assumptions about European integration. The accessibility measures used in the SASI model take account of existing barriers between countries, such as border waiting times and political, cultural and language barriers. These barriers are estimated for past years since 1981 and forecast for future years until 2031 taking into account the expected effects of further European integration.

(5) Assumptions about the development of trans-European transport networks (TEN-T). The European road, rail and air networks are backcast for the period between 1981 and 2006 in five-year increments and forecast in five-year increments until 2031. A policy scenario is a time-sequenced programme for addition or upgrading of links of the trans-European road, rail and air networks or other transport policies, such as different regimes of social marginal cost pricing.

The data for these assumptions do not need to be provided for each year nor for time intervals of equal length as the model performs the required interpolations for the years in between.

3.2 Regional Accessibility

The Regional Accessibility submodel calculates regional accessibility indicators expressing the locational advantage of each region with respect to relevant destinations in the region and in other regions as a function of the generalised travel cost needed to reach these destinations by the strategic road, rail and air networks. The model is similar to the accessibility model used in ESPON (Spiekermann and Schürmann, 2007) but uses generalised cost instead of travel time.

For the selection of accessibility indicators to be used in the model three, possibly conflicting, objectives were considered to be relevant: First, the accessibility indicators should contribute as much as possible to explaining regional economic development. Second, the accessibility indicators should be meaningful by itself as indicators of regional quality of life. Third, the accessibility indicators should be consistent with theories and empirical knowledge about human spatial perception and behaviour.

In the light of these objectives potential accessibility, i.e. the total of destination activities, here population, $W_s(t)$, in 1,330 internal and 41 external destination regions s in year t weighted by a negative exponential function of generalised transport cost $c_{rsm}(t)$ between origin region r and destination region s by mode m in year t was adopted:

$$A_{rm}(t) = \sum_s W_s(t) \exp[-\beta c_{rsm}(t)] \tag{1}$$

where A_{rm}(t) is the accessibility of region r by mode m in year t.

Modal generalised transport cost $c_{rsm}(t)$ consist of vehicle operating costs or ticket costs based on cost functions of the SCENES project (Marcial Echenique and Partners, 2000) and costs reflecting value of time. For the latter rail and air timetable travel times and road travel times calculated from road-type specific travel speeds are used and converted to cost by assumptions about the value of time of travellers and drivers. Only one common value of time is assumed for the whole study area, i.e. no distinction is made between the different wage levels and purchasing powers of countries. The border waiting times mentioned above are converted to monetary cost equivalents. In addition, political, cultural and language barriers are taken into account of as cost penalties added to the transport costs:

$$c_{rsm} = c'_{rsm}(t) + e_{r's'}(t) + s_{r's'} + \ell_{r's'} \quad \text{with } r \in \mathbf{R}_{r'} \tag{2}$$

in which $c'_{rsm}(t)$ is the travel cost between region r and region s in year t including the cost of travel time, and $e_{r's'}(t)$, $s_{r's'}$ and $\ell_{r's'}$ are exogenous time penalties for political, cultural and language diversity in year t between the countries $\boldsymbol{R}_{r'}$ to which regions r and s belong:

- $e_{r's'}(t)$ is a European integration factor reflecting in which supranational structures the two countries are, i.e. which political and economic relationship existed between them in year t,
- $s_{r's'}$ is a cultural similarity factor reflecting how similar are cultural and historical experience of the two countries.
- $\ell_{r's'}$ is a language factor describing the grade of similarity of the mother language(s) spoken in the two countries

While the latter two factors are kept constant over the whole simulation, $e_{r's'}(t)$ is reduced over time to account for the effect of European integration. The accessibility indicators used in the model are not standardised to the European average to show increases in accessibility over time.

Modal accessibility indicators are aggregated to one multimodal accessibility indicator expressing the combined effect of alternative modes by replacing the impedance term $c_{rsm}(t)$ by the composite or logsum impedance:

$$c_{rs}(t) = -\frac{1}{\lambda} \ln \sum_{m \in \mathbf{M}_{rs}} \exp[-\lambda\, c_{rsm}(t)] \tag{3}$$

where $\boldsymbol{M}_{rs}$ is the set of modes available between regions r and s. Four composite accessibility indicators are used: accessibility by rail and road for travel, accessibility by rail, road and air for travel, accessibility by road for freight and accessibility by rail and road for freight.

3.3 Regional GDP

The Regional GDP submodel is based on a quasi-production function incorporating accessibility as additional production factor. The economic output of a region is forecast separately for the six economic sectors agriculture, manufacturing, construction, trade/transport/tourism, financial services and other services in order to take different requirements for production by each sector into account. The regional production function predicts annual regional GDP per capita:

$$q_{ir}(t) = \mathrm{f}\,[\mathbf{C}_{ir}(t), \mathbf{L}_{ir}(t), \mathbf{A}_{ir}(t), \mathbf{X}_{ir}(t), \mathbf{S}_{r}(t), R_{ir}(t)] \tag{4}$$

where $q_{ir}(t)$ is annual GDP per capita of industrial sector i in region r in year t, $C_{ir}(t)$ is a vector of capital factors relevant for industrial sector i in region r in year t, $L_{ir}(t)$ is a vector of indicators of labour availability relevant for industrial sector i in region r in year t, A_{ir} is a vector of accessibility indicators relevant for industrial sector i in region r in year t, $X_{ir}(t)$ is a vector of endowment factors relevant for industrial sector i in region r in year t¸ $S_r(t)$ are annual transfers received by the region r in year t and $R_{ir}(t)$ is a region-specific residual taking account of factors not modelled (see below). Note that, even though annual GDP is in fact a flow variable relating to a particular year, it is modelled like a stock variable.

Assuming that the different production factors can be substituted by each other only to a certain degree, a multiplicative function which reflects a limitational relation between the factors was chosen. Since this kind of function introduces the coefficients as exponents of the explaining variables it is possible to interpret the coefficients as elasticities of production reflecting the importance of the different production factors for economic growth in a sector. The operational specification of the regional production functions used in the SASI model is:

$$q_{ir}(t) = C_{ir}(t-5)^{\alpha}\, L_{ir}(t-1)^{\beta}\, A_{ir}(t-1)^{\gamma} \ldots X_{ir}(t-1)^{\delta} \ldots S_{r}(t-1)^{\varepsilon}\, \exp(\rho)\, R_{ir}(t) \tag{5}$$

where $q_{ir}(t)$ is GDP per capita of sector i in region r in year t, $C_{ir}(t–5)$ is the economic structure (share of regional GDP of sector i) in region r in year t–5, $L_{ir}(t–1)$ is a labour market potential indicating the availability of qualified labour in region r and adjacent regions, $A_{ir}(t\text{-}1)$ is accessibility of region r relevant for sector i in year t–1, $X_{ir}(t–1)$ is an endowment factor relevant for sector i in region r in year t–1, $S_r(t–1)$ are transfer payments received by region r in year t–1, $R_{ir}(t)$ is the regression residual of the estimated GDP values of sector i in region r in year t and α, β, χ, δ, ε and ρ are regression coefficients.

The ... indicate that depending on the regression results multiple accessibility indicators and endowment indicators can be included in the equation. The economic structure variable is used as an explanatory variable because the conditions for production in a certain sector depend on the given sectoral structure, which reflects historic developments and path dependencies not covered by other indicators in the equation. The economic structure variable is delayed by five years as structural change is a slow process. Endowment factors are indicators measuring the suitability of the region for economic activity. They include traditional location factors such as capital stock (i.e. production facilities) and intraregional transport infrastructure as well as 'soft' quality-of-life factors such as indicators describing the spatial organisation of the region, i.e. its settlement structure and internal transport system, or institutions of higher education, cultural facilities, good housing and a pleasant climate and environment. In addition, monetary transfers to regions by the European Union such as assistance by the Structural or Cohesion Funds or the Common Agricultural Policy or by national governments are considered, as these may account for a sizeable portion of the economic development of peripheral regions. Regional transfers per capita $S_r(t)$ are provided by the European Developments submodel (see above).

To take account of 'soft' factors not captured by the endowment and accessibility indicators of the model, all GDP per capita forecasts are multiplied by a region- and sector-specific residual constant R_{ir}. In the period 1981 to 2001, R_{ir} is the ratio between observed and predicted GDP per capita of sector i in region r in each year; hence in this period observed sectoral regional GDP is exactly reproduced by the model. In the period 2002 to 2031, the last residuals calculated for the year 2001 are applied.

In addition, the results of the regional GDP per capita forecasts are adjusted such that the total of all regional GDP meets the exogenous forecast of economic development (GDP) of the study area as a whole by the European Developments submodel (see above). However, these constraints are applied only to the reference scenario; in the policy scenarios the adjustment factors calculated for the reference scenario in each forecasting year are applied. In this way, the changes in generative effects induced by the policies are forecast.

Regional GDP by industrial sector $Q_{ir}(t)$ is then

$$Q_{ir}(t) = q_{ir}(t)\, P_r(t) \tag{6}$$

where $P_r(t)$ is regional population (see below).

3.4 Regional Employment

Regional employment by industrial sector is derived from regional GDP by industrial sector and regional labour productivity.

Regional labour productivity is forecast in the SASI model exogenously based on exogenous forecasts of labour productivity in each country:

$$p_{ir}(t) = p_{ir}(t-1)\,\frac{p_{ir'}(t)}{p_{ir'}(t-1)} \qquad \text{with } r \in \mathbf{R}_{r'} \tag{7}$$

where $p_{ir}(t)$ is labour productivity, i.e. annual GDP per worker, of industrial sector i in region r in year t, $p_{ir'}(t)$ is average labour productivity in sector i in year t in country or group of regions $\boldsymbol{R}_{r'}$ to which region r belongs. The rationale behind this specification is the assumption that labour productivity by economic sector in a region is predominantly determined by historical conditions in the region, i.e. by its composition of industries and products, technologies and education and skill of labour and that it grows by an average sector-specific growth rate.

Regional employment by industrial sector is then

$$E_{ir}(t) = Q_{ir}(t) / p_{ir}(t) \tag{8}$$

where $E_{ir}(t)$ is employment in industrial sector *i* in region *r* in year *t*, $Q_{ir}(t)$ is the GDP of industrial sector *i* in region *r* in year *t* and $p_{ir}(t)$ is the annual GDP per worker of industrial sector *i* in region *r* in year *t*.

3.5 Regional Population

The Regional Population submodel forecasts regional population by five-year age groups and sex through natural change (fertility, mortality) and migration. Population forecasts are needed to represent the demand side of regional labour markets.

Changes of population due to births and deaths are modelled by a cohort-survival model subject to exogenous forecasts of regional fertility and mortality rates. To reduce data requirements, a simplified version of the cohort-survival population projection model with five-year age groups is applied. The method starts by calculating survivors for each age group and sex:

$$P'_{asr}(t) = P_{asr}(t-1)\ [1 - d_{asr'}(t-1,t)] \qquad \text{with } r \in \mathbf{R}_{r'} \tag{9}$$

where $P'_{asr}(t)$ are surviving persons of age group *a* and sex *s* in region *r* in year *t*, $P_{asr}(t–1)$ is population of age group *a* and sex *s* in year *t*–1 and $d_{asr'}(t-1,t)$ is the average annual death rate of age group *a* and sex *s* between years *t*–1 and *t* in country or group of regions $\boldsymbol{R}_{r'}$ to which region *r* belongs.

Next it is calculated how many persons change from one age group to the next through ageing employing a smoothing algorithm:

$$g_{asr}(t-1,t) = 0.12\ P'_{asr}(t) + 0.08\ P'_{a+1sr}(t) \qquad \text{for } a = 1, 19 \tag{10}$$

where $g_{asr}(t–1,t)$ is the number of persons of sex *s* changing from age group *a* to age group *a*+1 in region *r*. Surviving persons in year *t* are then

$$P_{asr}(t) = P'_{asr}(t) + g_{a-1sr}(t-1,t) - g_{asr}(t-1,t) \qquad \text{for } a = 2, 19 \tag{11}$$

with special cases

$$P_{20sr}(t) = P'_{20sr}(t) + g_{19sr}(t-1,t) \tag{12}$$

$$P_{1sr}(t) = P'_{1sr}(t) + B_{sr}(t-1,t) - g_{1sr}(t-1,t) \tag{13}$$

where $B_{sr}(t–1,t)$ are births of sex *s* in region *r* between years *t*–1 and *t*:

$$B_{sr}(t-1,t) = \sum_{a=4}^{10} 0.5\ [P'_{a2r}(t) + P_{a2r}(t)]\ \ b_{asr'}(t-1,t)\ \ [1 - d_{0sr'}(t-1,t)] \quad \text{with } r \in \mathbf{R}_{r'} \tag{14}$$

where $b_{asr'}(t-1,t)$ are the average number of births of sex *s* by women of child-bearing five-year age groups *a*, $a = 4,10$ (15 to 49 years of age) in country or group of regions $\boldsymbol{R}_{r'}$ to which region *r* belongs between years t–1 and t, and $d_{0sr'}(t-1,t)$ is the death rate during the first year of life of infants of sex s in country or group of regions $\boldsymbol{R}_{r'}$ to which region r belongs. The exogenous forecasts of death and birth rates in the above equations are national rates.

Migration within the European Union and immigration from non-EU countries is modelled in a simplified migration model as annual regional net migration as a function of regional indicators expressing the attractiveness of a region as a place of employment and a place to live to take into account both job-oriented migration and retirement migration:

$$m_r(t) = \alpha \left(\frac{q_r(t-3)}{\bar{q}(t-3)} - 1.5 \right) + \beta \left(\frac{v_r(t-3)}{\bar{v}(t-3)} - 1.5 \right) \tag{15}$$

The attractiveness of a region as a place of employment is expressed as the ratio of regional GDP per capita $q_r(t$–3) and average European GDP per capita . The attractiveness of a region as a place to live is expressed as the ratio of the regional quality of life $v_r(t$–3) and average European quality of life. Both indicators are lagged by three years to take account of delays in perception. The forecasts of regional net migration are adjusted to comply with total European net migration forecast by the European Developments submodel.

In a recent still experimental version of the migration model (ESPON 1.4.4, 2007) not regional migration balances (net migration) but interregional migration flows are explicitly modelled using an interregional push-and-pull migration model, in which the push and pull factors are the same as the ones used in the net migration model shown above plus a third indicator, population density $p_r(t$-3), expressing the trend of depopulation of remote, thinly populated regions.

