ASSESSMENT OF INTEGRATED STRATEGIES FOR SUSTAINABILITY IN DORTMUND

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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) was 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 were developed. The paper presents results for the metropolitan area of Dortmund, Germany. The results show that sustainability in Dortmund will deteriorate compared with the current situation. Public transport investments are not enough to halt this decline: they attract more passengers but accelerate urban sprawl. Car pricing policies improve urban sustainability. Land use policies have little effect but support the impacts of car pricing and public transport improvements. Best results are achieved by policy combinations, i.e. combinations of land use policies and push and pull transport measures such as car pricing and improvements of public transport.

Keywords: Urban sustainability, land-use transport environment modelling, policy evaluation

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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 and 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 decline in 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 was the objective of the EU research project PROPOLIS (Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability). The goal was to assess urban strategies and to demonstrate their long-term effect on sustainability in European cities. 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 were developed.

PROPOLIS was 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 were IRPUD and S&W (Dortmund), LT (Helsinki), ME&P (Cambridge), MECSA (Bilbao), STRATEC (Brussels), TRT (Milan) and UCL (London).

This paper introduces the methodology and the model system developed and presents typical results of the policy testing and evaluation using the metropolitan area of Dortmund as example. 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 was viewed as comprising the environmental, socio-cultural and economic dimension. For the three components, key indicators were 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 were 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 The PROPOLIS Methodology

For a systematic evaluation of policies with respect to their long-term impacts on urban sustainability in PROPOLIS, 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.

