

Modelling Urban Sustainability

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Abstract

The objective of the EU research project PROPOLIS (Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability) is to assess urban strategies and to demonstrate their long-term effect in European cities. To reach this goal, a comprehensive framework of methodologies including integrated land use, transport and environmental models as well as indicator, evaluation and presentation systems has been developed.

Sustainable development is viewed as comprising the environmental, socio-cultural and economic dimension. Thirty-five key indicators were defined to measure the three dimensions of sustainability, such as air pollution, consumption of natural resources, quality of open space, population exposure to air pollution and noise, equity and opportunities and economic benefits from transport and land use.

Indicator values are derived from state-of-the-art urban land use and transport models. A number of additional modules, including a justice evaluation module, an economic evaluation module and a GIS-based raster module, were developed and integrated to provide further indicator values. Both multicriteria and cost-benefit analysis methods are used to consistently evaluate the impacts of the policies. The environmental and social dimensions of sustainability are measured using multicriteria analysis for the evaluation of the indicators, whereas cost-benefit analysis is used for the economic dimension. The modelling and evaluation system is currently being implemented in seven European urban regions: Bilbao (Spain), Brussels (Belgium), Dortmund (Germany), Helsinki (Finland), Inverness (Scotland), Naples (Italy) and Vicenza (Italy).

A large number of policies are being tested with the modelling and evaluation system in the seven urban regions. Policies investigated are land use policies, transport infrastructure policies, transport regulation and pricing policies and combinations of these. Besides a common set of policies examined in all seven urban regions, also city-specific local policies are being assessed in each urban region.

The first part of the paper introduces the methodology and the model system developed. The second part presents first results of the policy testing and evaluation. The paper concludes with reflections on how successful strategies to enhance the long-term sustainability of urban regions can be developed.

1. Introduction

The notion of each generation's duty to its successors is at the heart of the concept of sustainable development and was captured by the Brundtland Commission (WCED, 1987) in its report 'Our Common Future', which defined sustainable development as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs." Many definitions have followed that of the Brundtland Commission. For example, Daly (1991) defines sustainable development as one that satisfies three basic conditions: (1) its rates of use of renewable resource do not exceed their rates of regeneration; (2) its rates of use of non-renewable resources do not exceed the rate at which sustainable renewable substitutes are developed; and (3) its rates of pollution do not exceed the assimilative capacity of the environment.

However, many definitions of sustainability are broader in concept and seek to extend the definition beyond environmental considerations and include issues of social equity and justice. Different weight is often also given to the importance of economic growth. For instance, the 'Charter of European Cities and Towns Towards Sustainability' states that the main basis for sustainable development is "to achieve social justice, sustainable economies, and environmental sustainability. Social justice will necessarily have to be based on economic sustainability and equity, which require environmental sustainability" (ICLEI, 1994).

In the sustainability discussion, often a distinction is drawn between major environmental threats to human life on the planet earth on the one hand and local concerns, which are more amenable to trade-offs on the other. In this discussion, cities and urban regions play an important role. Cities contribute to a large extent to global environmental problems, but at the same time people living in cities are confronted with environmental damage, pollution, health and social and economic problems.

Consequently, goals to make cities more sustainable have been formulated (e.g. European Environment Agency, 1995):

- minimising the consumption of space and natural resources,
- rationalising and efficiently managing urban flows,
- protecting the health of the urban population,
- ensuring equal access to resources and services,
- maintaining cultural and social diversity.

Also, different policies, including transport, land use, regulatory, investment, fiscal and pricing policies to improve the urban situation have been designed and partly implemented. However, actual urban developments show that these policies have not been able to stop the decrease of sustainability of our cities. Even to maintain the existing level of sustainability will probably require the introduction of more radical policy measures. But such policies will not be implemented if their effects cannot be clearly demonstrated. Policies might have very different effects. Besides direct environmental, social or economic impacts many policy options may have negative side effects. Some policy options may work against each other, whereas some may reinforce each other. Some policy options may improve the situation in part of the region, whereas in other parts the situation may get worse. Hence, the design of policies to improve urban sustainability is anything else than a straightforward task. Because the direct and indirect, the short-term and long-term effects have to be identified and measured in a transparent way, this calls for advanced methods of policy impact assessment and policy evaluation.

To develop and implement such a system is the objective of the EU research project PROPOLIS (Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability). The goal is to assess urban strategies and to demonstrate their long-term effect in European cities with respect to sustainability. To reach this goal, a comprehensive framework of methodologies including integrated land use, transport and environmental modelling as well as indicator, evaluation and presentation systems have been developed.

PROPOLIS is part of the Key Action 'City of Tomorrow and Cultural Heritage' of the 5th Framework Programme for Research and Technology Development of the European Union. Project partners are IRPUD and S&W (Dortmund), LT (Helsinki), ME&P (Cambridge), MECSA (Bilbao), STRATEC (Brussels), TRT (Milan) and UCL (London).

The first part of this paper introduces the methodology and the model system developed. The second part presents typical results of the policy testing and evaluation. The paper concludes with reflections on how successful strategies to enhance the long-term sustainability of urban regions can be developed.

2. Indicators of Urban Sustainability

As definitions of sustainability have broadened in scope over time, the number of possible indicators has grown to an extent where virtually all aspects of life are covered. Consequently, a vast number of sustainability indicator systems are in use today.

In PROPOLIS, sustainable development is viewed as comprising the environmental, socio-cultural and economic dimension. For the three components, key indicators have been identified by using a set of criteria:

- *Relevance.* The indicator should be relevant for describing important aspects of sustainability.
- *Representativeness.* In order to keep the indicator system manageable, not each suitable indicator can be included, the focus is on key indicators representing different domains of sustainability.
- *Policy sensitiveness.* Only indicators that are sensitive to the policies investigated are of interest.
- *Predictability.* There exist a large number of indicators suitable for monitoring but, as the objective is to model future policy impacts, it is essential that the indicator values can be forecast into the future by the model system.

The resulting PROPOLIS indicator system is presented in Table 1. To allow a structured evaluation, the three sustainability components are subdivided into themes. Then appropriate indicators are related to these themes.

Nine themes and thirty-five key indicators have been defined to measure the three dimensions of sustainability, such as greenhouse gas emissions, air pollution, consumption of natural resources, quality of open space, population exposure to air pollution and noise, equity and opportunities and economic benefits from transport. The present indicator list lacks indicators related to land use, such as greenhouse gas emissions, air pollution, noise, energy use or economic benefits. Some of these indicators are tested in individual case study cities, but it was outside the scope of PROPOLIS to implement these indicators in all case study cities.