Specific assumptions are made to take account of barriers to migration between some old member states and the new member states and between EU member states and non-EU countries, such as restrictions on immigration from certain countries as well as cultural and language barriers to take account of the fact that migrations between two regions in different countries are much less frequent than migrations between otherwise identical regions in the same country. These barriers were defined in analogy to the barriers to trade and travel assumed in ESPON 2.1.1 (Bröcker et al., 2005). In addition, airline distance between regions is included as a barrier to migration. Migration flows between regions r and s are then

$$M_{rs}(t) = P_r(t)\ E_s(t)\ g_{rs}(t-3)\ \exp\left[-\alpha\ b_{rs}(t)\right]\ \exp(-\beta\ d_{rs}) \tag{16}$$

with

$$g_{rs}(t-3) = \left(\frac{q_r(t-3)}{q_s(t-3)} \right)^{\gamma} \left(\frac{v_r(t-3)}{v_s(t-3)} \right)^{\delta} \left(\frac{p_r(t-3)}{p_s(t-3)} \right)^{\varepsilon} \tag{17}$$

where $P_r(t)$ is the population in region r in year t, $E_r(t)$ are jobs in region r in year t, $q_r(t$-3) is GDP per capita in region r in year t-3, $v_r(t$-3) is quality of life in region r in year t-3, $p_r(t$-3) is population density in region r in year t-3, $b_{rs}(t)$ are barriers to migration between regions r and s in year t and d_{rs} is airline distance between regions r and s.

Regional educational attainment, i.e. the proportion of residents with higher education in region r, is forecast exogenously assuming that it grows as in the country or group of regions to which region r belongs:

$$h_r(t) = h_r(t-1)\, h_{r'}(t) / h_{r'}(t-1) \qquad \text{with } r \in \mathbf{R}_{r'} \tag{18}$$

where $h_r(t)$ is the proportion of residents with higher education in region r in year t, and $h_{r'}(t)$ is the average proportion of residents with higher education in country or group of regions $\boldsymbol{R}_{r'}$ to which region r belongs.

3.6 Regional Labour Force

The regional labour force is derived from regional population and regional labour force participation.

Regional labour force participation by sex is partly forecast exogenously and partly affected endogenously by changes in job availability or unemployment. It is assumed that labour force participation in a region is predominantly determined by historical conditions in the region, i.e. by cultural and religious traditions and education and that it grows by an average country-specific growth rate. However, it is also assumed that it is positively affected by availability of jobs (or negatively by unemployment):

$$\ell_{sr}(t) = \ell_{sr}(t-1)\,\ell_{sr'}(t)\,/\,\ell_{sr'}(t-1) - \varphi_s\; u_r(t-1) \qquad \text{with } r \in \mathbf{R}_{r'} \tag{19}$$

where $\ell_{sr}(t)$ is labour force participation, i.e. the proportion of economically active persons of sex s of regional population of sex s 15 years of age and older, in region r in year t, $\ell_{sr'}(t)$ is average labour participation of sex s in year t in country or group of regions $\boldsymbol{R}_{r'}$ to which region r belongs, $u_r(t–1)$ is unemployment in region r in the previous year t–1 (see below), and φ_s is a linear elasticity indicating how much the growth in labour productivity is accelerated or slowed down by regional unemployment. Because at the time of execution of the Regional Labour Force submodel regional unemployment in year t is not yet known, unemployment in the previous year t–1 is used. Regional labour force by sex s in region r, $L_{sr}(t)$, is then

$$L_{sr}(t) = P_{sr}(t)\,\ell_{sr}(t) \tag{20}$$

where $P_{sr}(t)$ is population of sex s 15 years of age and older in region r at time t and $\ell_{sr}(t)$ is the labour force participation rate of sex s in region r in year t.

Regional labour force is disaggregated by skill in proportion to educational attainment in the region calculated in the Regional Population (see above):

$$L_{sr1}(t) = h_r(t)\,L_{sr}(t) \tag{21}$$

with $L_{sr1}(t)$ being skilled labour and the remainder unskilled labour:

$$L_{sr2}(t) = L_{sr}(t) - L_{sr1}(t) \tag{22}$$

3.7 Socio-economic Indicators

From regional accessibility and GDP per capita forecast by the model equity or cohesion indicators describing their distribution across regions are calculated. Cohesion indicators are macroanalytical indicators combining the indicators of individual regions into one measure of their spatial concentration. Changes in the cohesion indicators predicted by the model for future transport policies reveal whether these policies are likely to reduce or increase existing disparities in accessibility and GDP per capita between the regions.

In the SASI model five cohesion indicators are calculated:

- *Coefficient of variation*. The coefficient of variation is the standard deviation of region indicator values expressed in percent of their European average. The coefficient of variation informs about the degree of homogeneity or polarisation of a spatial distribution. A coefficient of variation of zero indicates that all areas have the same indicator values. The different size of regions is accounted for by treating each area as a collection of individuals having the same indicator value. The coefficient of variation can be used to compare two scenarios with respect to cohesion or equity or two points in time of one scenario with respect to whether convergence or divergence occurs.

- *Gini coefficient*. The Lorenz curve compares a rank-ordered cumulative distribution of indicator values of areas with a distribution in which all areas have the same indicator value. This is done graphically by sorting areas by increasing indicator value and drawing their cumulative distribution against a cumulative equal distribution (an upward sloping straight line). The surface between the two cumulative distributions indicates the degree of polarisation of the distribution of indicator values. The Gini coefficient calculates the ratio between the area of that surface and the area of the triangle under the upward sloping line of the equal distribution. A Gini coefficient of zero indicates that the distribution is equal-valued, i.e. that all areas have the same indicator value. A Gini coefficient close to one indicates that the distribution of indicator values is highly polarised, i.e. few areas have very high indicator values and all other areas very low values. The different size of areas can be accounted for by treating each area as a collection of individuals having the same indicator value.

- *Geometric/arithmetic mean*. This indicator compares two methods of averaging among observations: geometric (multiplicative) and arithmetic (additive) averaging. If all observations are equal, the geometric and arithmetic mean are identical, i.e. their ratio is one. If the observations are very heterogeneous, the geometric mean and hence the ratio between the geometric and the arithmetic mean go towards zero.

- *Correlation between relative change and level*. This indicator examines the relationship between the percentage change of an indicator and its magnitude by calculating the correlation coefficient between them. If for instance the correlation between the changes in GDP per capita of the region and the levels of GDP per capita in the regions is positive, the more affluent regions gain more than the poorer regions and that disparities in income are increased. If the correlation is negative, the poorer regions gain more than the rich regions and disparities decrease.

- *Correlation between absolute change and level*. This indicator is constructed as the previous one except that absolute changes are considered. This indicator expresses absolute convergence or divergence. The results differ substantially from the correlation between relative change and level. If, for instance, two regions, a rich and a poor region, both gain (or lose) ten percent of the GDP per capita in relative terms, in absolute terms the richer region gains (loses) much more than the poorer region.

4. Study Area

The study area of the model are the 27 countries of the European Union plus Norway and Switzerland and the western Balkan countries Albania, Bosnia-Herzegovina, Croatia, FYR Makedonia and Yugoslavia.

4.1 Regions

The SASI model presently forecasts accessibility and GDP per capita of 1,330 NUTS-3 or equivalent regions in the study area. (see Figure 3). All historical data since 1981 were converted to NUTS-3 regions of 2003 based on Eurostat information or estimates. These 1,330 regions are the 'internal' regions of the model. The remaining European countries, including the European part of Russia, are the 'external' regions, which are used as additional destinations when calculating accessibility indicators. The presently used system of regions is presented in Table 1:

Table 1. SASI model regions

EU member states		Other internal regions		External regions	
Country	No.	Country	No.	Country	No.
Austria	35	Switzerland	26	Belarus	6
Belgium	43	Norway	19	Iceland	1
Bulgaria	28	Albania	1	Liechtenstein	1
Cyprus	1	Bosnia Herzegovina	1	Moldavia	1
Czech Republic	14	Croatia	2	Russia	27
Germany	439	FYR Makedonia	1	Turkey	1
Denmark	15	Serbia/Montenegro	4	Ukraine	4
Estonia	5				
Spain	50				
Finland	20				
France	96				
Greece	51				
Hungary	20				
Ireland	8				
Italy	103				
Lithuania	10				
Luxembourg	1				
Latvia	6				
Malta	2				
Netherlands	40				
Poland	45				
Portugal	28				
Romania	42				
Sweden	21				
Slovenia	12				
Slovakia	8				
United Kingdom	133				
Total	1,276	Total	54	Total	41

Work is underway to convert all model data to the new system of NUTS-3 regions valid since 2008 (Hong, 2008).

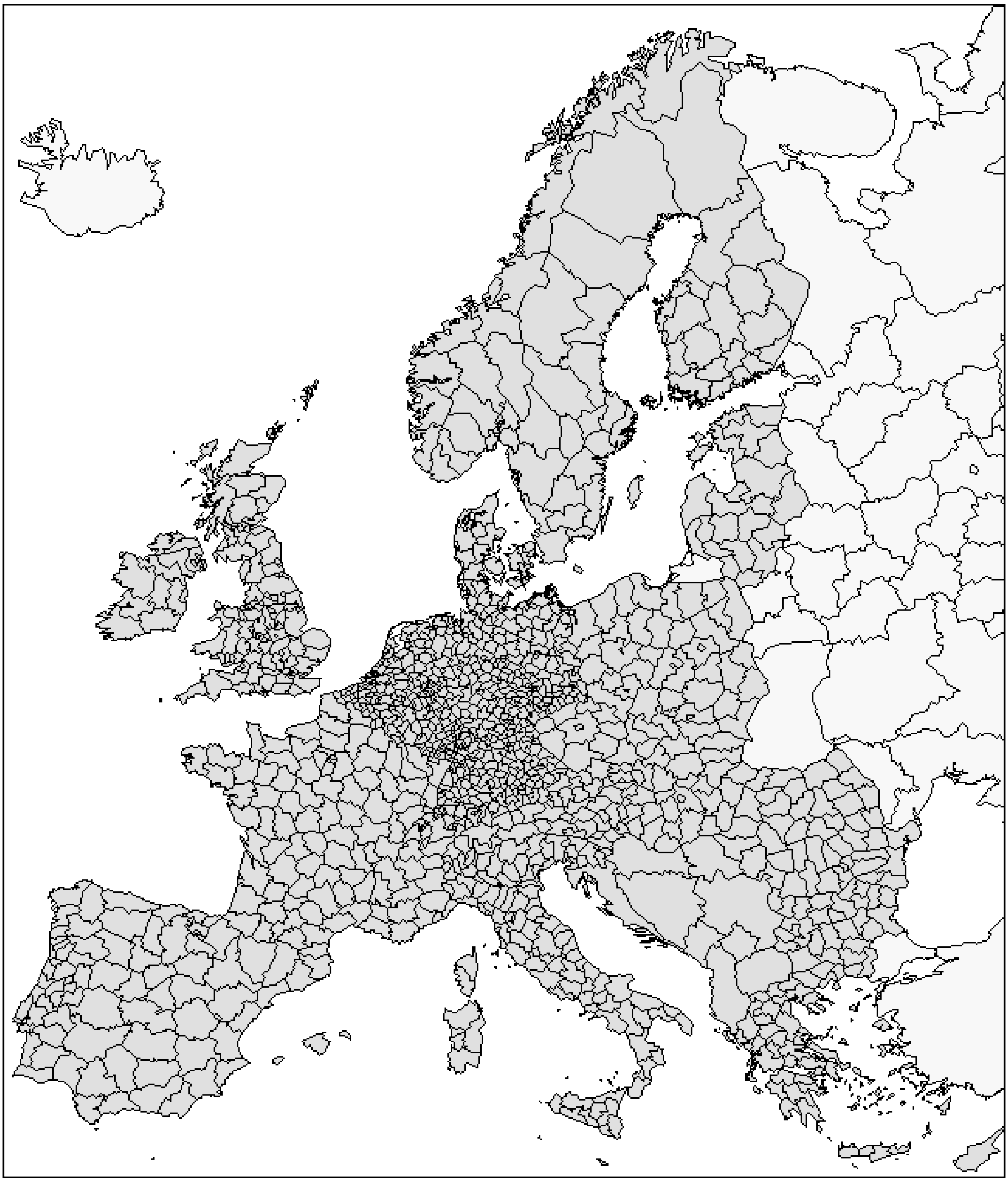

Figure 3. The regions of the SASI model in Europe

4.2 Networks

The transport networks used by the SASI model originated in the trans-European transport network GIS database developed by IRPUD (2003), and now maintained and further developed by RRG (2008). The strategic road, rail and waterways networks used by the SASI model are subsets of this database, comprising the trans-European networks specified in Decision 1692/96/EC of the European Parliament and of the Council (European Communities, 1996) and amended in Decision 884/2004 (European Union, 2004), further specified in the TEN Implementation Report (European Commission, 1998) and latest revisions of the TEN guidelines provided by the European Commission (1999; 2002a; 2003a) and by the European Communities (2001), information and decisions on priority projects (European Commission, 1995; 1999; 2002b; 2003b; 2004; European Union, 2004), on the TINA networks as identified and further promoted by the TINA Secretariat (1999, 2002), the Helsinki Corridors as well as selected additional links in eastern Europe and other links to guarantee connectivity of NUTS-3 level regions. The strategic air network is based on the TEN and TINA airports and other important airports in the remaining countries and contains all flights between these airports (Bröcker et al., 2002) and reflects the state of air travel in 2006.

The networks are used to calculate travel times and travel costs between regions and regional accessibility. For that the historical and future developments of the networks are required as input information. The development of the networks over time is reflected in intervals of five years in the database, i.e. the established network database contains information for all modes for the years 1981, 1986, 1991, 1996, 2001, 2006, 2011, 2016 and 2021. For the past period (until 2006) the same network evolution is used for the reference scenario and all scenarios to be evaluated. The scenarios differ in their assumptions about the future network development. Thus, different assumptions about the state of the transport networks in the years 2011, 2016 and 2021 are used for the reference scenario and the scenarios to be evaluated. This means that in contrast to other studies, the simulation of network scenarios is not a matter of 'with' or 'without' at only one point in time, but that there is gradual network evolution over time.