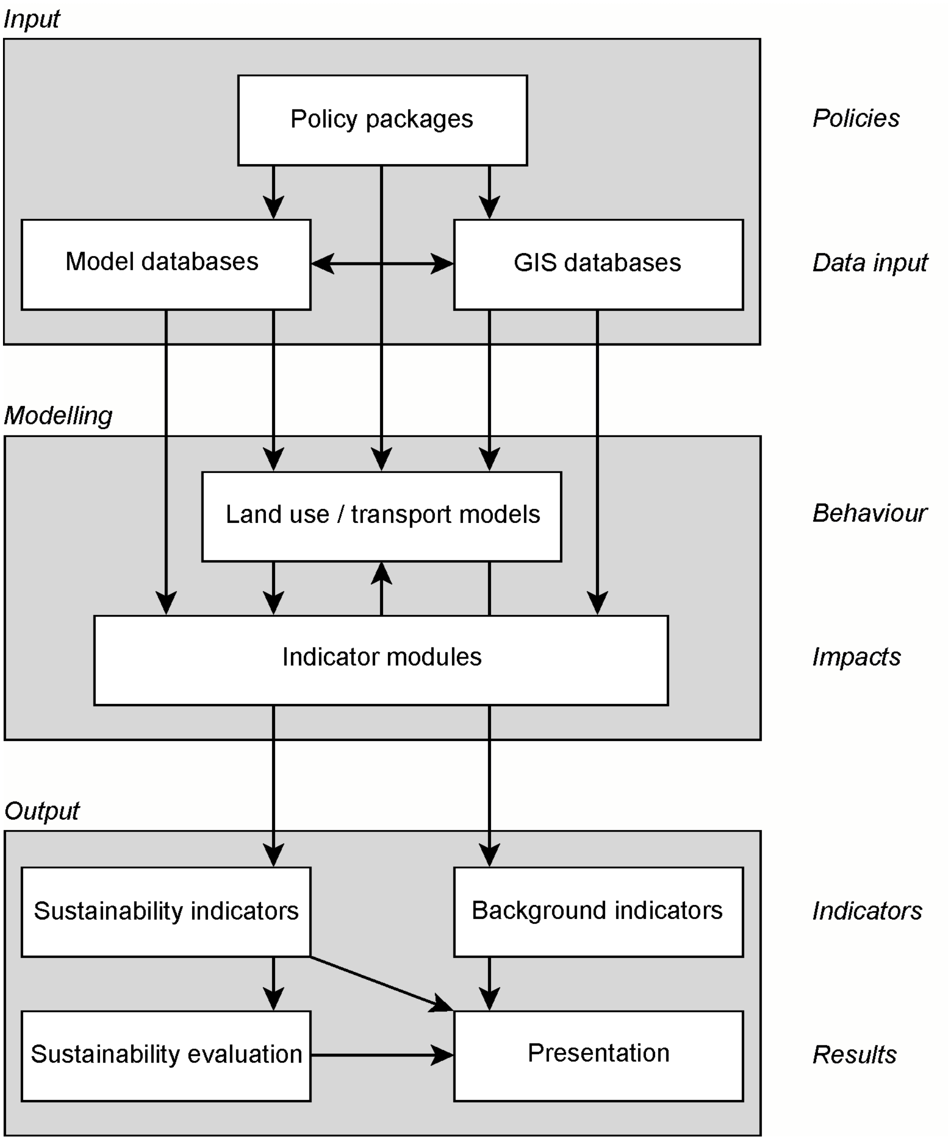

Figure 1 PROPOLIS model system

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 was 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	Brus-sels	Dort-mund	Helsinki	Inver-ness	Naples	Vicenza
Area (km²)	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/km²)	514	656	1,249	1,238	32	2,647	289
Mean 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 (€)	750	713	1,570	1,100	n.a.	695	1,079
Cars/1,000 inh	418	461	492	345	332	526	591
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.

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) was 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 predefined 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 CO_2 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.

4 Results for the Metropolitan Area of Dortmund

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, 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). 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.

4.1 The Dortmund Model

The land-use transport model applied to Dortmund is the simulation model of intraregional location and mobility decisions in a metropolitan area developed at the Institute of Spatial Planning of the University of Dortmund (IRPUD) (Wegener, 1996; 1998; 1999). It receives its spatial dimension by the subdivision of the study area into zones connected with each other by transport networks containing the most important links of the public transport and road networks coded as an integrated, multimodal network including all past and future network changes. It receives its temporal dimension by the subdivision of time into periods of one or more years' duration.

The model predicts for each simulation period intraregional location decisions of industry, residential developers and households, the resulting migration and travel patterns, construction activity and land-use development and the impacts of public policies in the fields of industrial development, housing, public facilities and transport. Figure 2 is a schematic diagram of the major subsystems considered in the model and their interactions and of the most important policy instruments.

