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Modelling Policies for 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 modelling as well as indicator, evaluation and presentation systems have been developed.

Sustainable development is viewed as comprising the environmental, socio-cultural and economic dimension. About thirty-five key indicators have been 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, have been developed and integrated to provide further indicator values. Both multicriteria and cost-benefit analysis methods are used to consistently evaluate the impact 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 agglomerations: Bilbao (Spain), Brussels (Belgium), Dortmund (Germany), Helsinki (Finland), Inverness (Scotland), Naples (Italy) and Vicenza (Italy).

A large number of policies will be tested with the modelling and evaluation system in the seven urban regions. Policies to be investigated are land use policies, transport infrastructure policies, transport regulation and pricing policies and combinations of these. Besides a common policy set for all seven urban regions, city-specific local policies will be assessed as well.

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 life or planet threatening concerns 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. On the one hand, cities contribute to a large extent to global environmental problems, on the other, people living in cities are facing increasing problems and 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, have been designed and partly implemented to improve the urban situation. However, the 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 the effects of these policies cannot be clearly demonstrated. Policies might have very different effects. Besides direct environmental, social or economic impacts many policy options might have negative side effects, some policy options may work against each other, whereas some may reinforce each other, some policy options might improve the situation in part of the region, whereas in other parts the situation might get worse. Hence, the design of policies to improve urban sustainability is everything 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 systems and methods for 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.

The first parts of the paper will introduce the sustainability indicator system, the methodology and the modelling system developed in PROPOLIS. The second part will present typical results of the policy testing and evaluation.

2. Indicators for 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 nowadays.

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.
- *Representativity*. In order to keep the indicator system handsome, 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 type of policies that can be tested are of interest.
- *Predictability.* There exist a lot of indicators suitable for monitoring but as the objective is on modelling future policy impacts, it is essential that the indicator values can be forecast by the modelling system into the future.

The resulting PROPOLIS indicator system is presented in Table 1. In order to allow a structured evaluation in the modelling system, the three sustainability components are first subdivided in themes, appropriate indicators are then related to themes. Nine themes and about thirty-five key indicators have been 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. Admittedly, the indicator list lacks some indicators related to land use, such as emission, energy use or economic benefits. Some of those indicators will be tested in a single case city, but it was outside the scope of the PROPOLIS project to implement those indicators in all case cities.

Table 1. PROPOLIS Indicator System

Component	**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 modelling system and shows how the policy testing and evaluation process will be organised.

3.1 Modelling System

To reach the objective of a systematically evaluation of policies with respect to their long term sustainability impacts a modelling system was designed in which different models and tools are integrated. Figure 2 illustrates the main components and data flows of the model system as a process from inputs via behaviour and impact modelling to outputs in terms of indicators and evaluation and presentation procedures.