The type of projects and their expected year of completion were taken from the TEN Implementation Report (European Commission, 1998) and the TINA Status Report (TINA Secretariat, 2002) and their most recent revisions (HLG, 2003; European Union, 2004). In case such information was not available in these sources, supplementary information from national ministries or bodies was used as well (for example, the REBIS study (European Commission, 2003c), Europe Aid (2001), or United Nations (1995; 2003). Most projects are composed of different sections with individual project types and completion years. The GIS database set up for this purpose tries to reflect this in that all projects are represented by their individual sections in the database, with individual specifications for type of work and completion year. Only in cases where such detailed information was not available, an overall completion year for all sections of one project was assigned.

Figures 4 and 5 on the following pages show the SASI road and rail networks with the projects studied in ESPON 2.1.1 highlighted (Bröcker et al, 2005).

The subsequent Figures 6 and 7 show the current TEN and TINA projects. Figure 6 shows the TEN and TINA priority projects (European Union, 2004). Figure 7 shows all TEN and TINA projects and the priority project corridors (European Union, 2004).

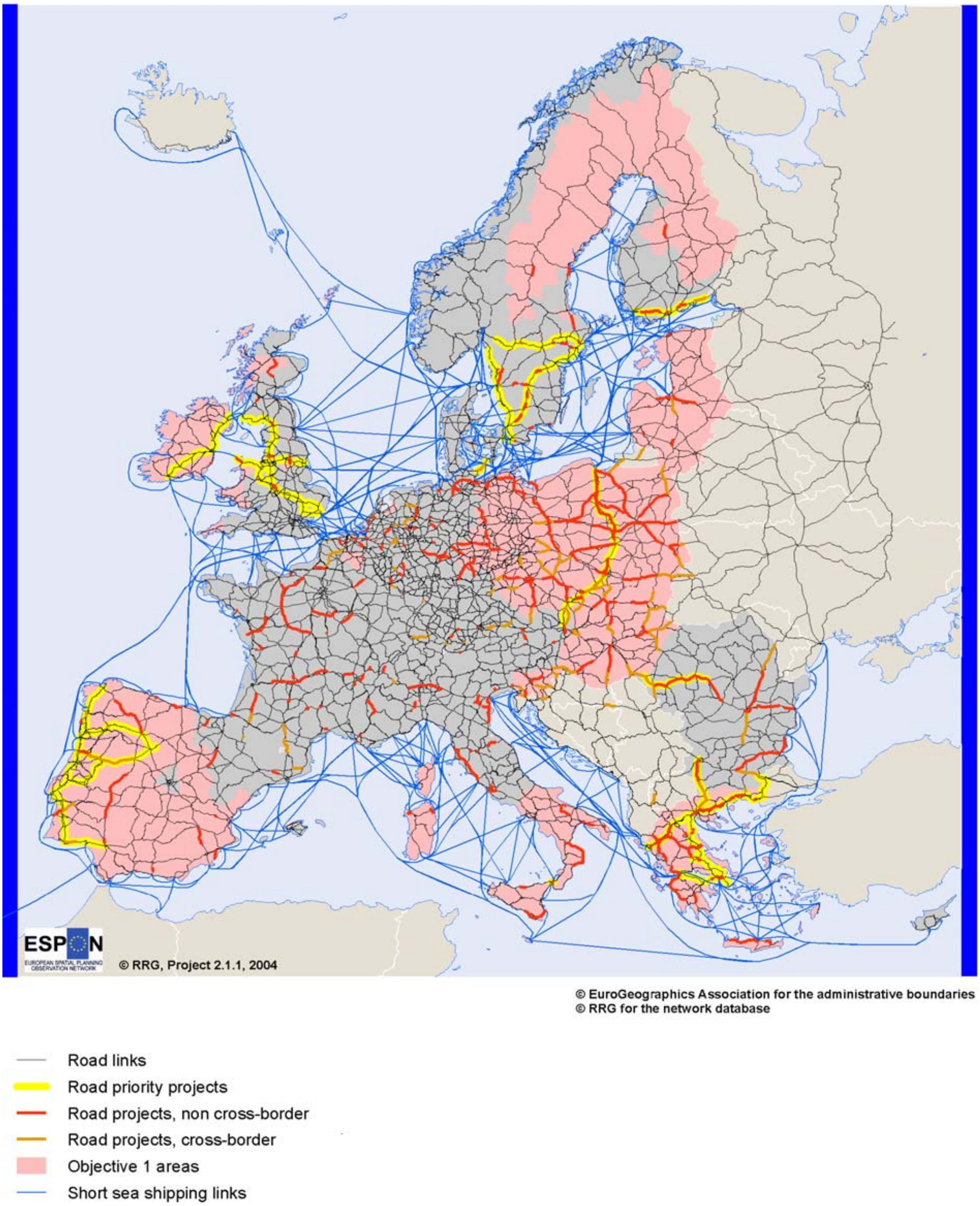

Figure 4. The SASI road network (Bröcker et al., 2005)

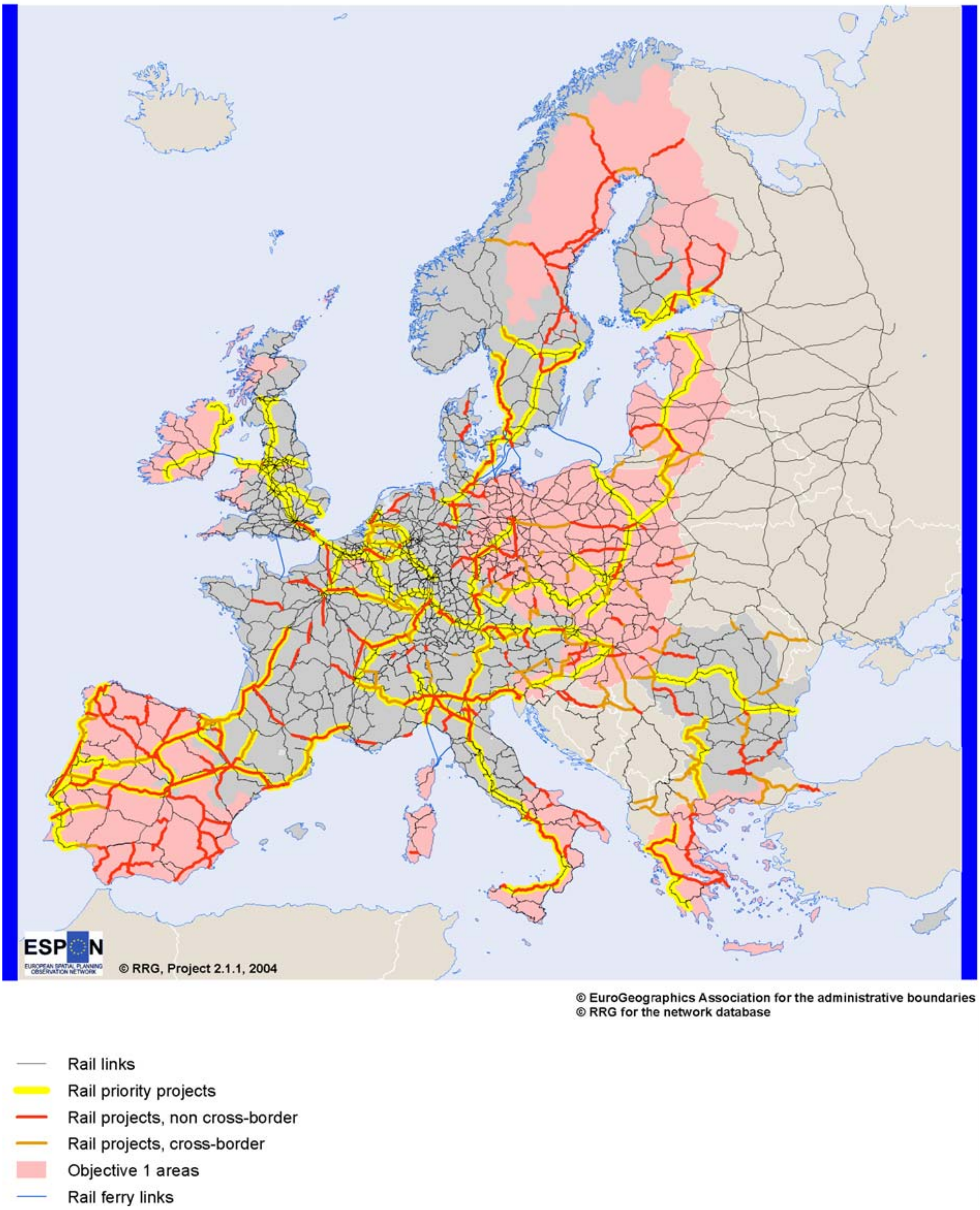

Figure 5. The SASI rail network (Bröcker et al., 2005)

Figure 6. TEN and TINA rail and road priority projects (Bröcker et al., 2004)

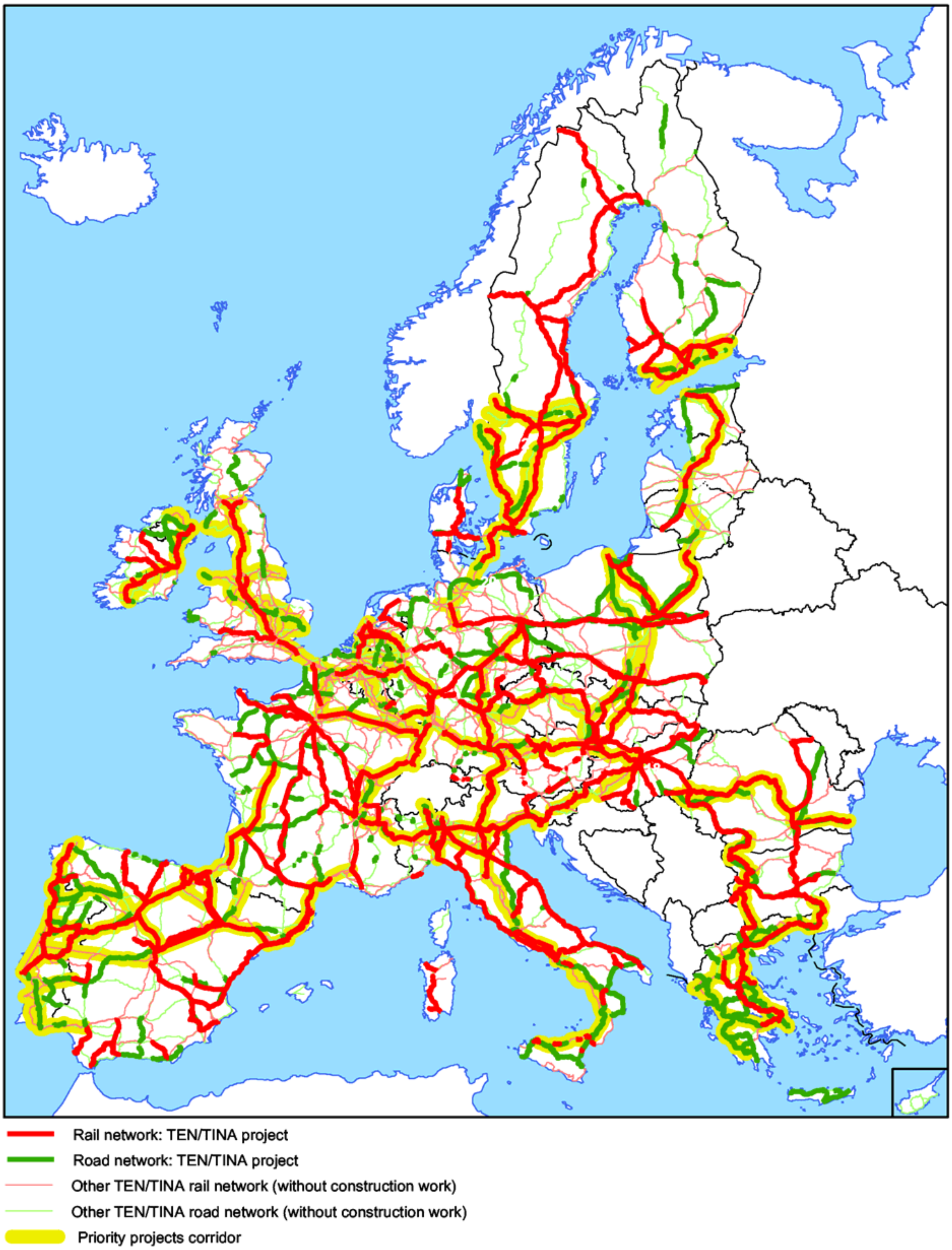

Figure 7. TEN and TINA road and rail projects and priority corridors (Bröcker et al., 2004)

5. Model Data

The data required to perform a typical simulation run with the SASI model can be grouped into base-year data and time-series data. Base-year data describe the state of the regions and the strategic road, rail and air networks in the base year 1981. Time-series data describe exogenous developments or policies defined to control or constrain the simulation. They are either collected or estimated from actual events for the time between the base year and the present or are assumptions or policies for the future. Time-series data must be defined for each simulation period, but in practice may be entered only for specific (not necessarily equidistant) years, with the simulation model interpolating between them.

Exogenous assumptions are required concerning changes in regional labour productivity, regional educational attainment and regional labour force participation. All other regional base-year values such as GDP, employment or labour force are calculated by the model. Network data specify the road, rail and air networks used for accessibility calculations, and the evolution of the networks over the simulation period is needed as input.

5.1 Calibration/Validation Data

The regional production function in the Regional GDP submodel and the migration function in the Regional Population submodel are the only model functions *calibrated* using statistical estimation techniques. All other model functions are *validated* by comparing the output of the whole model with observed values for the period between the base year and the present.

Calibration data are data used for calibrating the regional production functions in the Regional GDP submodel and the migration function in the Regional Population submodel. The four years 1981, 1986, 1991 and 1996 are used to gain insights into changes in parameter values over time; however, only the parameter estimates for 2001 are used in the simulation. The calibration data of 1981 are identical with the simulation data for the same year.