Table 1 PROPOLIS indicator system

	Theme	Indicator
Environmental indicators	Global climate change	Greenhouse gases from transport
	Air pollution	Acidifying gases from transport Volatile organic compounds from transport
	Consumption of natural resources	Consumption of mineral oil products, transport Land coverage Need for additional new construction
	Environmental quality	Fragmentation of open space Quality of open space
Social indicators	Health	Exposure to PM from transport in the living environment Exposure to NO ₂ from transport in the living environment Exposure to traffic noise Traffic deaths Traffic injuries
	Equity	Justice of distribution of economic benefits Justice of exposure to PM Justice of exposure to NO ₂ Justice of exposure to noise Segregation
	Opportunities	Housing standard Vitality of city centre Vitality of surrounding region Productivity gain from land use
	Accessibility and traffic	Total time spent in traffic Level of service of public transport and slow modes Accessibility to city centre Accessibility to services Accessibility to open space
Economic indicators	Total net benefit from transport	Transport investment costs Transport user benefits Transport operator benefits Government benefits from transport Transport external accident costs Transport external emissions costs Transport external greenhouse gases costs Transport external noise costs

3. PROPOLIS Methodology

This chapter presents the main components of the PROPOLIS model system and shows how the policy testing and evaluation process is organised.

3.1 The PROPOLIS Model System

For a systematic evaluation of policies with respect to their long-term impacts on urban sustainability, a model system was designed in which different models and tools are integrated. Figure 1 illustrates the main components and data flows of the model system from input through behaviour and impact modelling to output in the form of indicators and their evaluation and presentation.

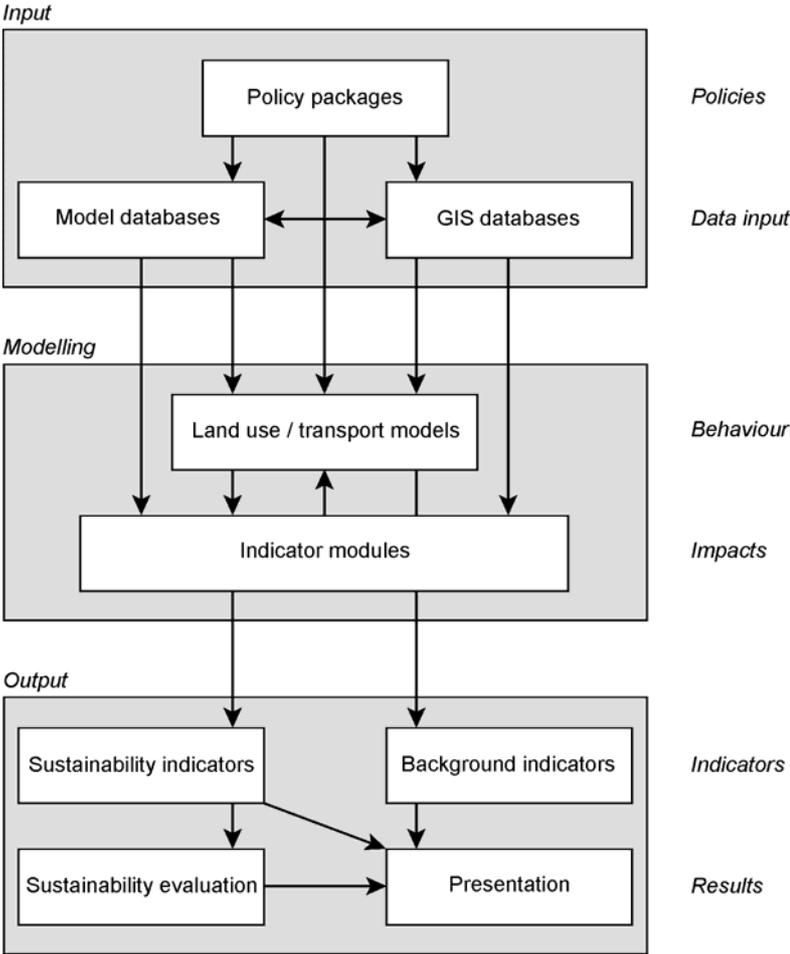


Figure 1 PROPOLIS model system

The *input data* include policy packages, GIS databases and model databases. Policy packages to be tested are transformed to 'model language' by changing some of the model parameters or model data. GIS databases contain georeferenced data of zone boundaries, transport networks, land use categories etc. in a geographic information system (GIS). All land-use transport models used are fully GIS-integrated, i.e. each model zone or model network link is represented in the GIS database.

In the *modelling part* the land-use transport models are the driving engines of the system. They have been previously calibrated to correspond to the observed behaviour in the test cities. The land-use transport models simulate the effects of policies on zonal activities, such as population or employment, and on mobility patterns, such as modal shares and link flows. The indicator modules receive the outputs of the land-use transport models and calculate the sustainability indicators.

The *output part* consists of sustainability indicator values which are further processed in the sustainability evaluation module. Other important information that helps to understand the behaviour of the system but is not used in the evaluation is stored as background variables. Examples for background variables are zonal population and employment, modal shares, car-km travelled etc. A web-based presentation tool shows the results of each policy in a standard form for comparisons between policies and between cities.

The Land-Use Transport Models

The PROPOLIS model system is implemented in seven European urban regions: Bilbao (Spain), Brussels (Belgium), Dortmund (Germany), Helsinki (Finland), Inverness (United Kingdom), Naples (Italy) and Vicenza (Italy). For each region an operational land-use transport model existed before the project. Table 2 presents the seven urban regions, their land-use transport models and their zoning systems. Figure 2 shows their location.

Table 2 Case city regions and land-use transport models

Case city	Bilbao	Brussels	Dortmund	Helsinki	Inverness	Naples	Vicenza
Area (km ²)	2,217	4,332	2,014	764	4,152	1,171	2,722
Population (1,000)	1,140	2,841	2,516	946	132	3,099	787
Density (inh/km ²)	514	656	1,249	1,238	32	2,647	289
Average household size	3.2	2.7	2.1	2.1	2.8	3.1	2.7
Unemployment rate	25.0 %	11.0 %	12.6 %	6.0 %	8.1 %	27.8 %	2.8 %
Income/inh/month (Euro)	750	713	1,570	1,100	n.a.	695	1,079
Cars/1,000 inh	418	461	492	345	332	526	591
Land-use transport model	MEPLAN	TRANUS	IRPUD	MEPLAN	TRANUS	MEPLAN	MEPLAN
Land use zones	111	139	246	173	153	179	102
Transport zones	111	139	246	173	153	39	27

The seven case study regions differ in many respects. Their sizes range from 130,000 to over three million inhabitants. Some have experienced strong growth while others are old declining cities, sometimes in the process of restructuring. Some have high, some very low unemployment rates. Income per person and car ownership differ considerably. The spatial structures range from highly compact and centralised to dispersed or polycentric patterns. With different conditions of transport supply, the modal shares vary significantly, however, car travel is always dominant.



Figure 2 PROPOLIS case study regions

The models applied belong to three different types of urban land-use transport model: the MEPLAN model (Hunt, 1994; Martino and Maffii, 1999; Williams, 1994) is implemented in four urban regions, the TRANUS model (de la Barra, 1989) in two and the IRPUD model (Wegener, 1996; 1998; 1999) in one. The models simulate the effects of policies on the location behaviour of households and firms and on the resulting mobility patterns in the case study regions. Common base year of the models is 1996, the final forecast year is 2021.