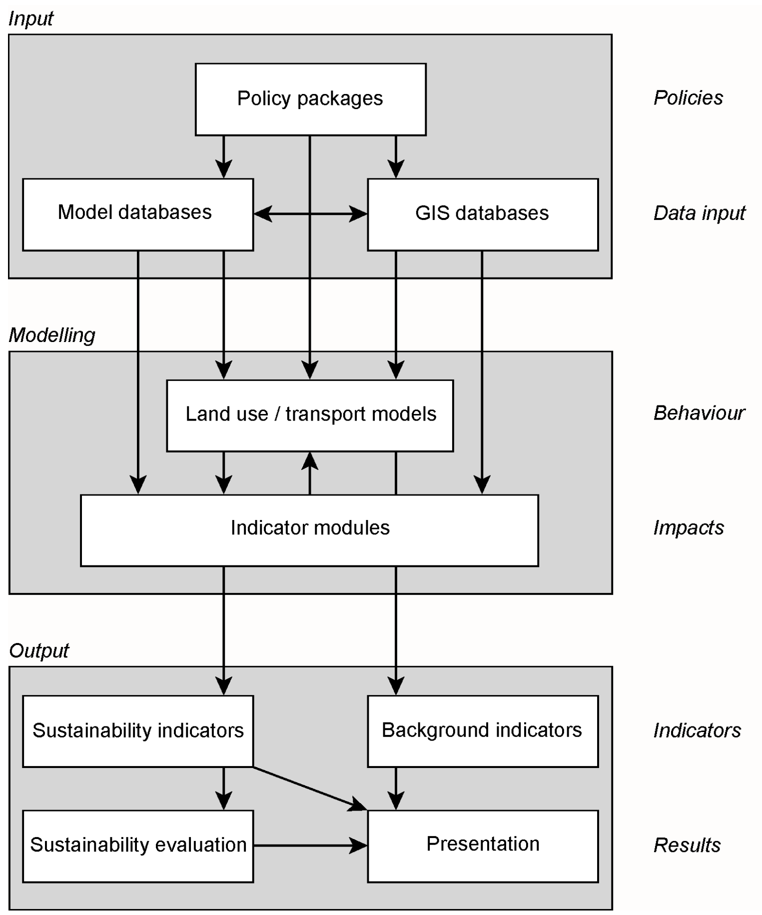


Figure 1. PROPOLIS Model System

The *input data* include policy packages, GIS databases and model databases. Policy packages to be tested have to be transformed to 'model language' by changing some of the model parameters or the model database. GIS databases contain spatial data on zonal boundaries, road and public transport networks, land use categories etc. All land use transport models used are fully GIS integrated, i.e. each model zone or model link is represented in the GIS database.

In the *modelling part* land use transport models are the driving engines of the system. They have been previously been calibrated to correspond with the perceived behaviour in the test cities. The land use transport models simulate the effects of the policies in terms of changing zonal activities such as population or employment and changing mobility pattern resulting in different modal splits and different link loads. The indicator modules receive the output of the land use transport models and calculate raw values of the sustainability indicators.

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

The land use transport models

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

Table 2. Case city regions and land use transport models

Case city	**Bilbao**	**Brussels**	**Dortmund**	**Helsinki**	**Inverness**	**Naples**	**Vicenca**
Area (km²)	2,217	4,332	2,014	764	4,152	1,171	2,722
Population (in 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
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 per person/month (EUR)	750	713	1,570	1,100	n.a.	695	1,079
Car ownership per 1,000 inhabitants	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 case city regions are very different in many respects. The population range from 130,000 to over 3 million inhabitants, some undergoing strong growth while others are old declining cities, sometimes in the process of being restructured. Some regions have high unemployment rates, some very low. Income per person and car ownership rates differ very much. The spatial structures are ranging from highly compact and centralised to dispersed or multicentric patterns. In such quite different conditions of transport supply, the modal splits do vary very much, however, always dominated by car.

The case city models applied belong to three different integrated urban land use and transport model types: 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 task of the models is to simulate the effects of the policies to be tested on the location behaviour of households and firms and on the resulting mobility patterns in the metropolitan regions of the case cities. Base year of the models is 1996, the final forecast year is 2021. Output of the land use transport models has to be provided in a common data format for a pre-defined set of variables. Because the models used are implemented in a very different way, the harmonisation of relevant model output was necessary. The harmonisation had to take place in form of aggregation based on the 'lowest common denominator'. This means that the land use transport models work as detailed as they were implemented and that subsequent stages of the modelling system work with less detail, but with a common set of variables in order to allow cross-city comparisons. Socio-economic groups have been aggregated to three types, employment sectors to four types, land and floorspace to three types, trips to five types, transport modes to five types, transport links to ten types.

The indicator modules

A set of modules calculating sustainability indicators is integrated in the system. These modules are post-processing the output from the land use transport models. Four modules are implemented in the system: a Raster Module, an Economic Indicator Module, a Justice Indicator Module and an Other Sustainability Indicator Module. The output of the indicator modules are raw values for the sustainability indicators listed in Table 1.

The *Raster Module* calculates those 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, energy consumption or 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-location. This is where the GIS-based Raster Module comes into play. It maintains the zonal organisation of the aggregate land use transport model and adds a disaggregate raster-based representation of space (100 x 100 m) for the calculation of local environmental and social impacts of policies. The Raster Module calculates most environmental indicators, the exposure indicators and an accessibility to open space indicator. 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 (Spiekermann, 1999; 2002; Spiekermann and Wegener, 1999).

The *Economic Indicator Module* provides a complete 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 an urban system which is measured on the basis of some potential determinants such as the size of the city, the speed at which people and goods are moved in the city, the sprawl of jobs and home (following Prud'Homme and Chang-Woon, 1999). The indicator addresses the variation in productivity of the urban fabric by comparing the policy scenarios with the reference scenario.