Regional data (1,330 regions)

- Regional GDP per capita by industrial sector in 1981, 1986, 1991, 1996, 2001
- Regional labour productivity by industrial sector in 1981, 1986, 1991, 1996, 2001
- Regional endowment factors in 1981, 1986, 1991, 1996, 2001
- Regional labour force in 1981, 1986, 1991, 1996, 2001
- Regional transfers in 1981, 1986, 1991, 1996, 2001

Network data

- Node and link data of strategic road network in 1981, 1986, 1991, 1996, 2001
- Node and link data of strategic rail network in 1981, 1986, 1991, 1996, 2001
- Node and link data of air network in 1981, 1986, 1991, 1996, 2001

Validation data are reference data with which the model results in the period between the base year and the present are compared to assess the validity of the model:

Regional data (1,330 regions)

- Regional population (by age and sex) in 1981, 1986, 1991, 1996, 2001
- Regional GDP (by industrial sector) in 1981, 1986, 1991, 1996, 2001
- Regional labour force (by sex) in 1981, 1986, 1991, 1996, 2001
- Regional employment (by industrial sector) in 1981, 1986, 1991, 1996, 2001

5.2 Simulation Data

Simulation data are the data required to perform a typical simulation. They can be grouped into *base-year* data and *time-series* data.

Base-year data describe the state of the regions and the strategic transport networks in the base year and so are either regional or network data. Regional base-year data provide base values for the Regional GDP submodel and the Regional Population submodel as well as base values for exogenous forecasts of changes in regional educational attainment and regional labour force participation. Network base-year data specify the road, rail and air networks used for accessibility calculations in the base year.

Regional data (1,330 regions)

- Regional GDP per capita by industrial sector in 1981
- Regional labour productivity (GDP per worker) by industrial sector in 1981
- Regional population by five-year age group and sex in 1981
- Regional educational attainment in 1981
- Regional labour force participation rate by sex in 1981
- Regional quality-of-life indicators in 1981

Network data

- Node and link data of strategic road network in 1981
- Node and link data of strategic rail network in 1981
- Node and link data of air network in 1981

Time-series data describe exogenous developments or policies defined to control or constrain the simulation. They are either collected or estimated from actual events for the time between the base year and the present or are assumptions or policies for the future. Time-series are defined for each simulation period. All GDP data are converted to Euro of 2006.

European data (34 countries)

- Total European GDP by industrial sector, 1981-2031
- Total European net migration, 1981-2031

National data (34 countries)

- National GDP per worker by industrial sector, 1981-2031
- National fertility rates by five-year age group and sex, 1981-2031
- National mortality rates by five-year age group and sex, 1981-2031
- National educational attainment, 1981-2031
- National labour force participation by sex, 1981-2031

Regional data (1,330 regions)

- Regional endowment factors, 1981-2031
- Regional transfers, 1981-2031

Network data

- Changes of node and link data of strategic road network, 1981-2031
- Changes of node and link data of strategic rail network, 1981-2031
- Changes of node and link data of air network, 1981-2031

6. Model Calibration

The regional production functions of the SASI model were estimated by linear regression of the logarithmically transformed Cobb-Douglas regional production functions for the 1,330 internal regions and the six industrial sectors used in AlpenCorS for the years 1981, 1986, 1991, 1996 and 2001. The dependent variable is regional GDP per capita in 1,000 Euro of 1998.

Because of numerous gaps and inconsistencies in the data, extensive research was necessary to substitute missing or inconsistent data by estimation or by analogy with similar regions. In particular for the accession countries in eastern Europe, which underwent the transition from planned economies to market economies, information on regional GDP was inconsistent or completely missing. It was therefore necessary to adjust regional sectoral GDP data for the years 1981 to 1991 to conform to estimates of regional GDP totals by Eurostat. In a similar way the sectoral composition of regional economies was cross-checked by comparison with the sectoral composition of gross value added in the Eurostat New Cronos database.

The independent variables of the regressions were a large set of regional indicators of potential explanatory value from which the following were selected:

*sgdp**n***	Share of GDP of sector ***n*** (%)
*gdpw**n***	GDP per worker in sector ***n*** (1,000 Euro of 1998)
acctrra	Accessibility travel road/rail/air
accfrr	Accessibility freight road/rail
rlmp	Regional labour market potential (accessibility to labour)
pdens	Population density (pop/ha)
devld	Developed land (%)
rdinv	R&D investment (% of GDP)
eduhi	Share of population with higher education (%)
quali	Quality of life indicator (0-100)

To take account of the slow process of economic structural change, independent variables *sgdp**n*** and *gdpw**n*** are lagged by five years; all other independent variables are lagged by one year, i.e. the most recent available value is taken. Because no data are available for years before 1981, no lags are applied for 1981.

Table 2 shows the regression coefficients for the selected variables for 2001. Given the large number of regions and the exclusion of region size by the choice of GDP per capita as dependent variable, the results are very satisfactory.

In the simulations for the years 1981 to 2001, predicted GDP values were corrected by their residuals to match observed values. The regression parameters and residuals for 2001 were used for the simulations for the years 2002 to 2031.

Table 2. SASI model: calibration results (2001)

Variables	Regression coefficients					
	Agriculture	Manufac-turing	Construc-tion	Trade, tourism, transport	Financial services	Other services
sgdpn	0.460475	0.762302	0.879101	0.709550	0.716462	1.003335
gdpwn	0.554202	0.881195	0.750888	0.900674	0.784505	0.793632
acctrra				0.034314	0.092961	0.238186
accfrr	0.170935	0.061114	0.149949			
rlmp		0.039794		0.029366		
pdens	–0.107152		0.043427			
devld	-0.050657			–0.110744		
rdinv		0.133867			0.271060	0.125108
eduhi		0.226394		0.297862	0.065298	0.109546
quali				0.052679		
Constant	–1.819437	–0.921640	–1.530766	–0.623225	-1.077333	-1.565620
r^2	0.711	0.692	0.637	0.786	0.830	0.699

7. Model Output

The main output of the SASI model are accessibility and GDP per capita for each region for each year of the simulation. However, a great number of other regional indicators are generated during the simulation. These indicators can be examined during the simulation by observing time-series diagrams, choropleth maps or 3D representations of variables of interest on the computer display. The user may interactively change the selection of variables to be displayed during processing. The same selection of variables can be analysed and post-processed after the simulation. The user can compare the results using a comparison programme. The following options can be selected:

Population indicators

- Population (1981=100)
- Percent population 0-5 years
- Percent population 6-14 years
- Percent population 15-29 years
- Percent population 30-59 years
- Percent population 60+ years
- Labour force (1981=100)
- Labour force participation rate (%)
- Percent lower education
- Percent medium education
- Percent higher education
- Net migration per year (%)
- Net commuting (% of labour force)

Economic indicators

- GDP (1981=100)
- Percent non-service GDP
- Percent service GDP
- GDP per capita (in 1,000 Euro of 2006)
- GDP per capita (EU15=100)
- GDP per worker (in 1,000 Euro of 2006)
- Employment (1981=100)
- Percent non-service employment
- Percent service employment
- Unemployment (%)
- Agricultural subsidies (% of GDP)
- European subsidies (% of GDP)
- National subsidies (% of GDP)

Attractiveness indicators

- Accessibility rail/road (travel, million)
- Accessibility rail/road/air (travel, million)
- Accessibility road (freight, million)
- Accessibility rail/road (freight, million)
- Soil quality (yield of cereals in t/ha)
- Developable land (%)
- R&D investment (% of GDP)
- Quality of life (0-100)

8. Regional Applications

The SASI model was originally developed to study European policy issues, such as European transport and cohesion policy. However, due to its relatively high spatial resolution, is can be applied also to smaller study areas at the level of European subregions, countries or parts of countries. In all sub-European applications the full European model was run to take account of the growing social and economic integration between countries and regions in Europe and to identify the impacts of both increasing competition and further integration between regions.

In this section a few model applications below the European level are demonstrated by maps showing examples of spatial distributions of accessibility, economic performance and population of NUTS-3 regions in the year 2006 (for scenario results see the reports cited):

Figures 8 and 9 show maps used in ESPON 1.1.3 to compare the development of regions in the new EU member states with the development of those in the old EU member states in western Europe and to highlight the still existing large differences between them in economic development in the context of EU enlargement and polycentricity and cohesion policy (ESPON 1.1.3, 2006).

Figures 10 and 11 show examples of ongoing work for Germany. Because of the adoption of the 439 *Kreise* as NUTS-3 regions, Germany is represented spatially more disaggregate in the model than other countries (except Belgium and the Netherlands). This makes the comparison of model results between countries more difficult but it has significant advantages for the analysis of spatial processes. As most medium and large cities are independent *Kreise* ("Stadtkreise"), it is possible to present and analyse spatial processes, such as spatial polarisation at the national scale and suburbanisation within urban regions. Figure 10 shows multimodal accessibility with its peak in western Germany dominated by the impacts of Frankfurt and Düsseldorf airports. Figure 11 shows GDP per capita clearly expressing the urban-rural dichotomy and the still existing gap in economic development between western and eastern Germany.

Figures 12 and 13 show accessibility and GDP results for the regions along the Alpen Corridor South or European Corridor V leading from Lyon in France via northern Italy and Slovenia to Budapest in Hungary from the AlpenCorS project (Spiekermann and Wegener, 2005a). The decline in accessibility from north to south as well as the exceptional economic position of Switzerland becomes apparent.

Figures 14 and 15 are examples of one of the fifteen country studies conducted for all cohesion countries in the project "Strategic Evaluation on Transport Investment Priorities under Structural and Cohesion Funds for the Programming Period 2007-2013" (ECORYS, 2006). The task in this project was to assess the impacts of trans-European transport investments on accessibility and regional economic development in the cohesion countries, with special emphasis on cross-border projects and effects.

Figures 16 and 17, finally, are maps showing accessibility and GDP per capita in the state of Saxony in Germany taken from the project "Spatial Impacts of Internalising External Costs of Transport in Saxony" (Spiekermann and Wegener, 2005b). The maps demonstrate that even in a relatively small study area *Kreise* are a useful and sufficient spatial disaggregation to show both intraregional and interregional spatial processes, such as the role and development of cities, the scope and dynamics of interregional and international relationships and the barrier effects of national boundaries.