Output of the land-use transport models is provided in a common data format for a pre-defined set of variables. Because the models are implemented in very different ways, harmonisation of the model outputs is necessary. The harmonisation is performed by aggregation to the 'lowest common denominator'. This means that the land-use transport models work with as much detail as they were implemented and that subsequent stages of the model system work with less detail but with a common set of variables in order to allow comparisons between cities. Socio-economic groups are aggregated to three types, employment sectors to four types, land and floorspace to three types, trips to five types, transport modes to five types and transport links to ten types.

The Indicator Modules

The indicator modules calculate the sustainability indicators. They post-process the output of the land-use transport models. Four indicator modules are implemented in the system: the *Raster Module*, the *Economic Indicator Module*, the *Justice Indicator Module* and the *Other Sustainability Indicator Module*. The output of the indicator modules are values of the sustainability indicators listed in Table 1.

The *Raster Module* calculates indicators for which a disaggregate treatment of space is required. The land-use transport models are not directly capable of capturing important aspects of urban sustainability because their zone-based spatial resolution is too coarse to represent other environmental phenomena than total resource use, total energy consumption or total CO₂ emissions. In particular emission-concentration algorithms such as air dispersion, noise propagation, but also land coverage, landscape fragmentation or the exposure of population to pollutants and noise, require a much higher spatial resolution than large zones. In all cases, the information needed is configurational. This implies that not only the attributes of the components of the modelled system such as quantity or cost are of interest but also their

physical *micro locations*. This is where the Raster Module comes into play. It maintains the zonal organisation of the aggregate land-use transport model but complements it by a disaggregate representation of space in 100 x 100 m raster cells for the calculation of local environmental and social impacts of policies (Spiekermann, 1999; 2003; Spiekermann and Wegener, 1999; 2000). The Raster Module calculates most environmental indicators, the exposure indicators and an indicator of accessibility to open space. In addition the Raster Module feeds the Economic Indicator Module with information on emission and noise exposure and the Justice Indicator Module with information on exposure of different socio-economic groups to air pollution and noise.

The *Economic Indicator Module* performs a cost benefit analysis of the transport sector. Single indicators address transport investment costs, user, operator and governmental benefits as well as external costs of transport. In addition the module provides an indicator describing the efficiency of the urban system measured on the basis of variables, such as the size of the city, the speed at which people and goods are moved in the city and the sprawl of jobs and home following Prud'homme and Chang-Woon (1999).

The *Justice Indicator Module* addresses equity implications of the investigated policies. It translates the percent of people of different socio-economic groups who are exposed to air pollution and traffic noise into equity indicators. Four different theories of justice are incorporated in the module: the equal-shares principle, the utilitarian principle, the egalitarian principle and the Rawlsian difference principle.

The *Other Sustainability Indicator Module* calculates a small set of indicators which is not covered by the previous modules but may of general interest for understanding the behaviour of the urban system, such as zonal population and employment, modal shares and car-km travelled.

The Evaluation and Presentation Modules

Finally, the indicators are evaluated by a multicriteria evaluation tool and are analysed and presented in a harmonised way for comparisons between policies and between cities.

The multicriteria evaluation tool *USE-IT* determines the sustainability of policies with respect to environmental, social and economic sustainability. It calculates the contribution of each indicator to sustainability and aggregates them to the sustainability themes and components defined in Table 1.

Value functions are used to transform the indicator values to a scale from zero to one by taking existing target values into account. Indicators are given weights for aggregation to indices. The weights are the outcome of an internal expert survey performed to determine a common set of weights for all case study cities. In addition, local value systems are explored to determine weights in the local contexts. Indices are formed as weighted averages of the evaluated indicators. Aggregation is performed separately for the environmental, social and economic components of sustainability. A single index aggregating the three components is not calculated to avoid double-counting, because some aspects are considered in more than one component, i.e. are treated from different viewpoints.

An Internet-based *Analysis and Presentation Tool* presents the results of the policy testing for all cities in a standardised format. The tool analyses and displays sustainability indicators and background variables for comparison between policies and between cities. The Internet tool is designed to be used by planners and policy makers in the case study regions to make it easier for them to understand the impacts of policy decisions and so aid them in the process of selecting the most appropriate policy measures.

3.2 Implementation and Policy Testing

The PROPOLIS model system is currently being implemented in the seven European urban regions. Figure 3 shows how the system is used to define strategies that increase urban sustainability. The model system is the core of the policy analysis. First single policies are defined and introduced into the system. Policies include land use, transport, pricing and regulatory and investment policies. The evaluation of policies and the comparison between policies and between cities may lead to a reformulation of policies ('Replanning'). Replanning includes the refinement of policies, e.g. finding an optimal level of a pricing policy, but also experimenting with policy combinations to improve the results. The final output of the systematic policy tests are general and city-specific recommendations which policies or combinations of policies are likely to contribute most to sustainable development.

There are various points in the system at which planners and policy makers in the case study regions may intervene and introduce their ideas and values into the modelling and evaluation process. They may contribute to the formulation of the assumptions about external developments for the models, such as assumptions about the likely overall economic development of the region or about migration flows across the regions' borders. Or they may want to test the impacts of alternative assumptions about external developments. An important task of the local partners is to contribute to the formulation of strategies and policies common for all case study cities or specific to their regions. Finally, the local experts are asked to indicate their values, i.e. enter their own weights into the evaluation system.

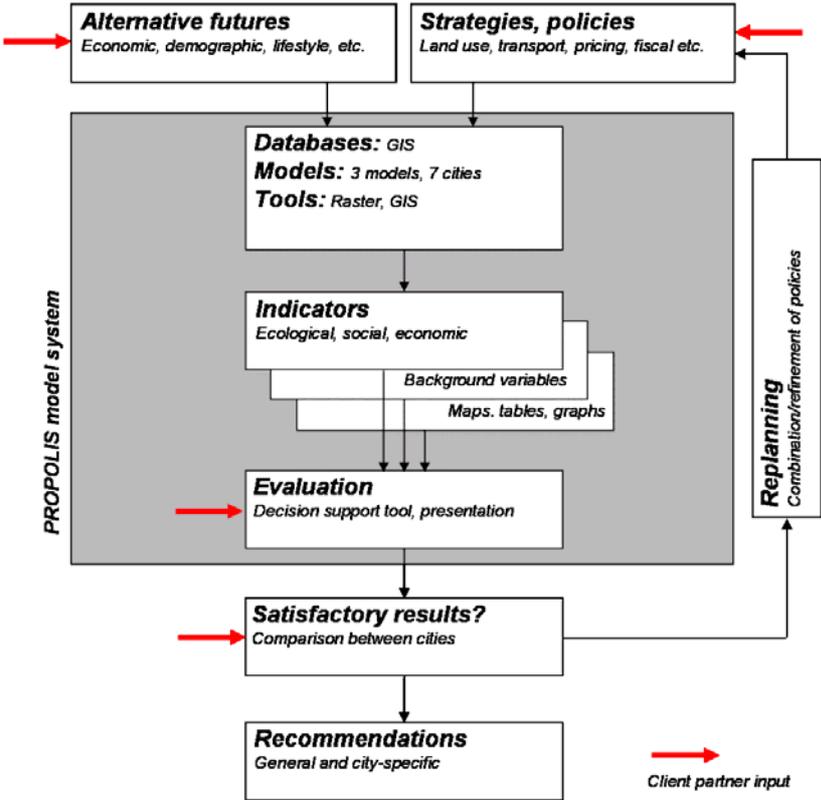


Figure 3 Policy testing process

4. Typical Results

The PROPOLIS project is still ongoing and will be completed in mid-2003. Policy testing and analysis has started but has not yet been completed. In this section typical preliminary results of the modelling work for the Dortmund case study region are presented. The first part will discuss typical output indicator of the land-use transport model, the second will focus on some key sustainability indicators calculated with the tools introduced in Section 3.1.