The *Justice Indicator Module* addresses some equity implications of the policies tested. It processes the different exposure shares of different socio-economic groups to air pollution and noise and translates this into equity indicators. For that purpose, different theories of justice are incorporated in the module: equal shares principle, utilitarian approach, egalitarianism and the Rawlsian difference principle.

The *Other Sustainability Indicator Module* calculates a small set of indicators which is not covered by the previous modules.

The evaluation and presentation modules

Finally, the indicators are evaluated by a multicriteria evaluation tool and are analysed and presented in a harmonised way.

The multicriteria evaluation tool *USE-IT* has been set up to solve the problem whether policy A is more sustainable than policy B. The tool allows to compare the contribution of indicators to sustainability and allows to aggregate from single indicators to sustainability themes and components as defined in Table 1. First, value functions help to transform the raw indicator value to a scale from zero to unity by taking existing target values into account. Then, indicators are weighted in order to aggregate the evaluated indicator values into indices. The weights applied are the outcome of an internal expert exercise that will be used for a common set of weights for all case cities. In addition, local value systems have been obtained and are used as weights in the local contexts. Indices are formed using additive aggregation separately for the environmental, social and economic components of sustainability. A single index aggregating the three components will not be calculated in order to avoid double-counting, because some issues are considered in more than one component, i.e. are treated from different viewpoints.

An internet-based *Analysis and Presentation Tool* will present the results of the policy testing for all cities in a standardised format. The tool is in particular concerned with the requirement for comparative analysis of the effects of similar policies in different test cities. The tool analyses and displays sustainability indicators and background variables. This will make the task of visualising and understanding the impacts of policy decisions easier and so aid the process of selecting the most appropriate policy measures.

3.2 Implementation and Policy Testing

The PROPOLIS modelling system is currently being implemented in the seven European urban regions presented in the last section. Figure 2 shows how the system will be used to define urban strategies that increase sustainability. The modelling system is the core of the policy analysis process. First, single policies will be defined and introduced into the system. Policies include land use, transport, pricing and regulatory and investment policies. The evaluation of policies and the intra and intercity comparison of policies will lead to a replanning of policies. The replanning includes the refinement of policies, e.g. to find an optimal level of a pricing policy, but also to a formulation of policy combinations in order to improve the results. The final output of the systematically testing are general and city specific recommendations which policies or combination of policies are contributing to sustainable development and which do not.

There are various points in the system at which client partners can intervene and can introduce their ideas and values in the modelling and evaluation process. Client partners are in most cases local or regional governments. First of all, they can contribute in formulating the basic assumptions on general developments which are external assumptions of the models such as overall economic developments or migration flows across the regions' outer borders. Or, they might want to test the impacts of alternative framework scenarios. An important task is to contribute to the formulation of strategies and policies; in addition to the set of policies to be common for all case cities there is also a slot in which very specific local policies can be analysed. Finally, the local experts are asked to state their values, i.e. weights in the evaluation system.