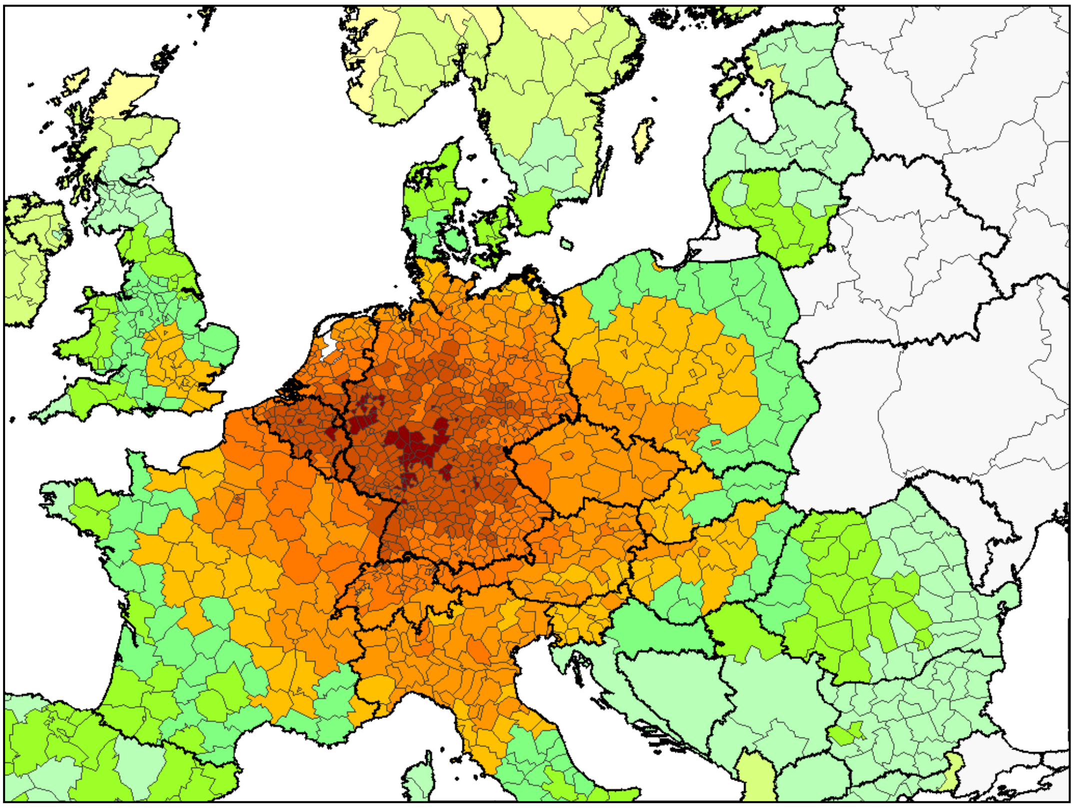

Figure 8. Accessibility road/rail in central Europe, 2006

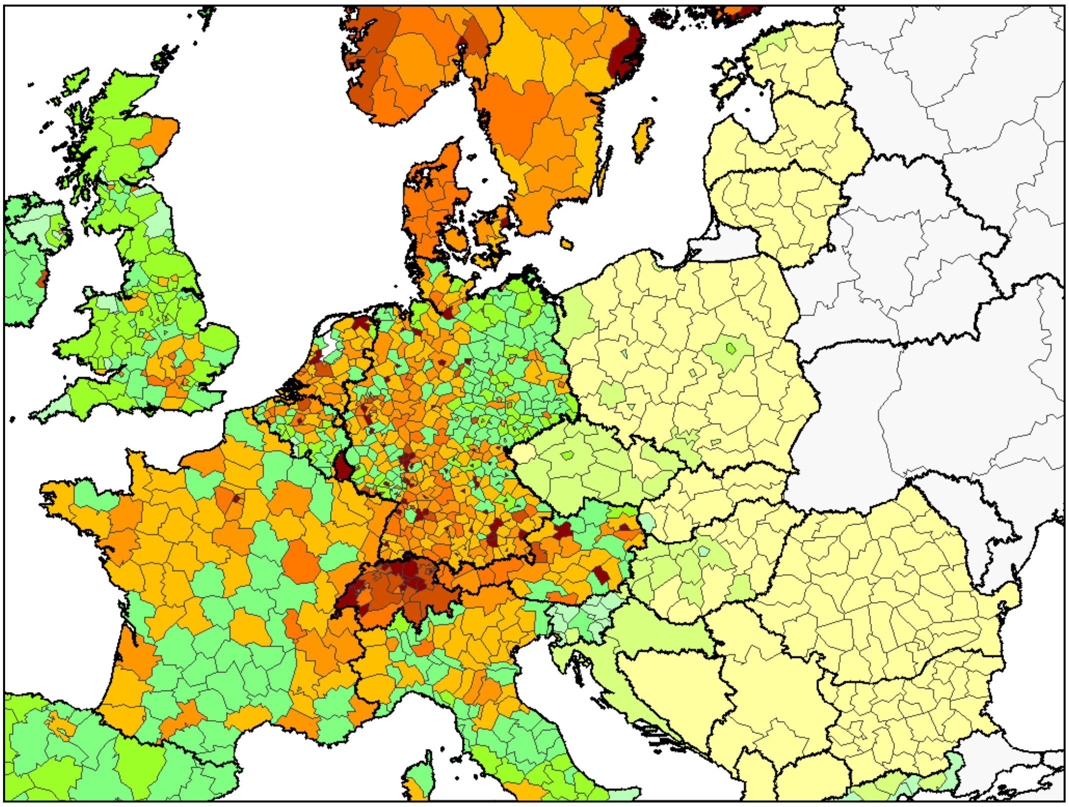

Figure 9. GDP per capita in central Europe, 2006

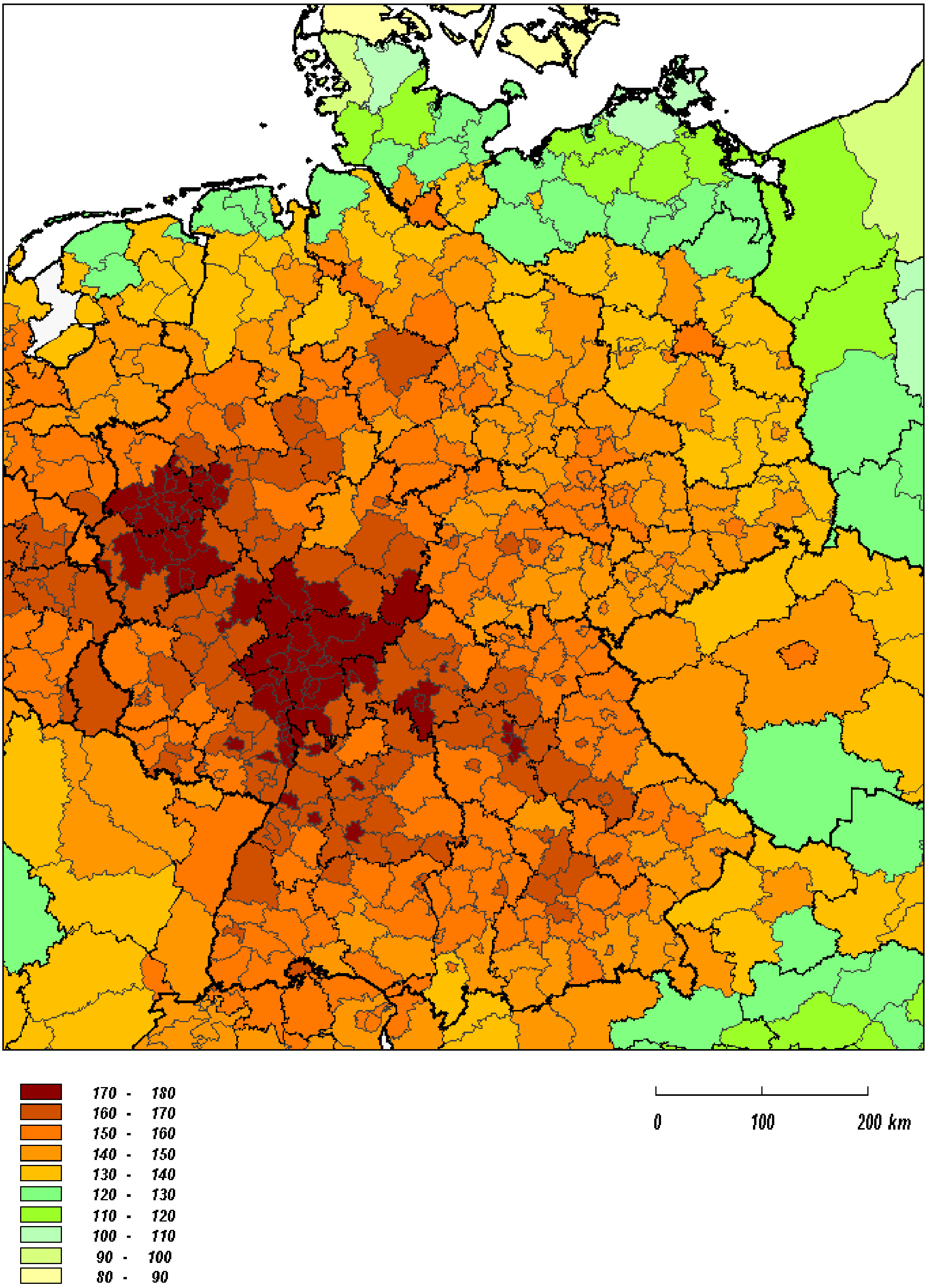

Figure 10. Accessibility road/rail/air, Germany, 2006

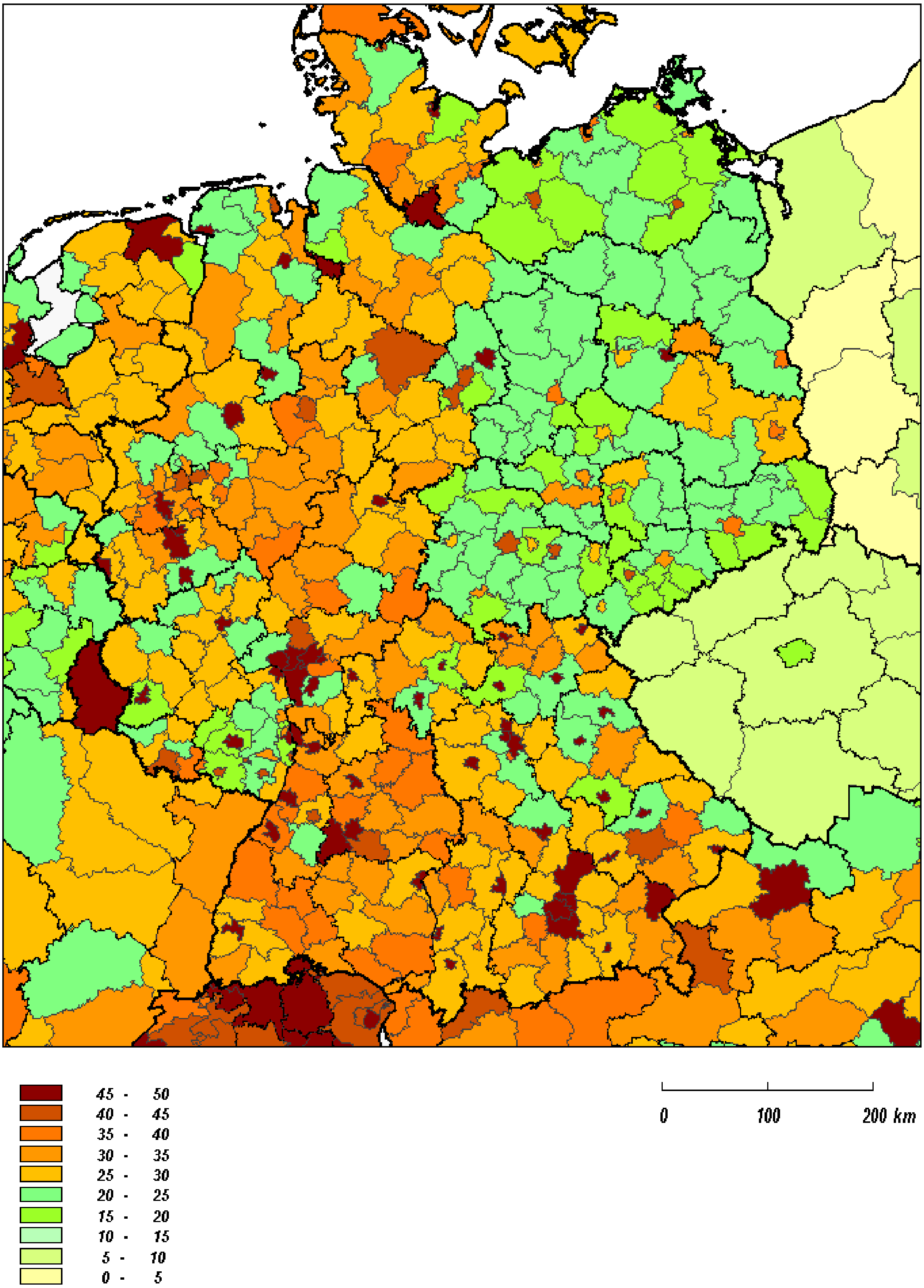

Figure 11. GDP per capita, Germany, 2006

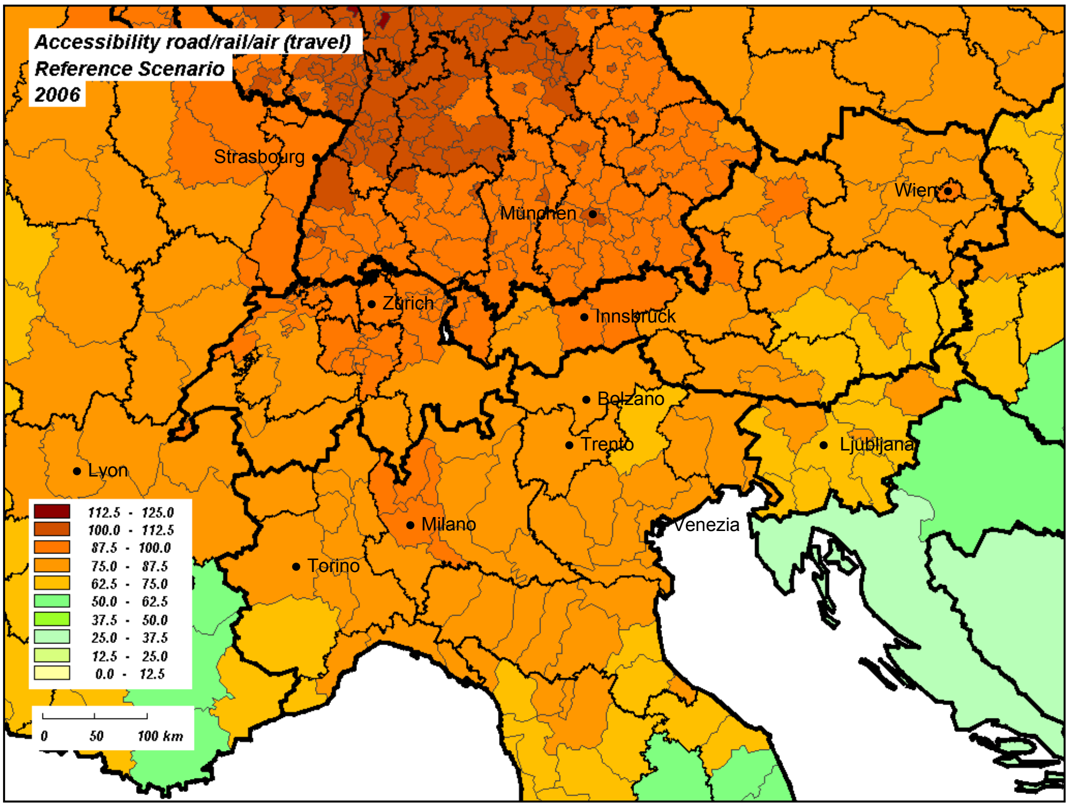

Figure 11. Accessibility road/rail/air in the AlpenCorS regions in 2006

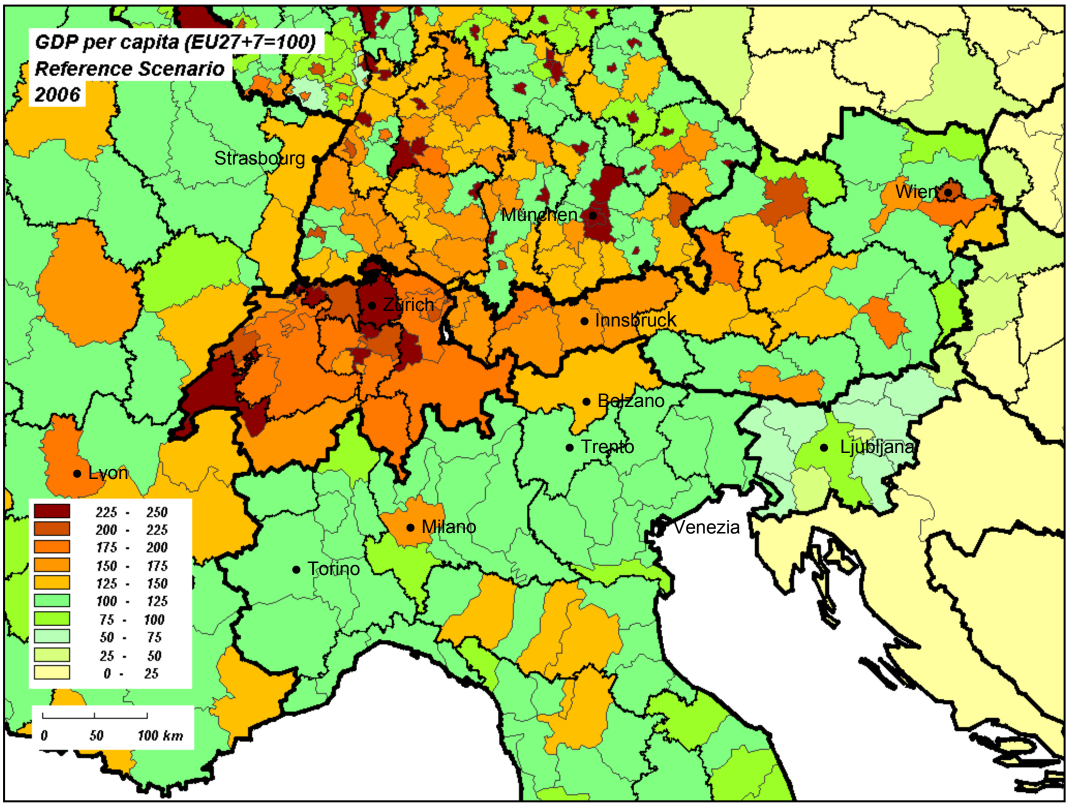

Figure 13. GDP per capita in the AlpenCorS regions in 2006

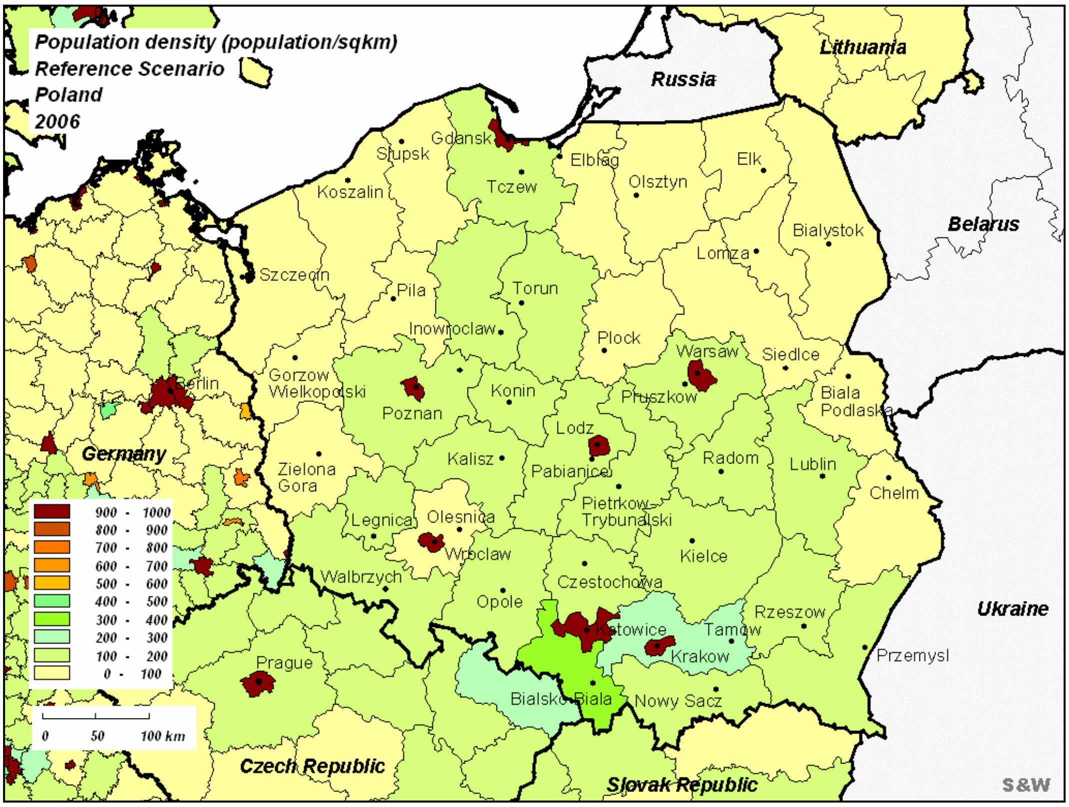

Figure 14. Population density (population/sqkm), Poland, 2006

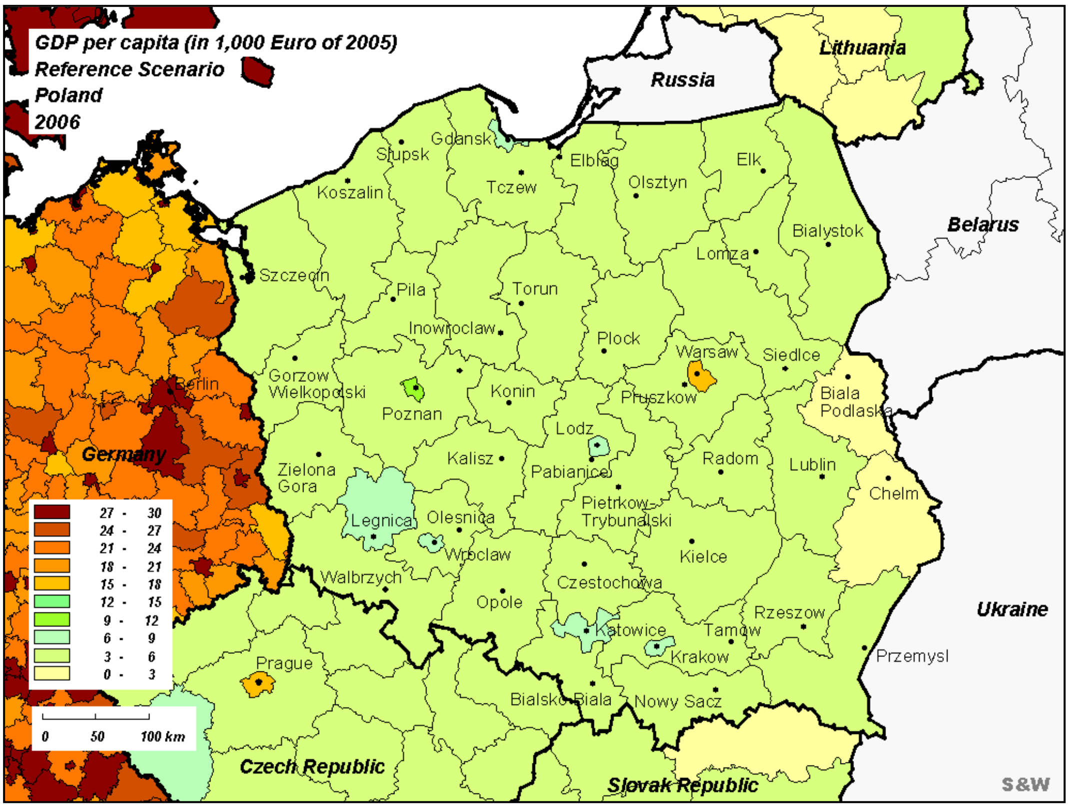