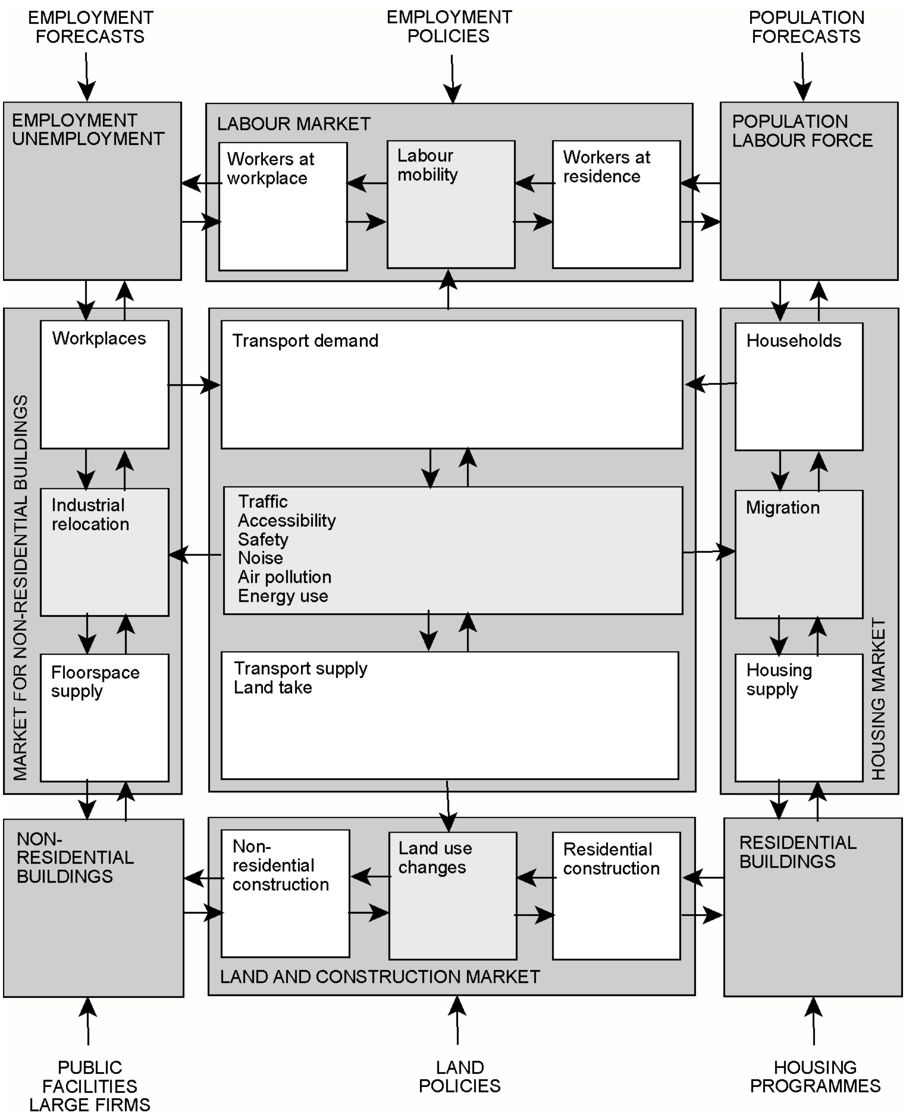

Figure 2 The Dortmund model

The four square boxes in the corners of the diagram show the major stock variables of the model: population, employment, residential buildings (housing) and non-residential buildings (industrial and commercial workplaces and public facilities). The actors representing these stocks are individuals or households, workers, housing investors and firms.

These actors interact on five *submarkets* of urban development. The five submarkets treated in the model and the market transactions occurring on them are:

- labour market: new jobs and redundancies,
- the market for non-residential buildings: new firms and firm relocations,
- the housing market: immigration, outmigration, new households and moves,
- the land and construction market: changes of land use through new construction, modernisation or demolition.
- the transport market: trips.

For each submarket, the diagram shows supply and demand and the resulting market transactions. Choice in the submarkets is constrained by supply (jobs, vacant housing, vacant land, vacant industrial or commercial floorspace) and guided by attractiveness, which in general terms is an actor-specific aggregate of neighbourhood quality, accessibility and price. The large arrows in the diagram indicate exogenous inputs: these are either forecasts of regional employment and population subject to long-term economic and demographic trends or policies in the fields of industrial development, housing, public facilities and transport.

The software environment of the Dortmund model consists of, besides the model itself, supporting software modules: a *network scenario generator* module extracts regional transport networks from GIS coverages and pre-processes them for efficient use in the model; a *scenario manager* module assists the user interactively in composing input for the scenario simulations; a *monitor* module displays output indicators selected by the user during a simulation run, and a *compare* module analyses and displays indicators from one or more simulation runs in time-series diagrams, maps and 3D surfaces. Figure 3 shows as an example a typical screenshot of the network scenario generator (Talaat and Schwarze, 2003).