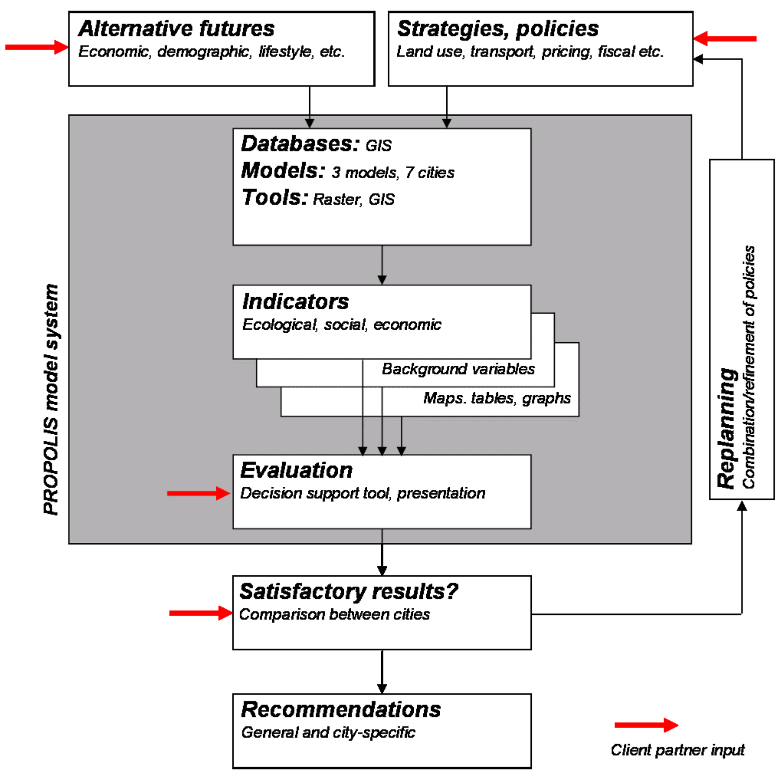


Figure 2. Policy testing process.

4. Typical Results

The PROPOLIS project is still ongoing and will be finalised by spring 2003. Currently, system development has reached a mature state, policy testing and analysis will start in autumn 2002. Therefore, this section can only present typical results of the modelling system which partly are produced in from preceding projects of PROPOLIS (LT et al., 1998; MECSA et al., 2002). The modelling system does offer much more information than can be presented here; the focus in this section is on illustrative results.

Sample output of the land use transport models

The land use transport models are used to predict long term changes in the urban land use and transport system. Figure 3 shows as an example the impact of a combination of a teleworking scenario with a transport cost policy (increase by 50 percent) on the change of zonal population in the Helsinki metropolitan area. Figure 4 is an example for the dynamics of the land use transport models and shows the change of population in superzones of the Dortmund region over time. Figure 5 presents one output of the transport models, the link loads on the road network in the Dortmund region.

Sample output of indicator modules

The indicator modules are using the output of the land use transport models, link it partly with GIS data and produce the sustainability indicators. Figure 6 shows as an example for the Raster Module the traffic noise situation in the base scenario for the urban region of Naples from which the exposure to noise indicator and the different exposures of socio-economic groups for the justice evaluation are derived. Figure 7 displays a typical evaluation screen of the Economic Indicator Module.

Sample output of the sustainability evaluation

Figure 8 shows sample results of the PROPOLIS evaluation tool USE-IT: The upper part shows an example of an evaluated indicator (exposure to noise) for selected combination policies. The diagrams in the middle show the environmental indices and the social indices for the same group of policies as well as the contribution of the themes within the components. The lower diagram displays the economic indices for those policies. Finally, Figure 9 shows for another group of policies the highest level of aggregation within the evaluation procedure for three cities. For each policy, the indices for the three components are presented with a colour scheme that indicates whether a policy leads to better results than the reference scenario (green) or whether the situation for that component might get worse compared to the reference scenario (red).