Figure 15. GDP per capita (Euro of 2005), Poland, 2006

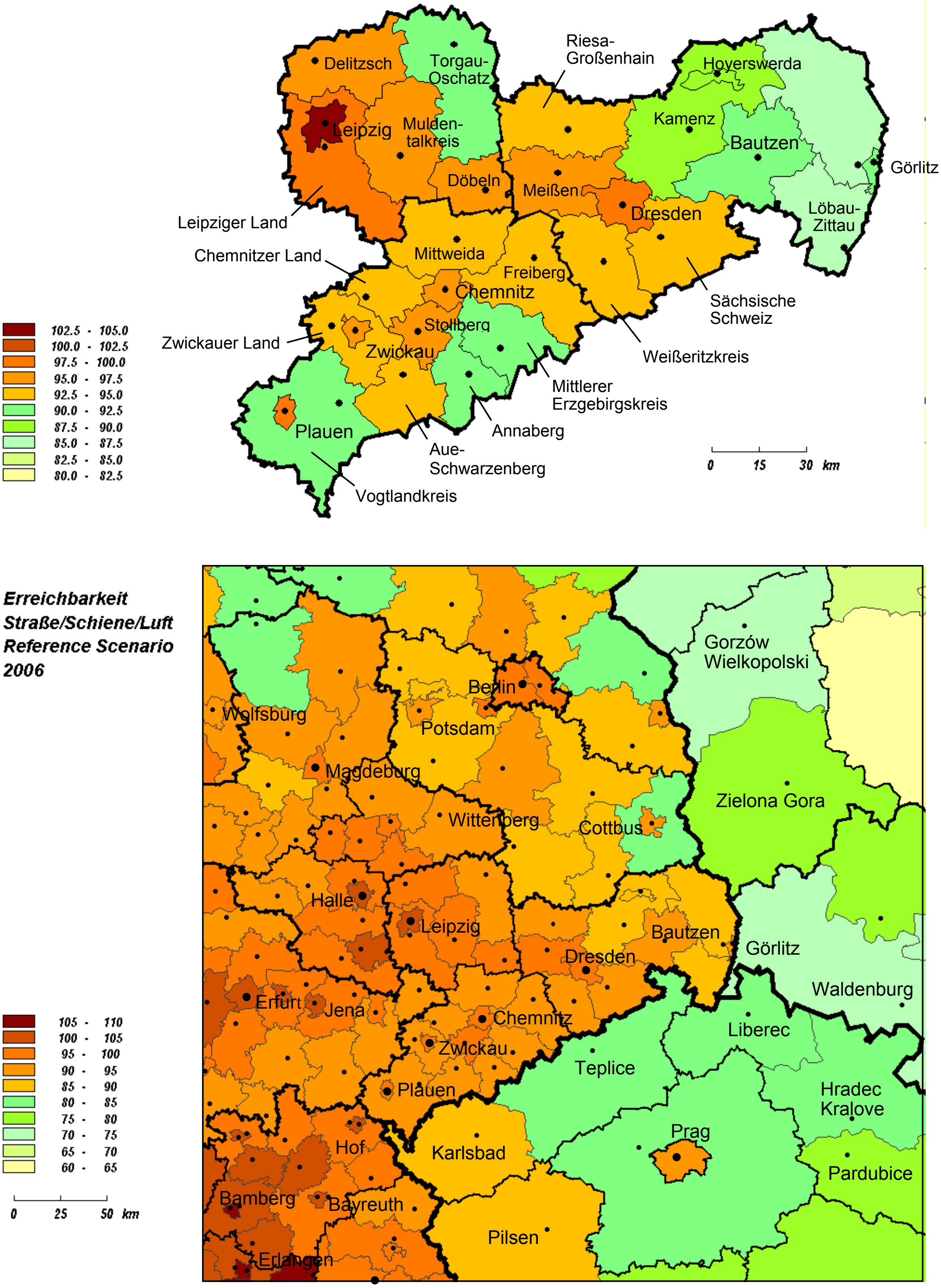

Figure 16. Accessibility road/rail/air in Saxony, 2006

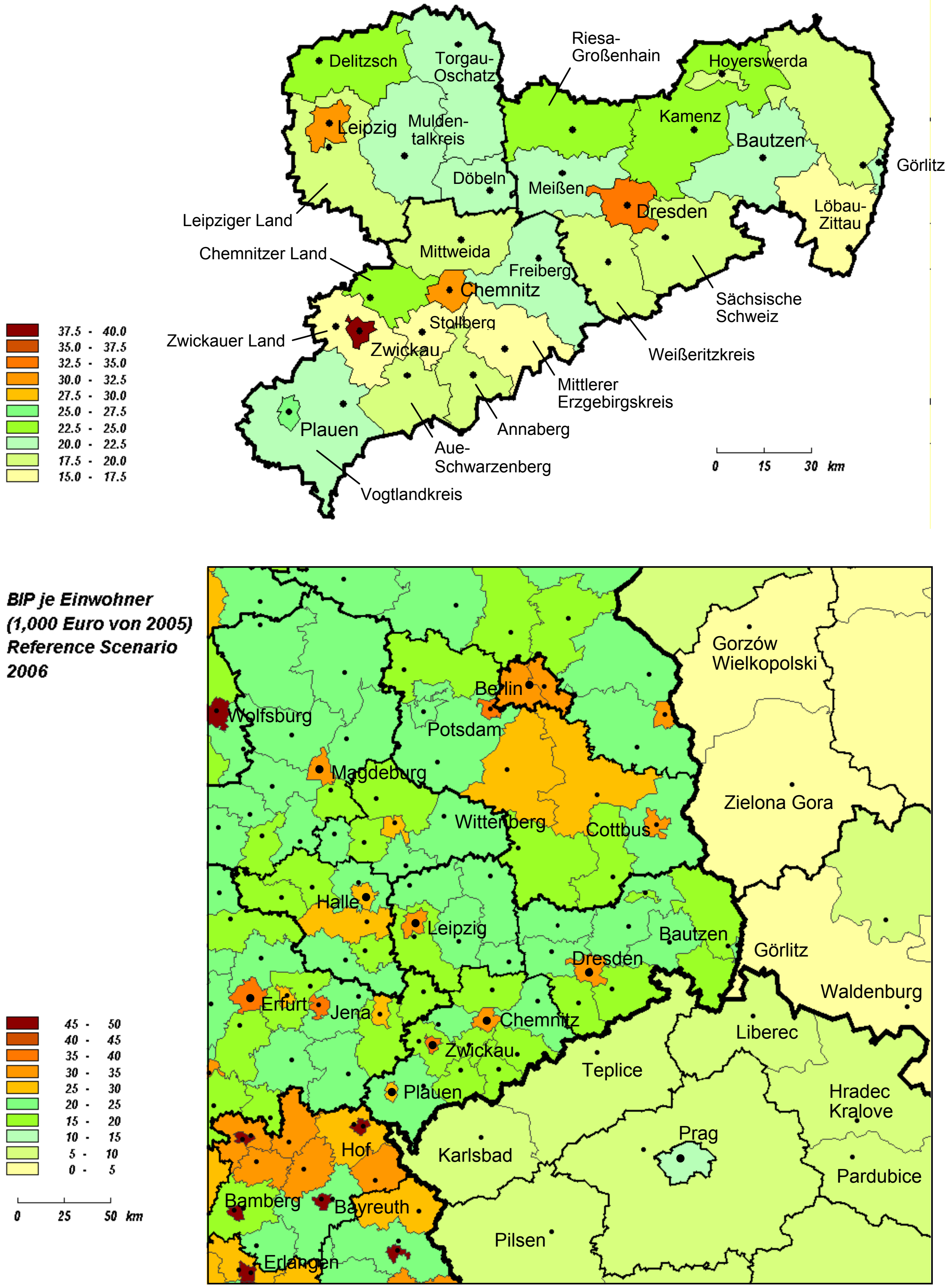

Figure 17. GDP per capita in Saxony, 2006

9. Future Work

Several future extensions and enhancements of the SASI model are planned or already underway. The most important of them are the following:

Data and Calibration:

- Work is underway to update the regional data of the model until 2006 and simultaneously convert all historical data of the model to the new NUTS-3 regions of 2008 (see Section 4).
- Once the data of 2006 have been assembled, the sectoral regional production functions will be re-calibrated using these data.