The Dortmund case study region is the urban region of Dortmund consisting of the city of Dortmund and its 25 surrounding municipalities. The region is subdivided into 246 statistical areas or zones. However, as it was explained in Section 3.1, the spatial resolution of 246 zones is not sufficient for the simulation of environmental impacts, such as air quality and traffic noise. Therefore the zone-based and link-based results of the land-use transport model are disaggregated to raster cells by the *Raster Module* (see Section 3.1). Raster cells of 100 x 100 m size are used to model environmental impacts. In total, about 207,000 raster cells cover the study area. The same spatial reference system will be used in a microsimulation model currently developed for the Dortmund region (see Möckel et al., this issue).

4.1 Land-Use Transport Model Indicators

Figures 4 to 6 show selected results of altogether 22 policy scenarios modelled in PROPOLIS. The policy scenarios included, besides local infrastructure improvement policies specific for each case study city, policies for car pricing, speed limits, public transport and land use as well as policy packages consisting of several land use and transport policies combined. All policy scenarios are compared with a reference or base scenario, in which no policy changes are assumed after the year 2001. All policies in the policy scenarios start after 2001, i.e. all policy scenarios are identical with the reference scenario until that year.

Each of the three diagrams shows trajectories for one system variable between the base year 1970 and the target year 2030. Each line in the diagrams corresponds to one policy scenario. The heavy line represents the development of the variable in the reference or base scenario 000. After the year 2000, the lines representing the policy scenarios diverge from the line of the reference scenario; the numbers attached to each line is the scenario number. The policies modelled in each policy scenario are listed in short form on the diagram.

Figure 4 shows the development of mean travel cost per trip in the scenarios. The increase in mean travel cost in the reference scenario is the combined effect of inflation, increasing fuel costs and public transport fares, longer distances travelled and growing fuel efficiency of cars (see Figure 4). The differences in mean travel cost between the scenarios and the reference scenario are indicate the effect of the pricing policies. There is only one scenario, scenario 421, in which mean travel costs are lower than in the reference scenario, whereas in all other scenarios they are higher. The highest increases are shown in scenarios 213 and 218, in which significant increases of fuel taxes are assumed.

Figure 5 shows the development of mean trip lengths. In the reference scenario mean trip lengths increase from under 10 to about 15 km between 1970 and 2030. This is the combined result of growing affluence, decentralisation of population through suburbanisation and only moderate increases of fuel prices, which have in effect made fuel less expensive in real terms during the forecasting period. The differences between the policy scenarios and the reference scenario are as expected. Scenario 421, in which travel by public transport is made less expensive, longer trips are made – something not always expected by proponents of subsidisation of public transport. All other scenarios result in shorter average trip lengths, which is in line with economic theory.

Mean travel cost (Euro)

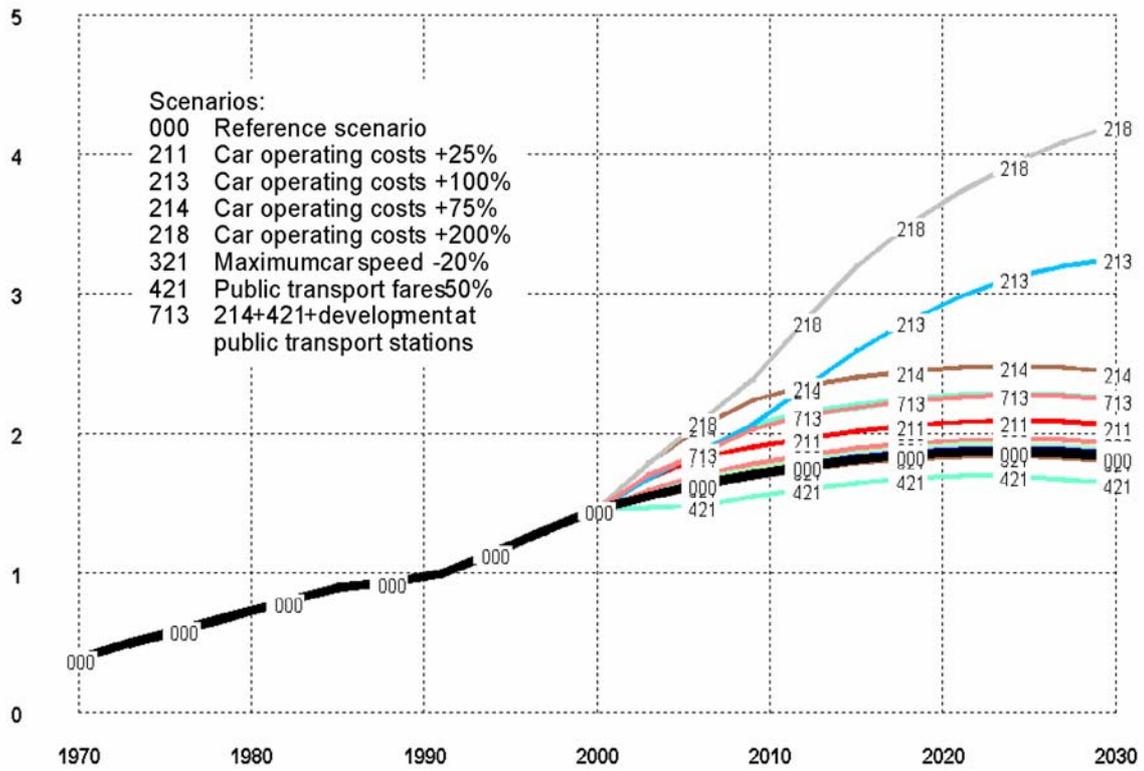


Figure 4 Scenario results: mean travel cost

Mean trip length (km)