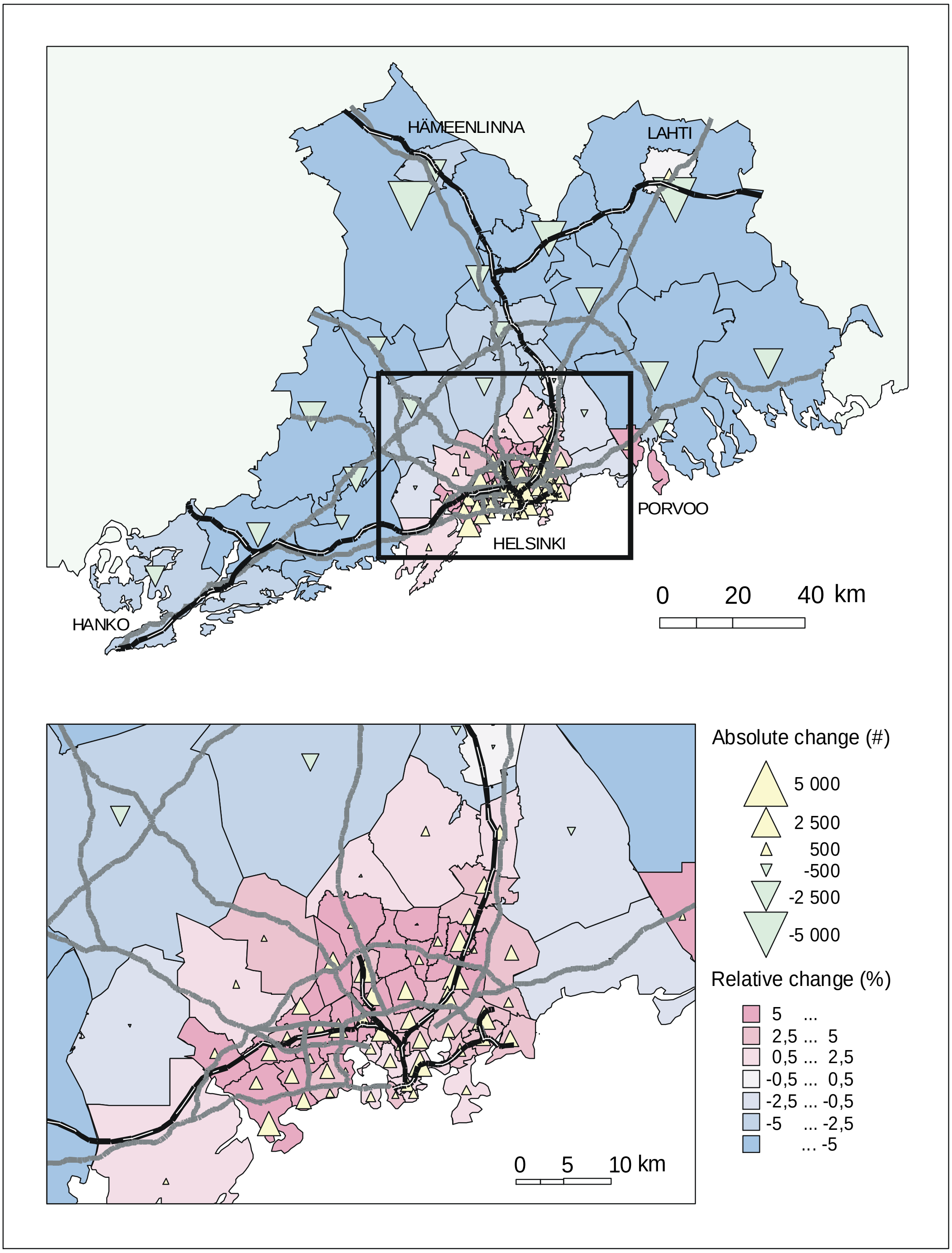


Figure 3. Forecast of zonal activities (population) for the Helsinki metropolitan region.

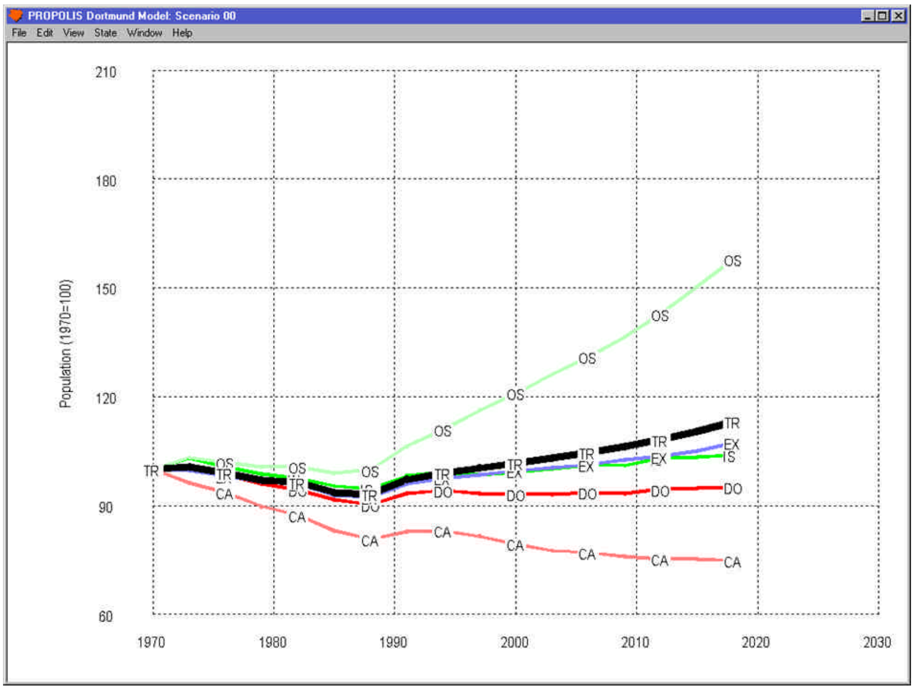


Figure 4. Forecast of population development in superzones of the Dortmund region.