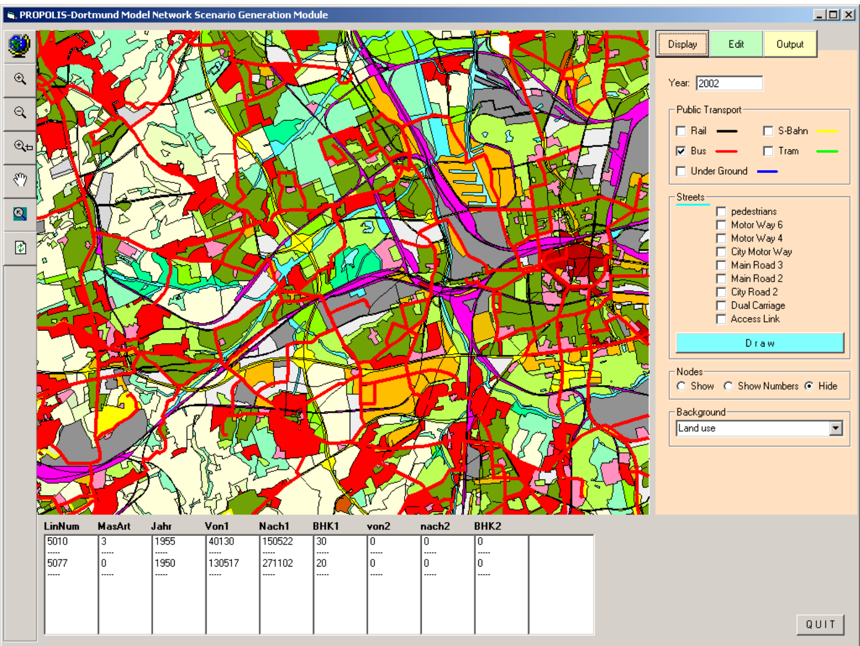

Figure 3 The Dortmund model network scenario generator

4.2 Land-Use Transport Model Indicators

Figures 4 and 5 show selected results of the 23 policy scenarios modelled in PROPOLIS. The policy scenarios include, 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.

The two diagrams show 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 trip length. 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. In 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.

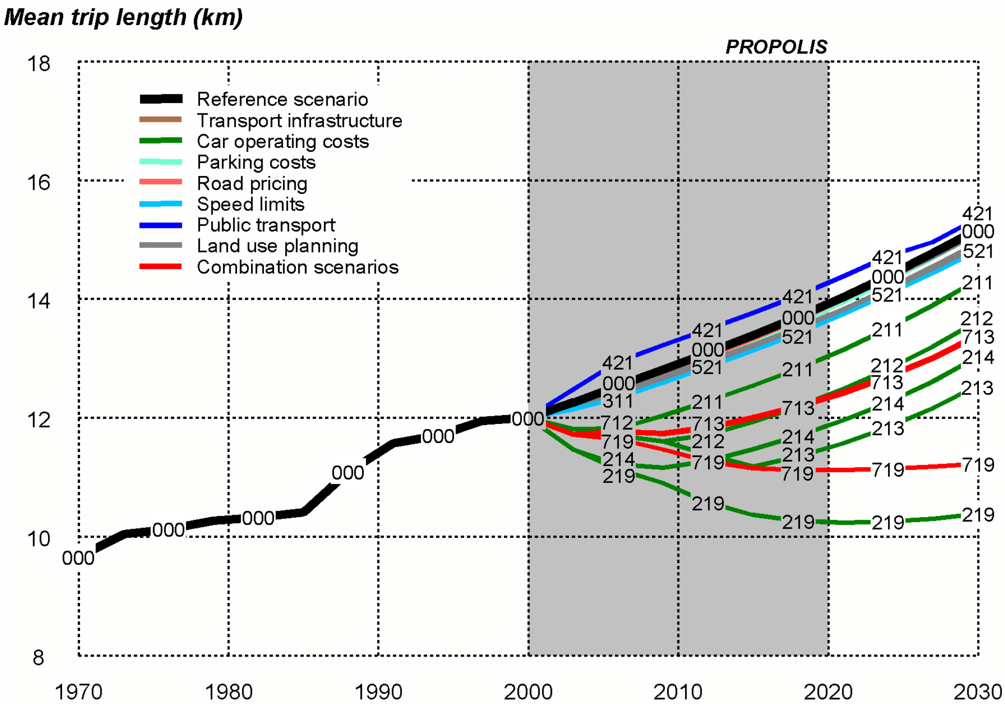

Figure 4 Scenario results: mean trip length

A similar picture emerges if only car km are considered. Figure 5 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.