New Submodels:

- Regional productivity: It is intended to forecast regional labour productivity, which currently is forecast exogenously, endogenously as a function of accessibility and other variables by sectoral regional productivity functions similar to the sectoral regional production functions explained in Section 3.3.
- ICT: The regional production function will be extended by variables informing about the availability and penetration of information and communication technologies.
- Capital mobility: A proposal to model capital mobility without data on the regional capital stock assuming that marginal productivity of capital is comparable in all regions (Bröcker, 2003) will be tested.
- Regional competitiveness: In order to better take account of factors influencing regional production costs, such as regional subsidies, corporate taxes and labour costs, will considered in the regional production functions.
- Migration flows: It is planned to calibrate, test and validate the experimental model of international and interregional migration flows developed in ESPON 1.4.4. and explained in Section 3.5. Since ESPON 1.4.4 a study on the state and future prospects of immigration legislation of EU and non-EU countries in Europe has been completed (Günther, 2007).

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Annex: Model Software

The SASI model is a self-standing executable written in Intel Visual Fortran. It reads region boundaries and centroids and network data prepared in ESRI ArcGIS. No other software is required. Besides the model itself, there are supporting programs for pre-processing of region and network data, model calibration and visualisation of results. Figure A1 presents the organisation of the software:

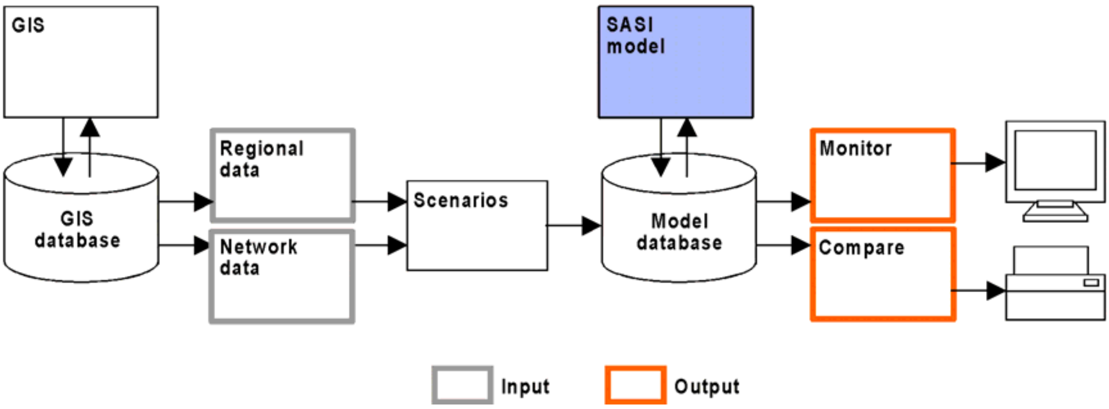

Figure A1. Model software

A1. Scenario Definition

The pre-processing modules shown in grey in Figure 1 extract regional and network data from the GIS database and other sources and convert it to scenario-specific input files. When starting a simulation, the user defines a scenario by selecting the required input files to be transferred to the model database. Figure A2 shows the dialog window for this.

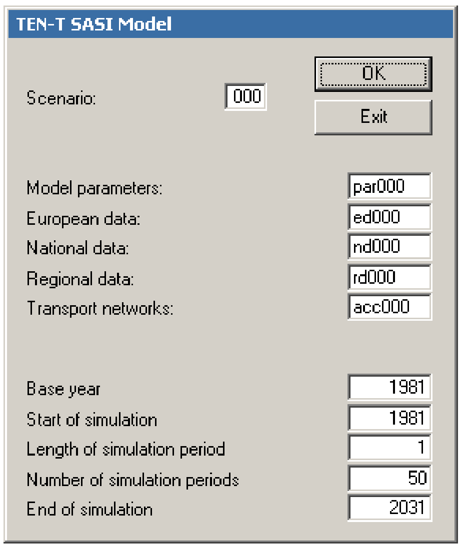

Figure A2. Scenario definition

A.2 Monitoring

During the simulation, the user may monitor the progress of the simulation by calling, with a right mouse-click, a dialog offering a selection of indicators from the fields of Population, Economy and Attractiveness to be visualised as time series diagram, map or 3D surfaces using the <monitor> module shown in red in Figure 1. Figure A3 shows the dialog window:

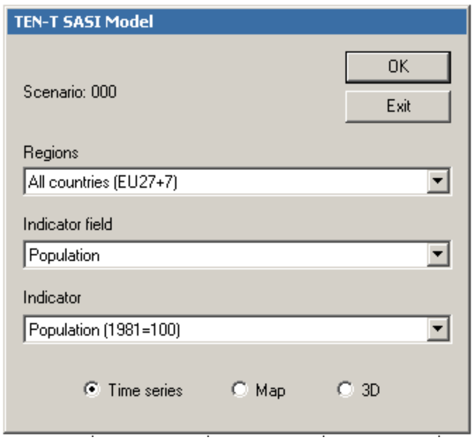

Figure A3. Selection of monitoring indicators and modes

After each simulated year, the selected visualisation is updated based on the results of the simulation. The user may again call the dialog and select another indicator or visualisation mode.

Figure A4 on the following page shows an example in which the user first observes the development of GDP per capita in the 34 countries in a time series diagram and in the year 1999 selects another indicator, percent of population of 0-4 years of age. In 2018 the user changes to another indicator, multimodal accessibility road/rail/air, and selects 3D as the visualisation mode until the end of the simulation in the year 2031.

A3. Comparison between scenarios/regions

When a number of scenarios have been simulated, the user may use the program <compare> shown in red in Figure 1 to compare the results. Also the program <compare> is a self-standing executable written in Intel Visual Fortran. No other software is required.

The program <compare> works in one of three modes:

- In the basic mode, the program displays the results of one scenario in a similar way as in the monitoring mode of the SASI model. The results can be presented in the form of time series diagrams, maps or 3D surfaces.

- In the 'Compare regions' mode, the program compares the results of a policy scenario with those of the reference scenario. The differences between the policy scenario and the Reference Scenario can be presented in the form of time series diagrams, maps or 3D surfaces.

- In the 'Compare scenarios' mode, the program compares the results of several scenarios over time in the form of different trajectories in time-series diagrams.

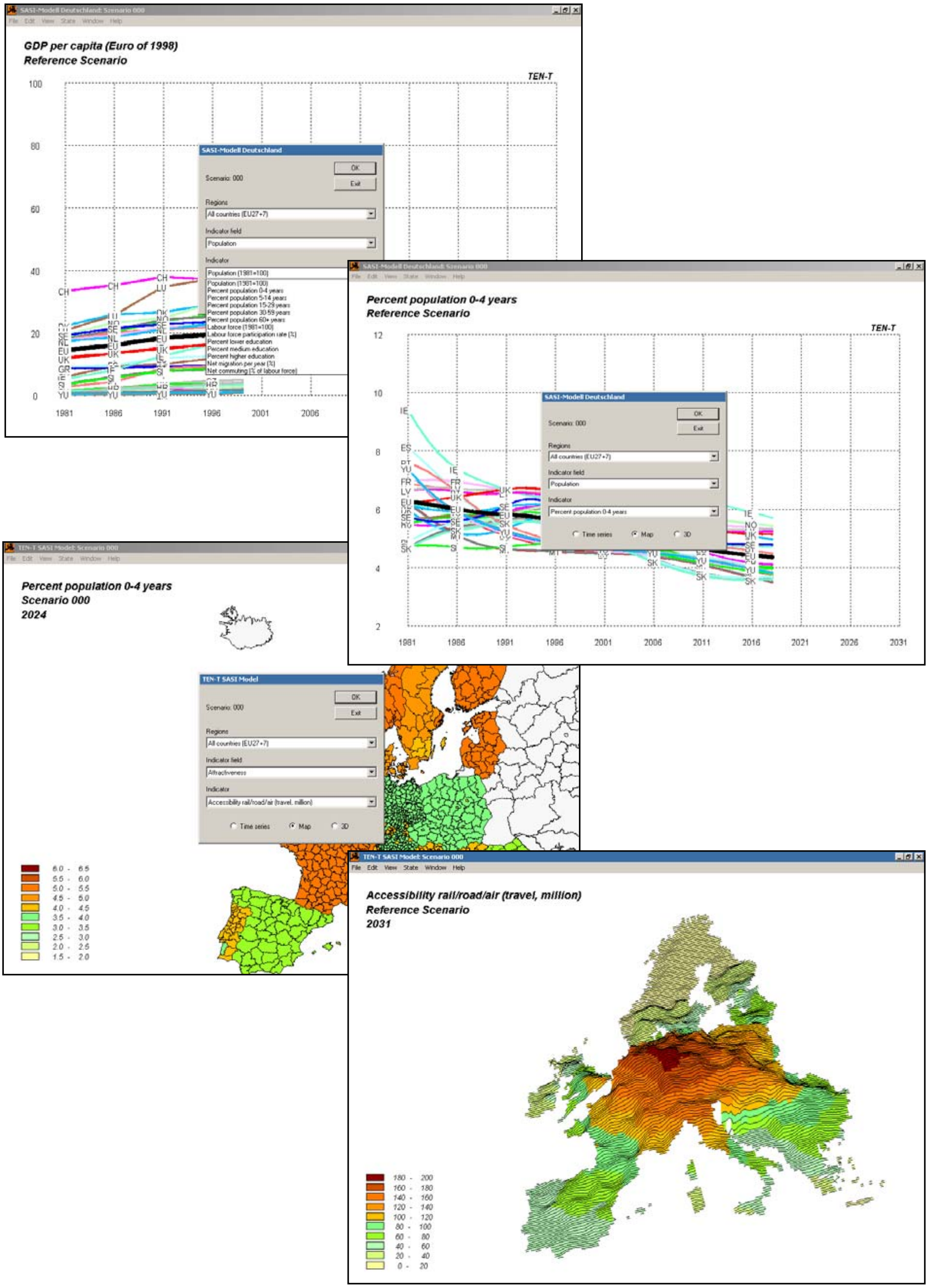

Figure A4. Monitoring the simulation

Figure A5 shows the dialog by which the user can select from the above options:

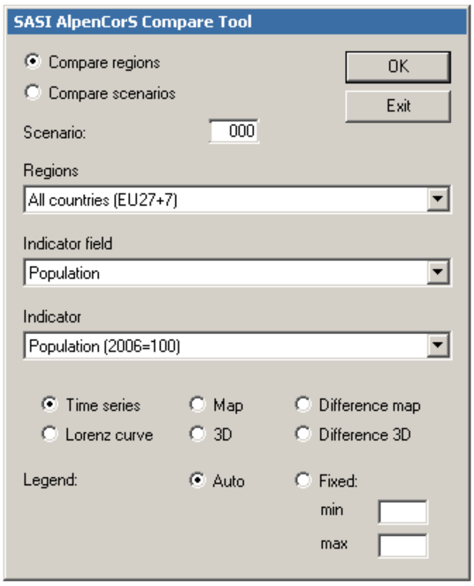

Figure A5. Comparison between regions/scenarios

The indicators that can be displayed are the output indicators from the fields of Population, Economy and Attractiveness listed in Section 7. In addition to selecting the indicator and display mode, the user can choose either automatic definition of legend classes or enter fixed minimum and maximum class boundaries.

Maps and 3D surfaces are displayed for all years between 1981 and 2031. Because at the time of execution of the <compare> program the results of the simulation are already there, the displays change fast and so can serve as animation.

Figure A6 shows examples of output of the basic mode of <compare> from the AlpenCorS project (Spiekermann and Wegener, 2005a). The time-series diagram is similar to the one produced during monitoring. The mapping sub-program has two additional features. After showing the map of the whole of Europe, a enlarged map of the specific study area of the project with NUTS-3, NUTS-2, NUTS-1 and NUTS-0 boundaries displayed.

In addition, the user can right-click on any point in the map to evoke an annotation box with region code and indicator values of the NUTS-3 region pointed at. In the example, NUTS-3 region Trento (IT312) was selected. The 3D surface is again similar to the one produced during monitoring, but now the user can experiment with different class boundaries.

Figure A7 shows examples of the 'Compare regions' mode of the <compare> program, again from the AlpenCors project. The two maps and the 3D surface show the difference (in percent) between Scenario AS1 of AlpenCors, the Brenner Tunnel scenario, with the Reference Scenario 000, in which it was assumed that the Brenner Tunnel will not be built.

It can be seen that the positive economic effects of the tunnel would radiate out in northern and southern direction across the Europe, whereas the regions east and west of this corridor are only little affected – negatively, as the indicator shown is scaled to the pan-European average.