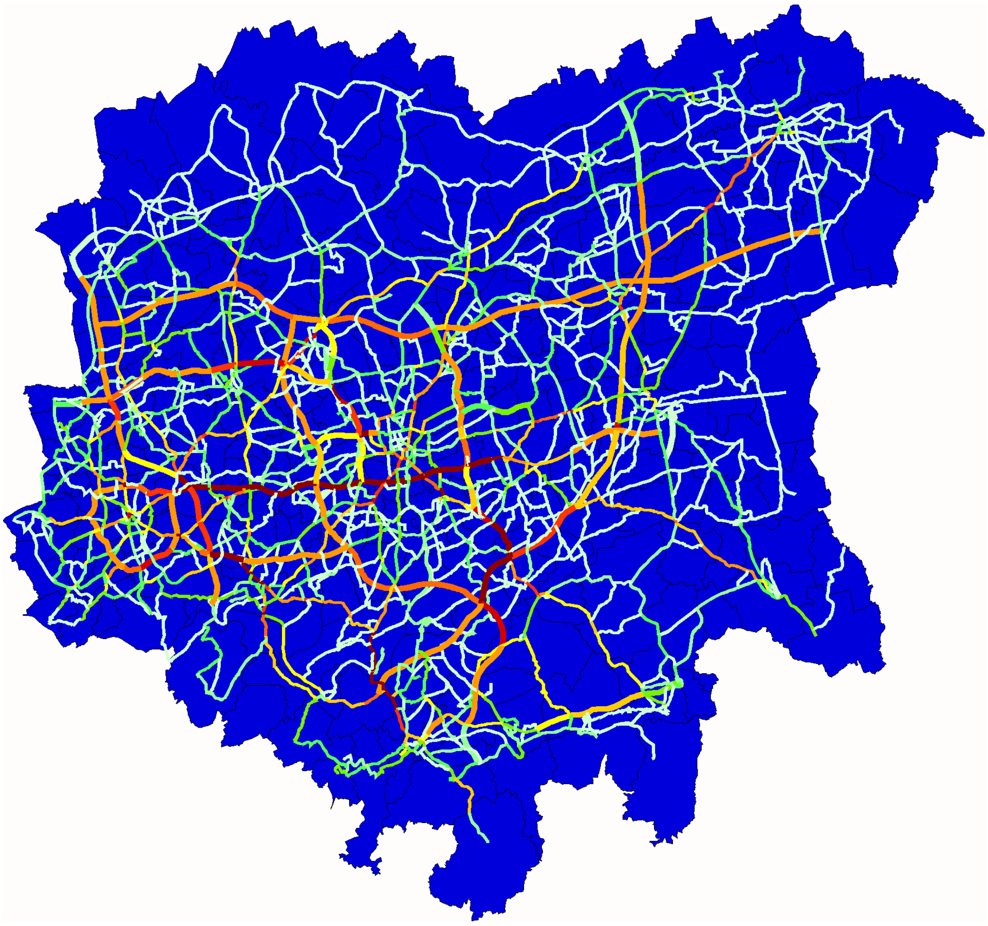


Figure 5. Forecast of traffic flows for the Dortmund region.