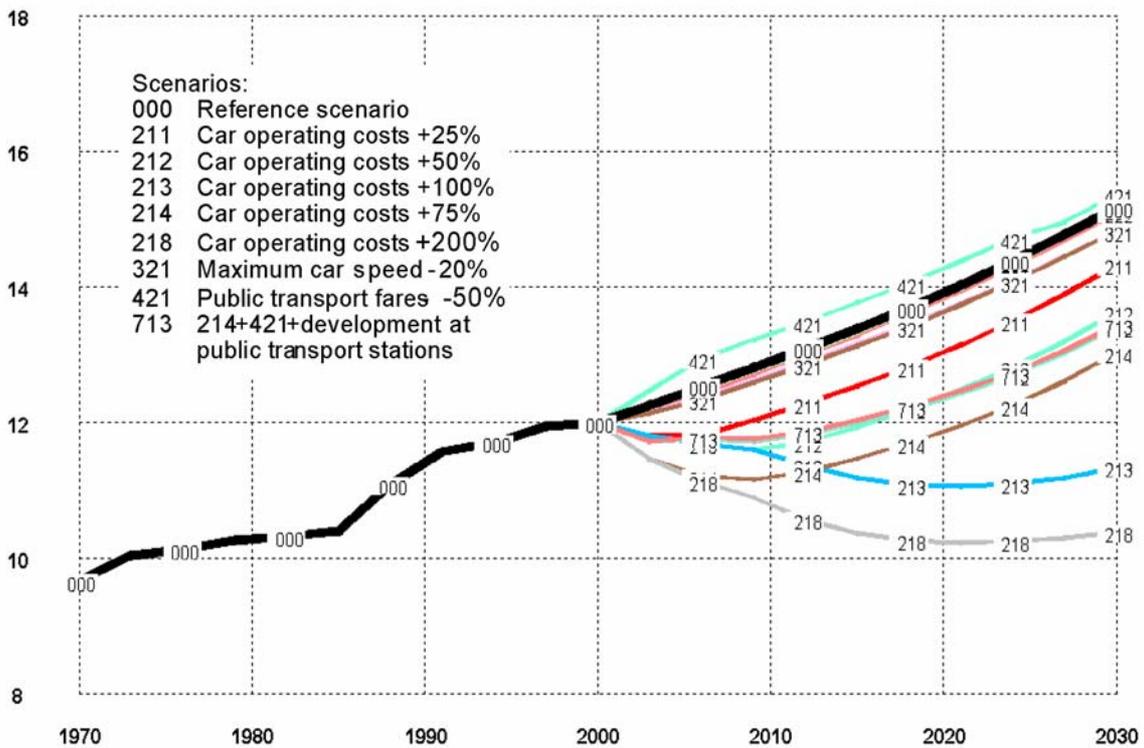


Figure 5 Scenario results: mean trip length

A similar picture emerges if only car km are considered. Figure 6 shows that only car pricing policies have a significant effect on car distances travelled. All other policy types, including the land use policies have only insignificant effects.

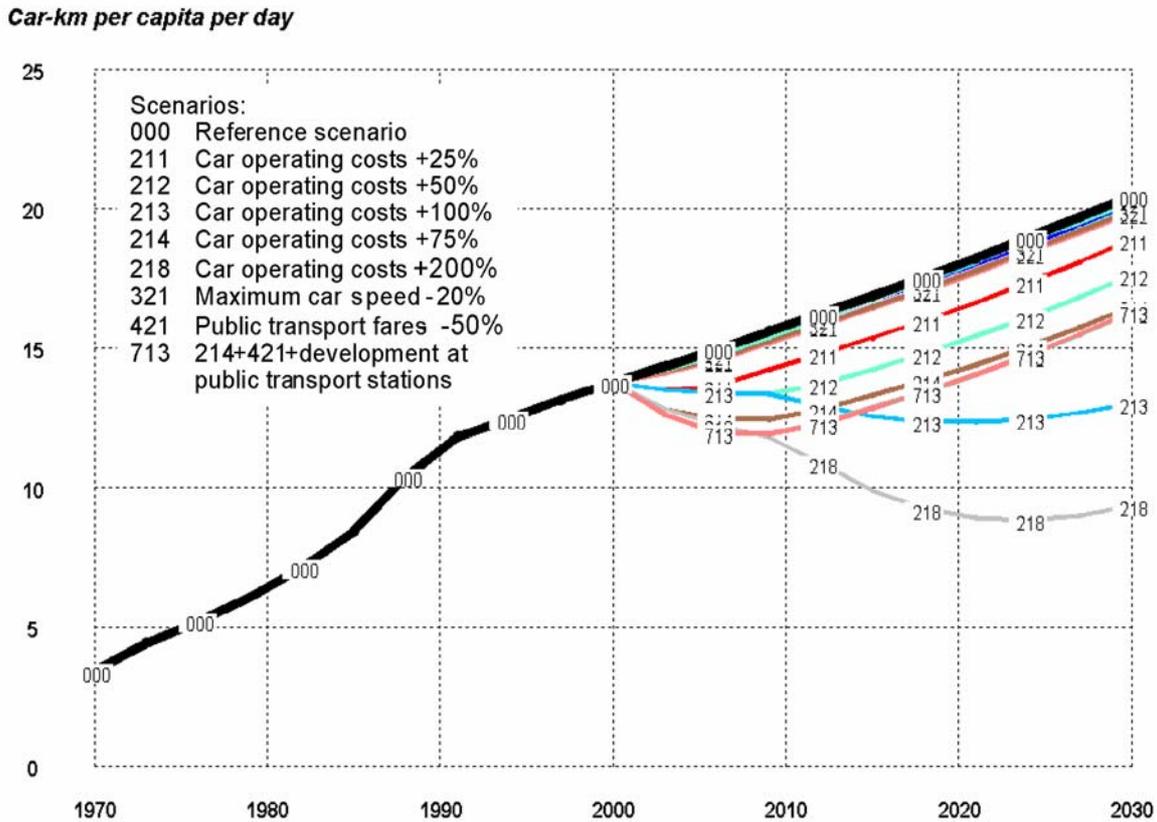


Figure 6 Scenario results: car km

4.2 Sustainability Indicators

The land-use transport models predict long term changes in the urban land use and transport system. The indicator modules (see Figure 1) use the output of the land-use transport models (zone data and link flows), disaggregate it to raster cells using GIS information and produce the sustainability indicators. If the land-use transport model results are translated into sustainability effects the same overall picture with respect to the policy impacts holds true.

Only making car travel more expensive, significant reductions in greenhouse gas emissions can be expected (Figure 7). However, the diagram also shows that equally important are efforts to make cars more energy efficient: the decline in CO₂ emissions after 2000 in the reference scenario is due to the assumptions about growing energy efficient car technology built into all of the scenarios.

Figures 8 to 11 show examples of raster-based output of environmental and social indicators in the Dortmund urban region for the year 2021 for the base scenario 000.