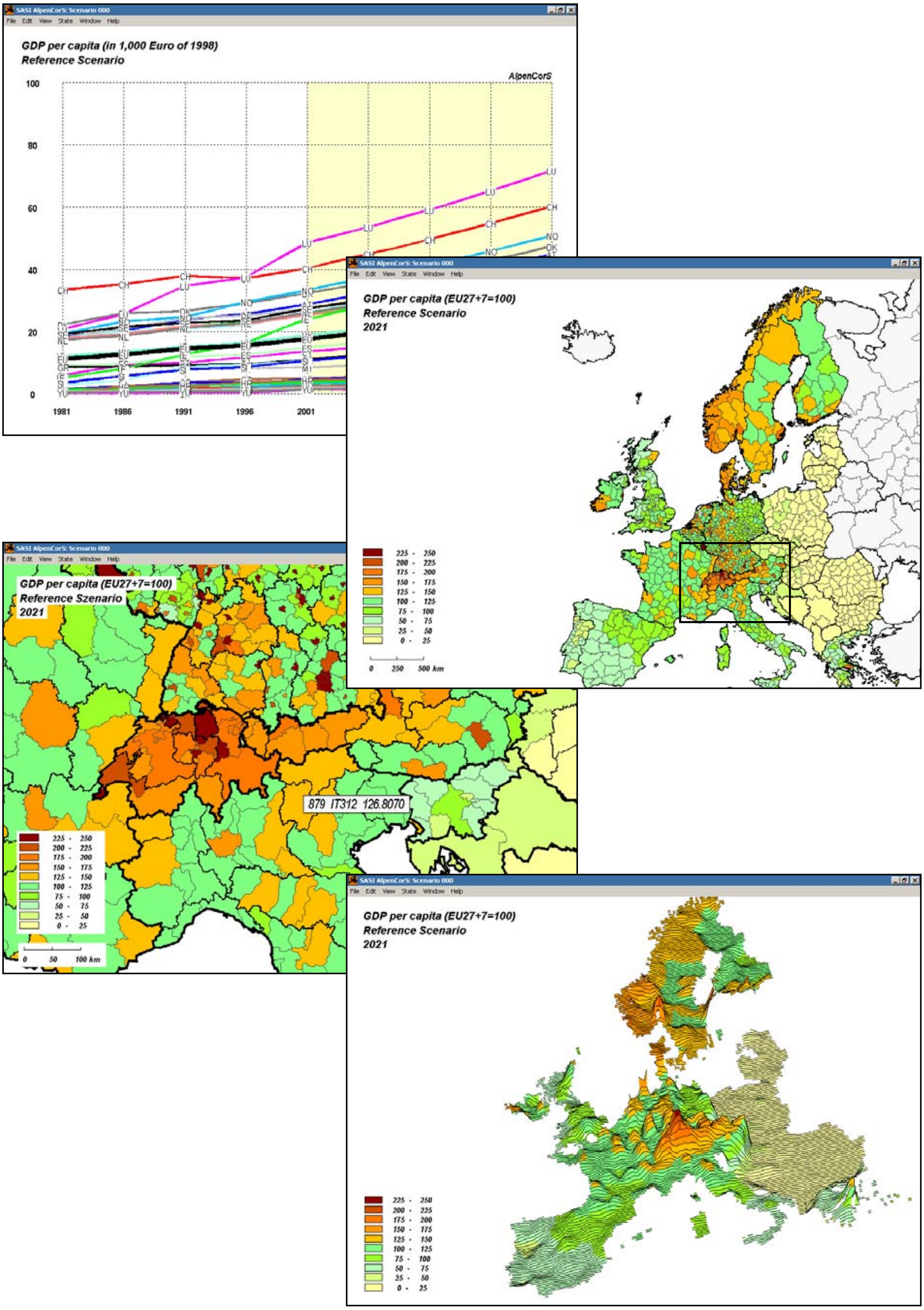

Figure A6. Comparison of regions

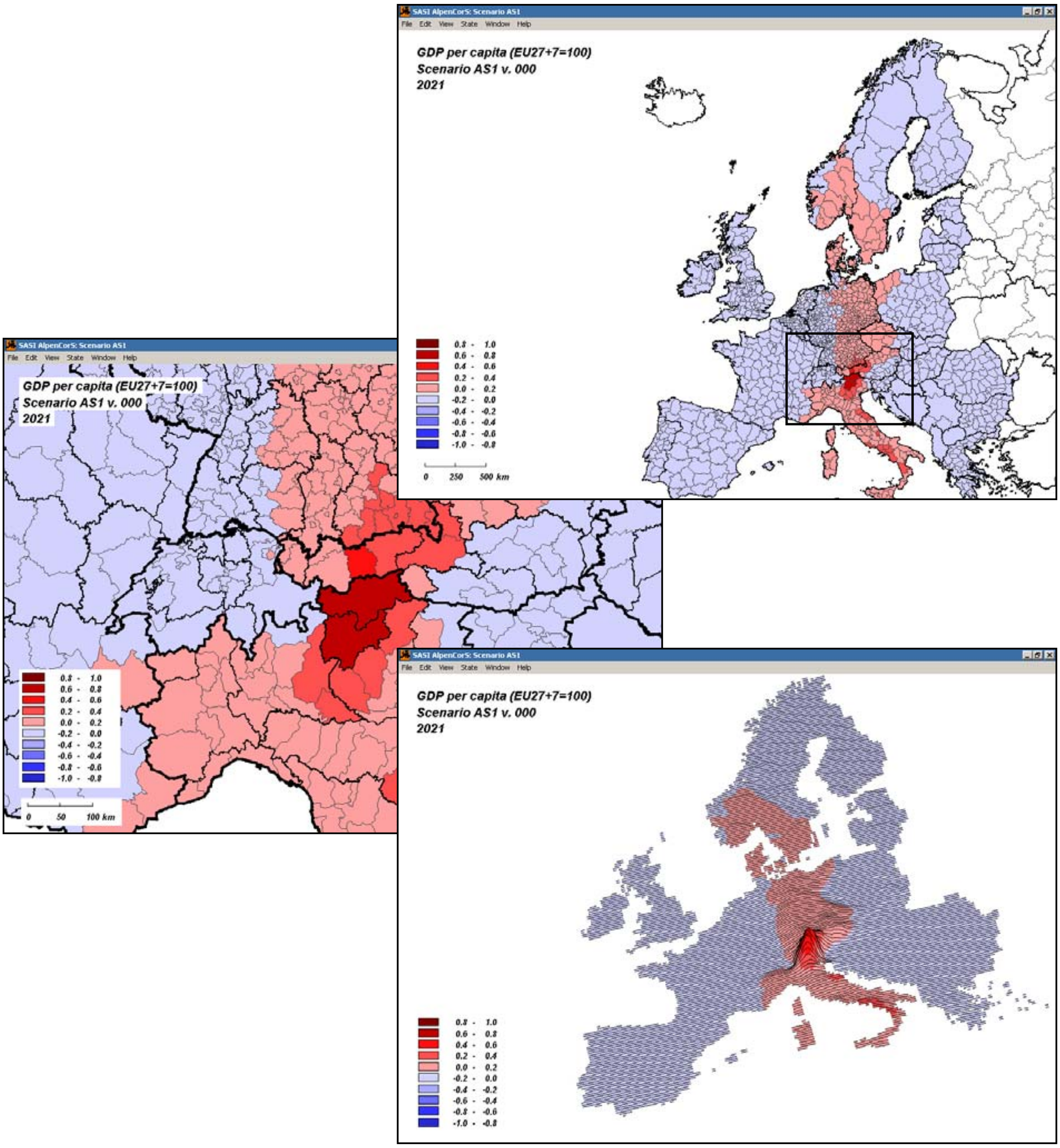

Figure A7. Comparison of scenario with reference scenario

Figure A8 shows examples of the 'Compare scenarios' mode of <compare> taken from the STEPs project (STEPs, 2006; Fiorello et al., 2006). The two time-series diagrams show the development of accessibility and GDP per capita between 1981 and 2031 for the fifteen scenarios examined in STEPs. Each of the scenarios represents one combination of energy price increase assumptions and related policy responses. Until 2006, the trajectories of all scenaries are identical as the price increases and policy responses come into effect only aftef that year.

It can be seen that energy price increases have significant negative effects on accessibility, but that these effects translate only into relatively small reductions in economic growth.

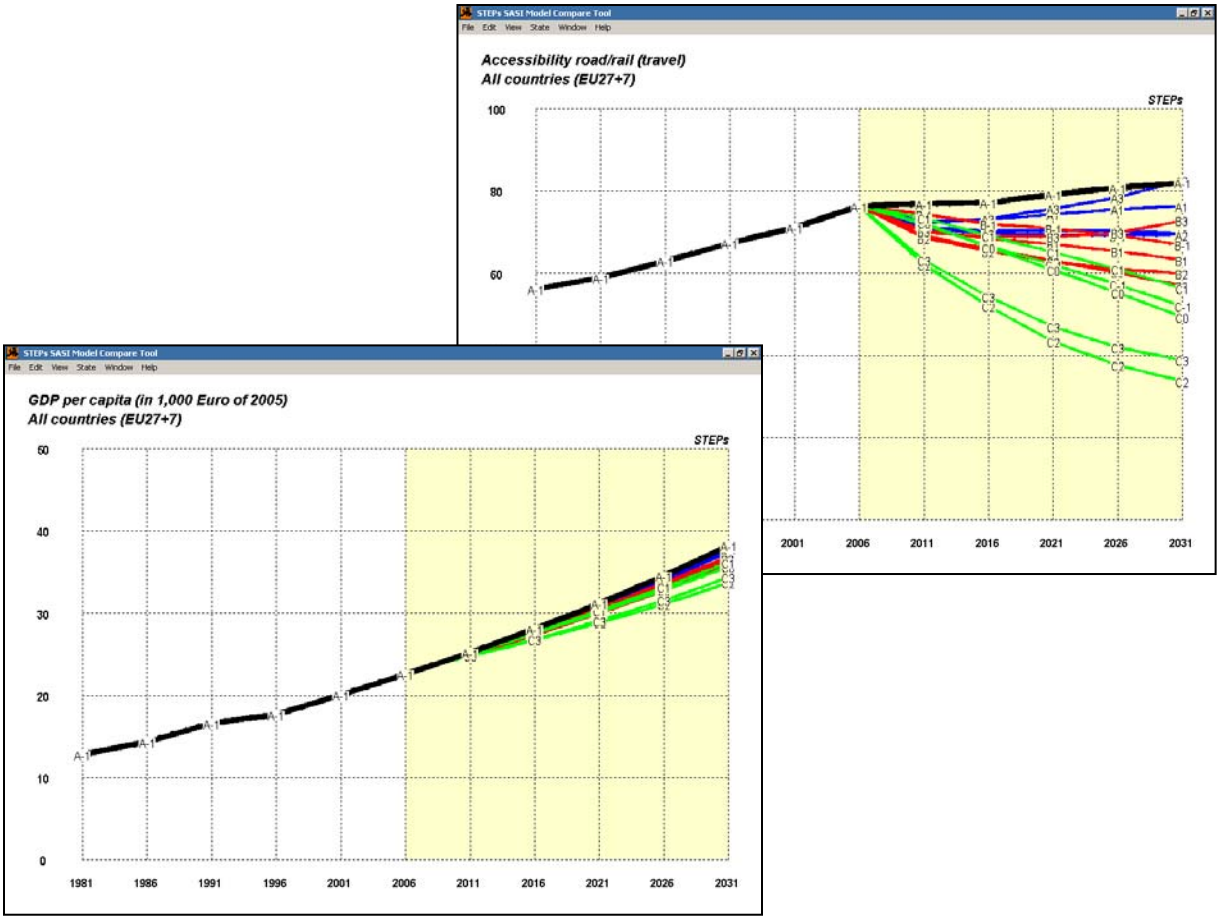

Figure A8. Comparison between multiple scenarios

A4. High-resolution graphics

In addition to the screen-oriented presentation of the simulation results discussed so far, the <compare> program may output all displays in a common vector graphics format (.wpg). These graphics files may be processed with any graphics software and edited, enhanced, annotated and saved in any desired resolution for high-quality printed output.

As only one example of this process, the following page contains snapshots in ten-year intervals of multimodal accessibility in Europe between 1981 and 2031 as high-resolution bitmaps produced from vector graphics

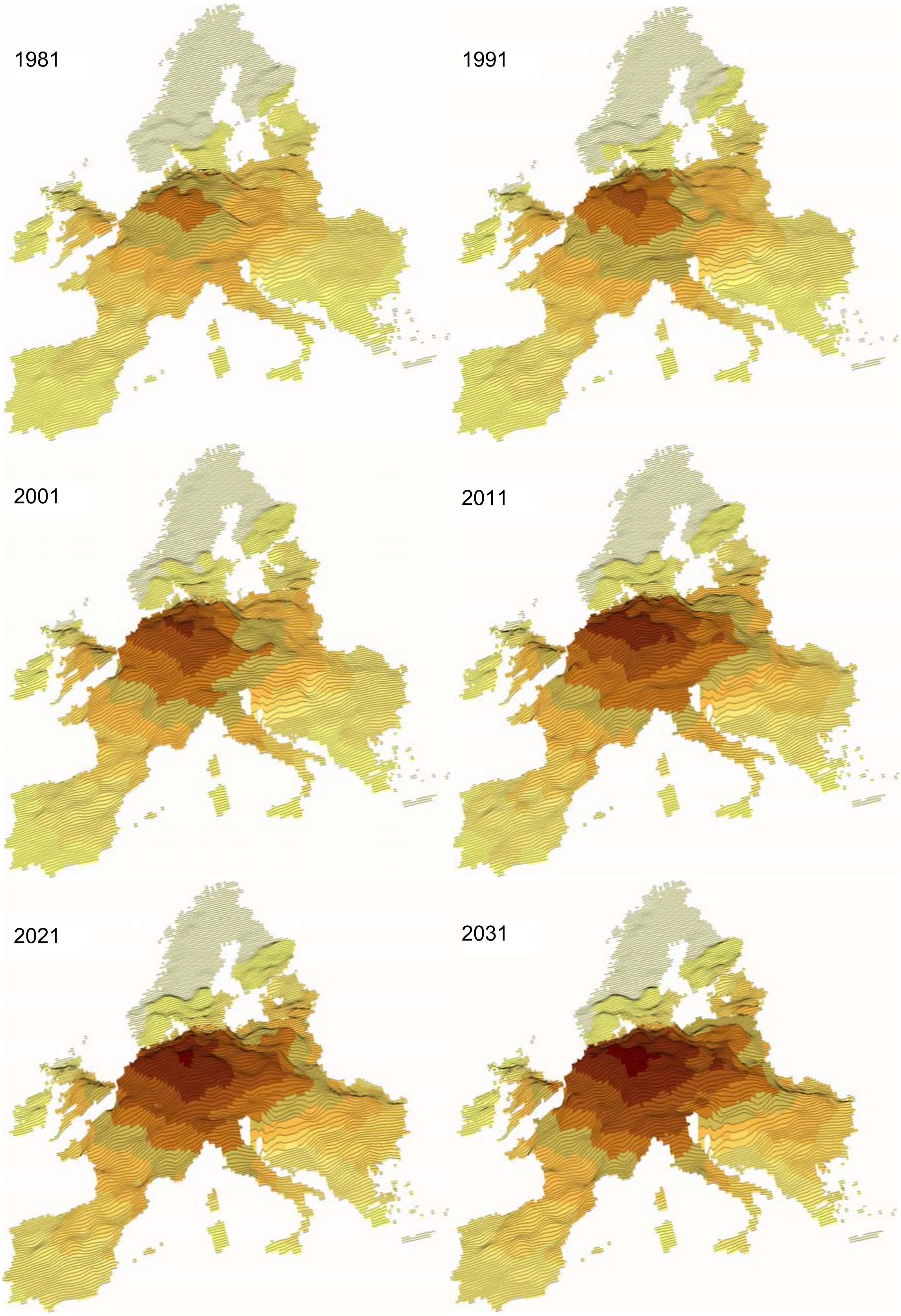

Figure A9. Multimodal accessibility 1981-2031