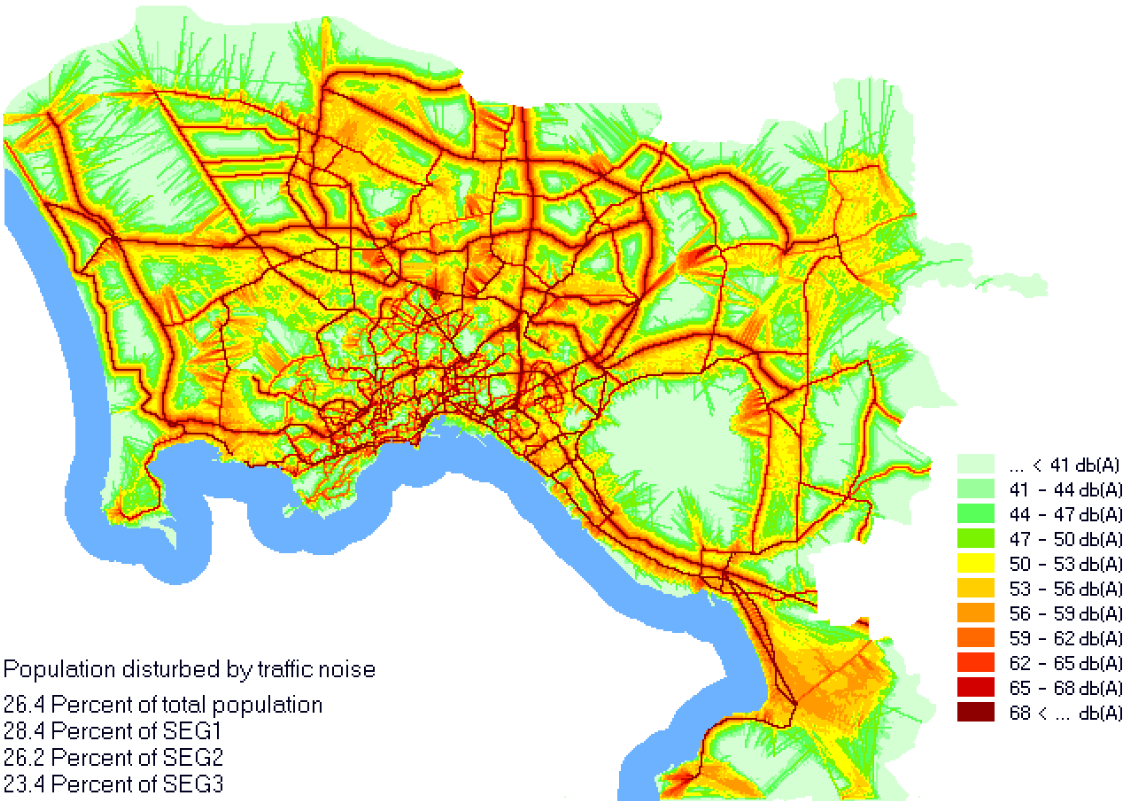


Figure 6. Forecast of traffic noise for the Naples urban region.