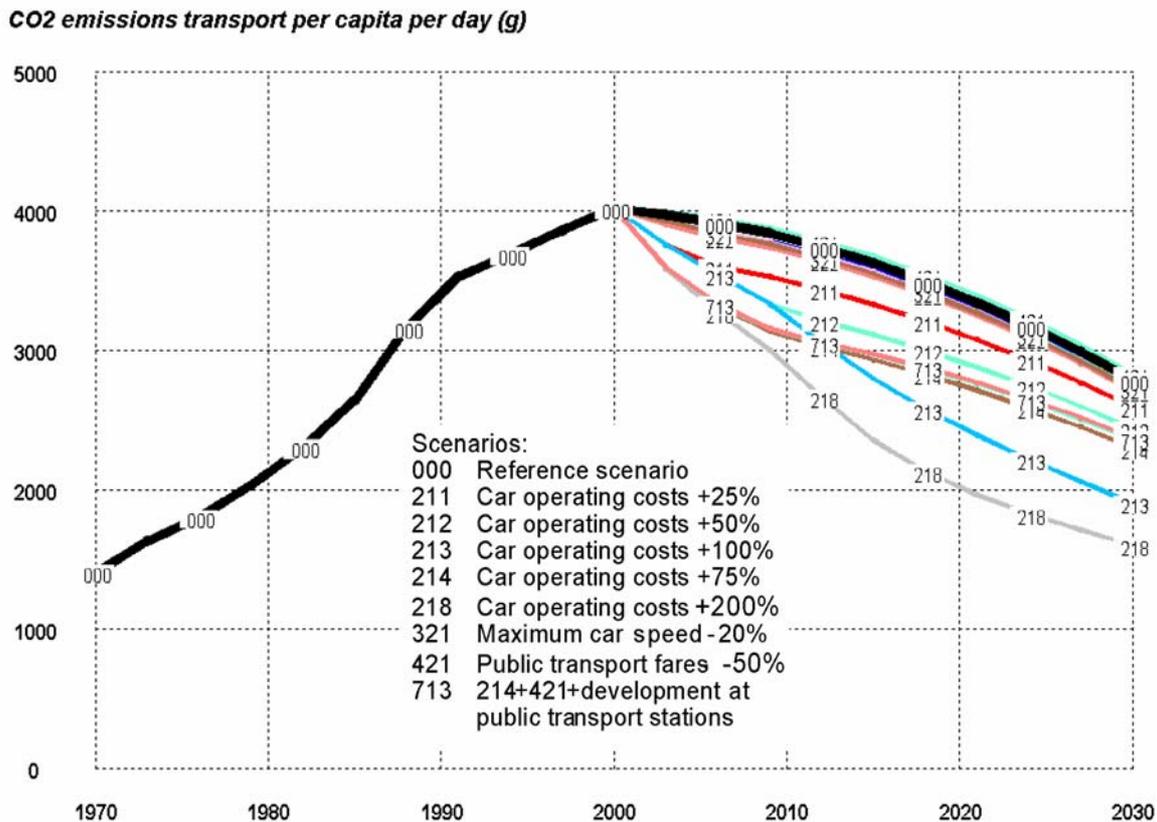


Figure 7 Scenario results: CO₂ emissions by transport

Figure 8 shows a forecast of air quality in the Dortmund urban region as it would result in the reference scenario. Based on a forecast of number and type of vehicles on the links of the road network, emission functions are used to determine the volume of pollutants, in this case of NO₂, emitted along the links. An air distribution model is used to forecast the dispersion of the pollutant on adjacent areas – the predominant south-west wind direction in the Dortmund area is clearly visible. As also population by socio-economic group is disaggregated to raster cells, it is possible to calculate how many people in each neighbourhood and in each socio-economic group are exposed to this type of air pollution. This information is used for the health and equity indicators in the system of indicators (see Table 1).

Figure 9 shows exposure to traffic noise. Again link loads by vehicle type are used to calculate traffic noise emissions along links. A noise propagation model is used to calculate the dispersion of noise on both sides of the links. To take into account that buildings along the roadways act as noise barriers, assumptions about the reduction of noise propagation in areas of higher density are made. As with air quality, exposure to noise can be related to residences of population by socio-economic group and used in the health and equity evaluations.

Figure 10 is a raster-based representation of open space, i.e. all land that is neither built-up area nor a transport link. In the map the traffic noise corridors of Figure 7 are overlaid with the open space. Red raster cells are disturbed by traffic noise, green areas are not. It is assumed that only the remaining open space, which is not disturbed by traffic noise, is of value for recreation and can therefore serve as an indicator of the quality of open space in a zone.

Figure 11 shows accessibility to open space. The indicator is calculated by a potential accessibility model using open space as mass term and walking distance as impedance. The average accessibility to open space is influenced in the different scenarios by settlement activities, by infrastructure development and by movement of households.