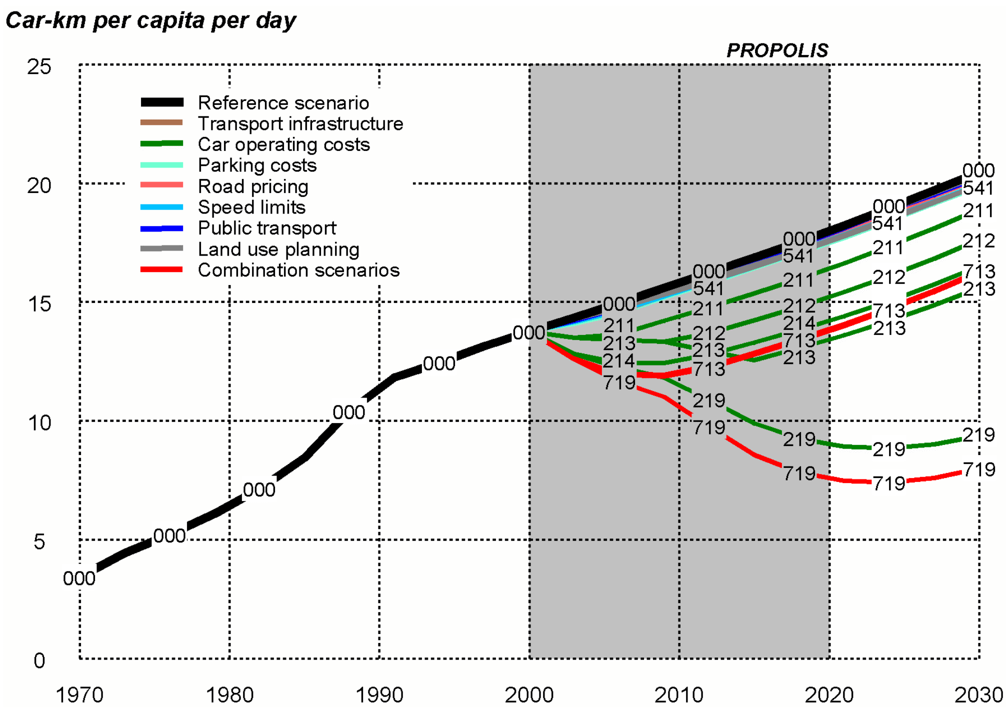

Figure 5 Scenario results: car km per capita per day

4.3 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 emerges.

Figures 6 and 7 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 6 shows exposure to traffic noise. 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. Exposure to noise of residences of population by socio-economic group is calculated for raster cells.

Figure 7 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 6 are overlaid with the open space. Red raster cells are disturbed by traffic noise. 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.