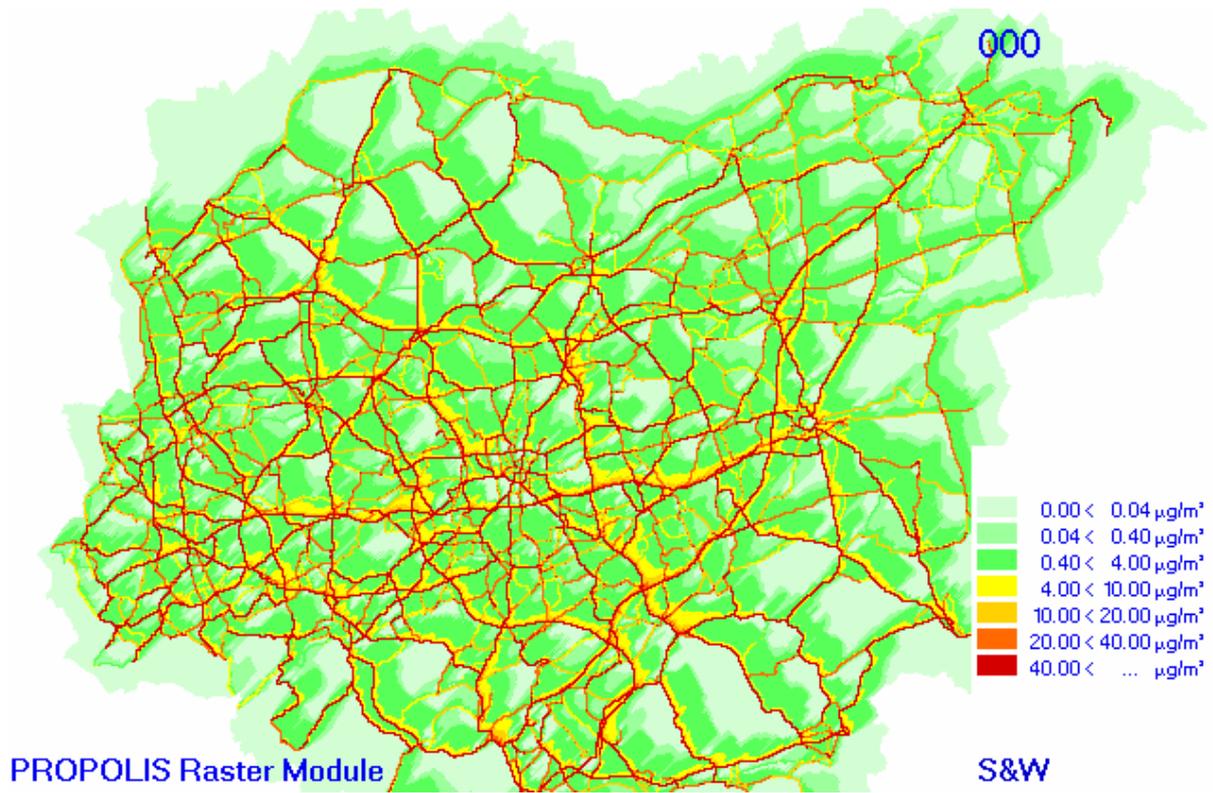


Figure 8 Air quality in the Dortmund region

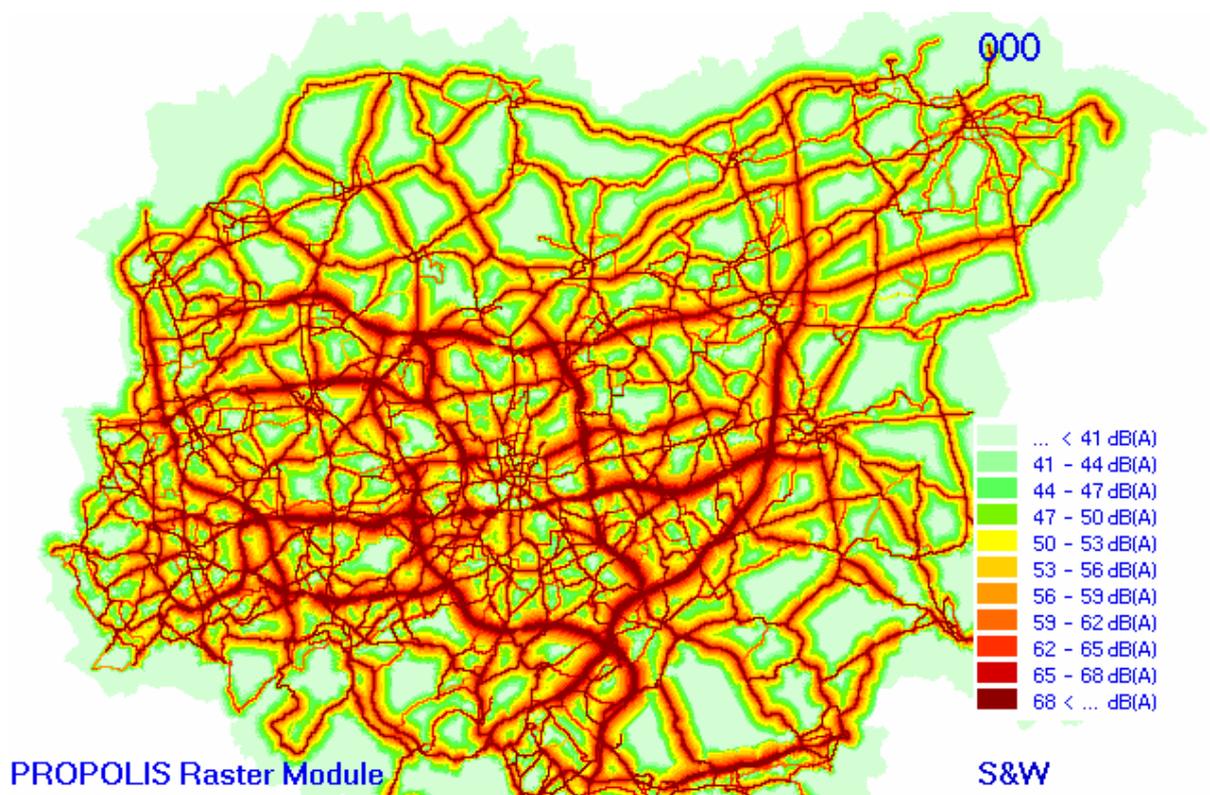


Figure 9 Traffic noise in the Dortmund region

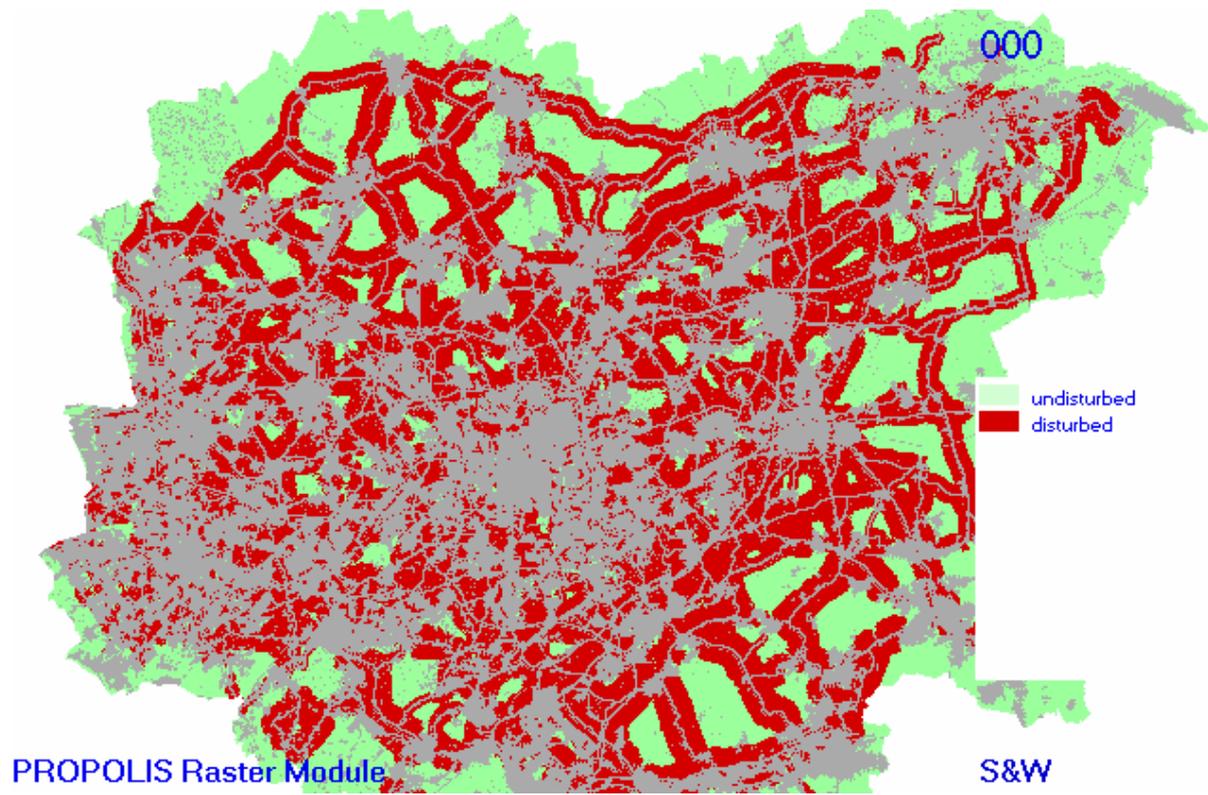


Figure 10 Quality of open space in the Dortmund region

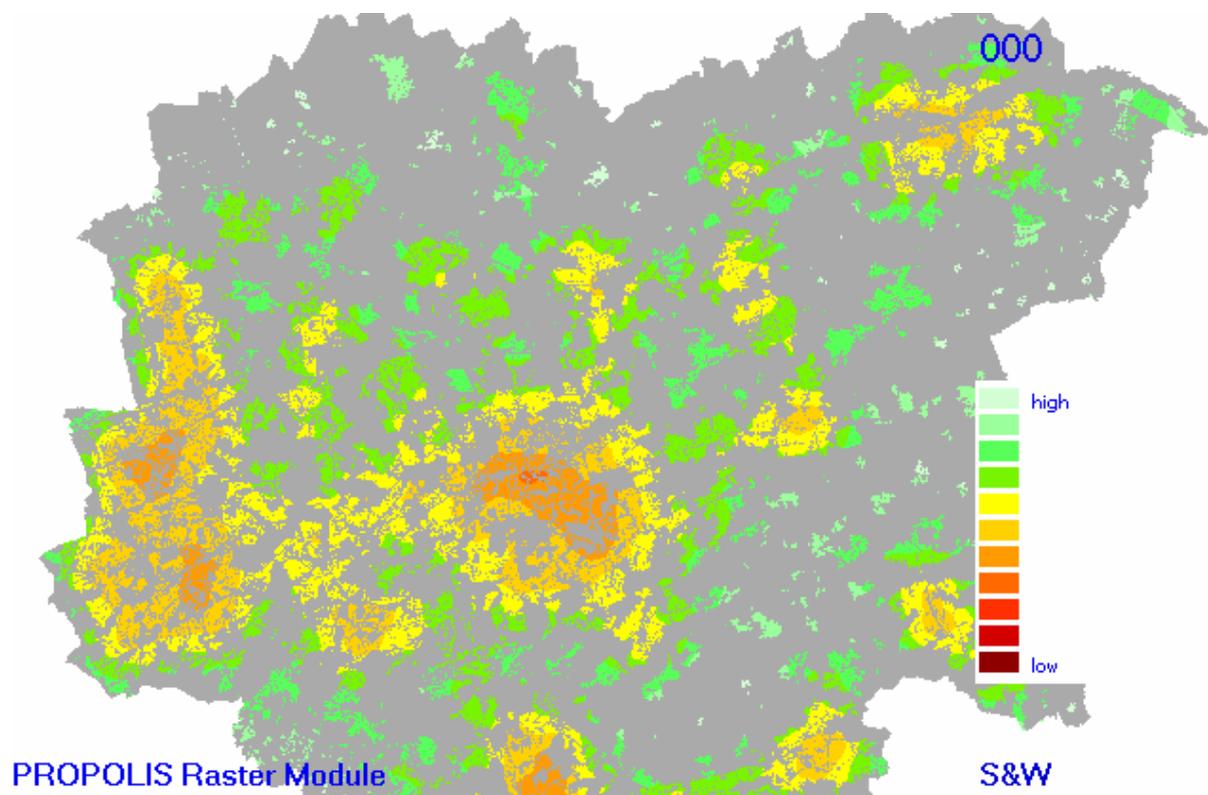


Figure 11 Accessibility to open space in the Dortmund region

The maps presented are used as means to understand the spatial distribution of effects of a certain policy. For the policy evaluation, the indicator numbers are used. Table 3 presents for selected sustainability indicators the outcome of the selected policies presented in the previous sections. Emission of air pollutants will clearly go down in all scenarios because of new emission standards for new vehicles replacing old ones assumed already in the base scenario. The increase in car operating costs will result in even lower numbers of population exposed to air pollution and traffic noise. However, most significant effects can only be achieved by a clear increase in costs as in Scenario 218. Quality of open space and also the accessibility to open space are becoming worse in the future, mainly because of the fact that the ongoing trend of land consumption will continue in all scenarios. However, quality of open space might be improved compared to the base scenario by appropriate policies such as increase of car operating costs, reduction of speeds or combinations of policies.

Table 3 Scenario results: selected sustainability indicators

Scenario			Quality of open space	Exposure to NO ₂	Exposure to noise	Accessibility to open space
Number	Policy	Year	Index 2001 = 100	Percent of population above EU guidelines	Percent of population disturbed	Index 2001 = 100
000	Base scenario	2001	100.0	20.5	39.5	100.0
000	Base scenario	2021	89.4	12.3	37.6	88.7
211	Car operating costs +25%	2021	90.1	12.0	37.4	88.7
212	Car operating costs +50%	2021	91.3	11.7	37.1	88.6
213	Car operating costs +100%	2021	92.9	10.8	36.5	88.5
214	Car operating costs +75%	2021	92.1	11.4	37.0	88.7
218	Car operating costs +200%	2021	91.3	8.9	34.4	88.6
321	Maximum car speed - 20%	2021	95.1	13.0	35.6	88.5
421	Public transport fares - 50%	2021	89.8	12.0	37.5	88.8
713	214 + 421 + development at public transport stations	2021	95.0	11.0	36.7	88.1

5. Conclusions

This paper presented a model system developed to simulate and evaluate the impacts of land use and transport policies on sustainability in seven European urban regions.

The PROPOLIS system of sustainability indicators differs from other sustainability indicator systems. Other systems are based on monitoring approaches in which the quantities in question are directly observed or measured, whereas in PROPOLIS the indicators are modelled, i.e. can be forecast. Another distinction is that the PROPOLIS indicators were chosen as near as possible at the tail-ends of causal chains. For example, vehicle kilometres or average travel times are not presented as indicators for sustainability but emissions or numbers of residents in the most polluted areas.

The land-use transport models implemented in PROPOLIS are integrated with geographic information systems. All model zones and network links have their direct correspondence in a GIS. Tools were developed to exchange information back and forth between the models and the GIS, such as tools for editing links and link attributes in the GIS and to load them into the models. In this way the land-use transport models follow the trend to link spatial models to georeferenced data (Fotheringham and Wegener, 2000). GIS integration is a precondition for linking land-use transport models with environmental impact modules.

The PROPOLIS model system is one of the first attempts to address the issue of urban sustainability in a comprehensive long-term forecasting framework. The model system moves from two-way land-use transport modelling towards three-way land-use transport environment modelling (LTE), even though the feedback from environment to land use and transport, i.e. the way by which changes in environmental quality affect location decisions of investors, firms and households and so indirectly also influence activity and mobility patterns, has so far been only poorly developed (Spiekermann and Wegener, 2003),

The few results presented suggest that a clear increase of car operating might be the single best policies to support sustainability and might also suggest that other policies, such as regulatory policies or land use policies are not important. However, the latter would be a misleading conclusion. High-density, mixed-used settlement patterns are an essential precondition for less car-dependent cities. Therefore land use policies supporting high densities and smaller distances between residences and work places are a necessary ingredient of sustainability-oriented urban planning.

The PROPOLIS system is currently being implemented in seven European urban regions. Therefore, only typical preliminary results could be presented in this paper. All case city model systems are expected to calculate all PROPOLIS sustainability indicators and test the same set of policies. This will allow the systematic comparison of policy scenarios and individual policies with respect to their impact on urban sustainability. This comparison will lead to recommendations which policies should be adopted to improve urban sustainability in the long term.

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