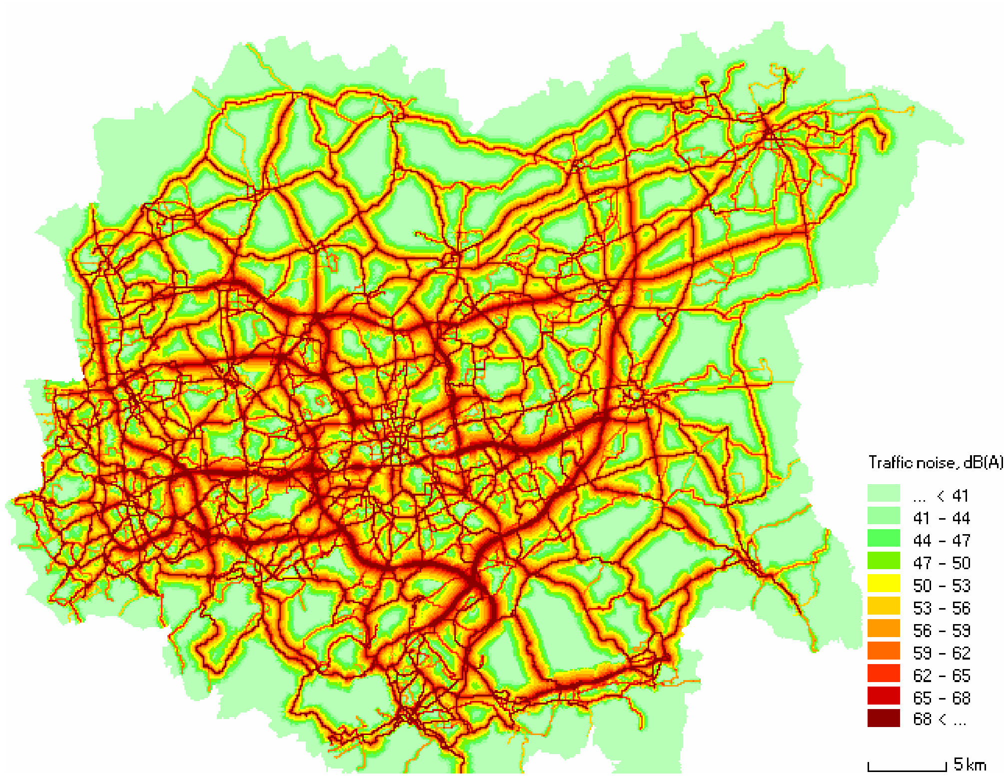

Figure 6 Traffic noise in the Dortmund region

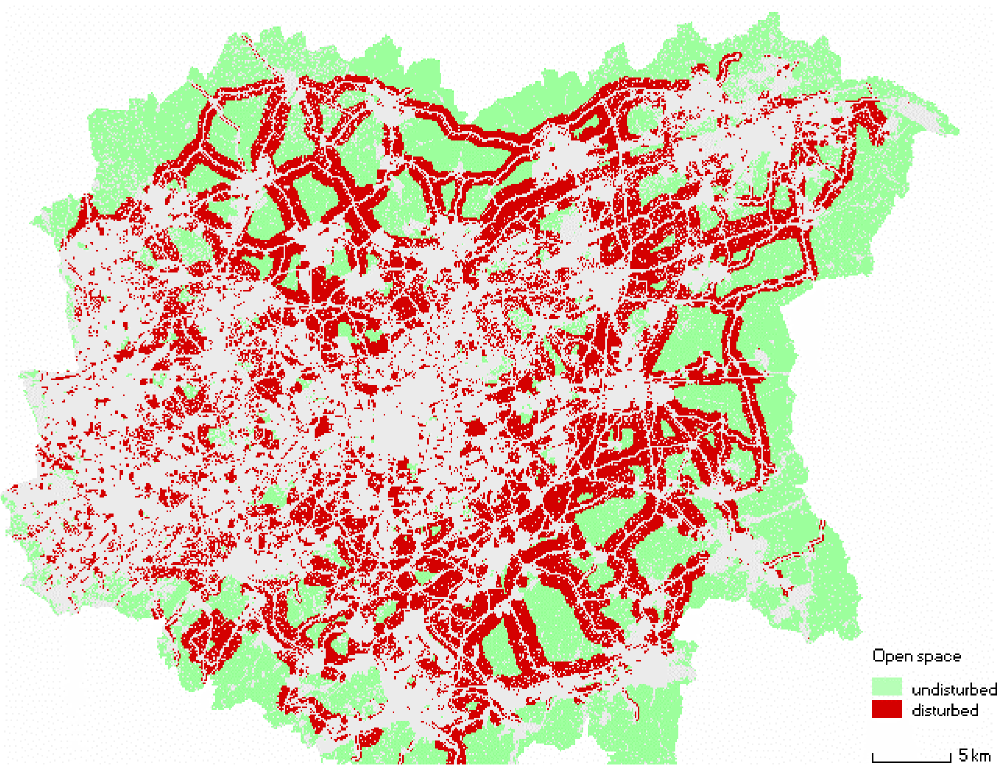

Figure 7 Quality of open space in the Dortmund region

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 clearly go down in all scenarios because new emission standards for new vehicles replacing old ones are assumed already in the base scenario. Increases in car operating costs result in less people exposed to air pollution and traffic noise. The most significant effects are achieved by a strong increase in car operating costs as in scenario 219. The quality of open space declines in scenarios in which travel is made cheaper or faster and improves where travel is made more expensive. The best results are accomplished by *integrated* strategies combining several interacting policies, such as scenarios 713 and 719, which combine transport pricing, transport infrastructure and land use policies which support each other.

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	92.4	12.2	36.8	88.6
214	Car operating costs +75%	2021	92.1	11.4	37.0	88.7
219	Car operating costs +300%	2021	99.3	8.9	34.4	88.6
321	Maximum car speed –20%	2021	95.1	13.0	35.6	88.5
412	Public transport travel time –5%	2021	89.1	12.2	37.7	88.7
421	Public transport fares –50%	2021	89.8	12.0	37.5	88.8
713	214+412+421+development at rail stations	2021	96.2	11.1	36.8	87.9
719	219+412+421+urban growth boundary	2021	109.1	6.7	33.0	87.3

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. 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, 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 results presented suggest that a clear increase of car operating might be the single best policy to support sustainability and might also suggest that other polices, such as regulatory policies or land use polices are not important. However, high-density, mixed-used settlement patterns are an essential precondition for less car-dependent cities. Integrated land use and transport policies combining land use policies and push and pull transport measures such as car pricing and improvements of public transport are therefore necessary ingredients of sustainability-oriented urban planning.

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