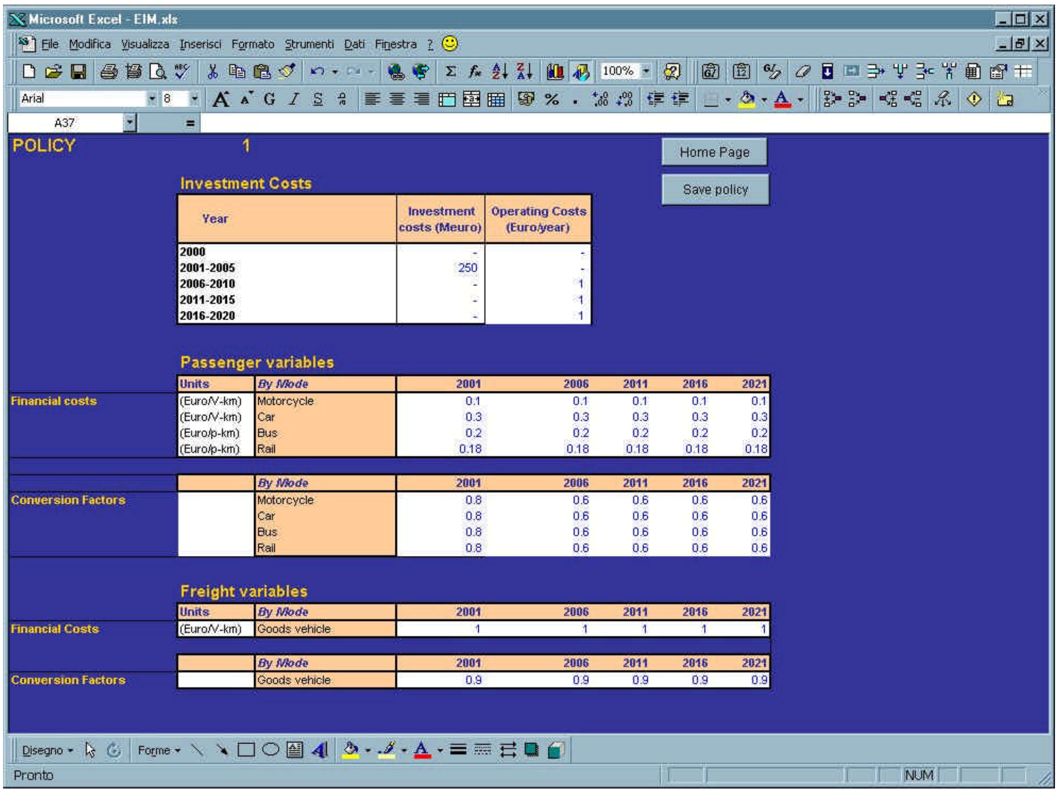
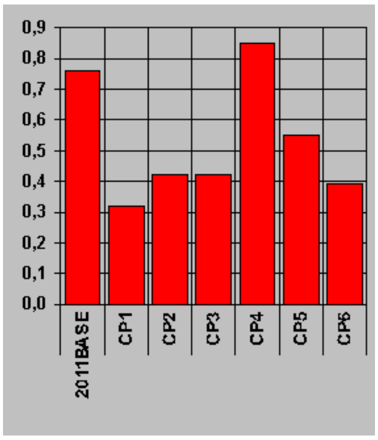
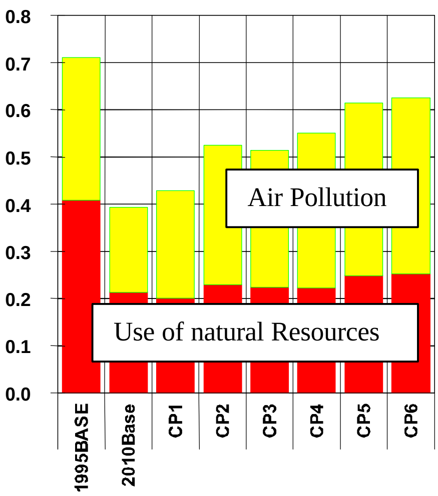


Figure 7. Result screen of the Economic Indicator Module.

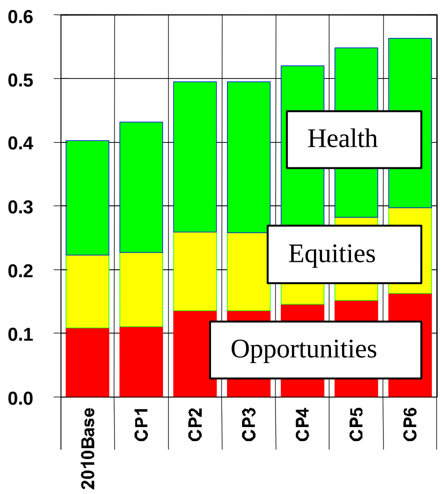
Single Indicator (exposure to noise)



Environmental index



Social index



Economic index

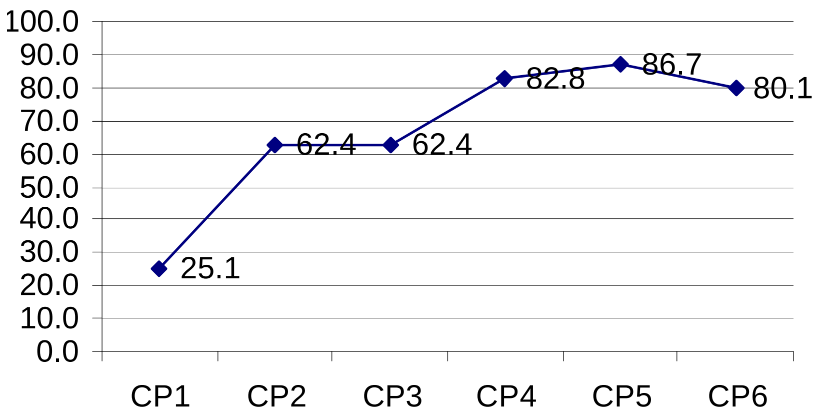


Figure 8. Environmental, social and economic evaluation for combination policies (MECSA et al., 2002).

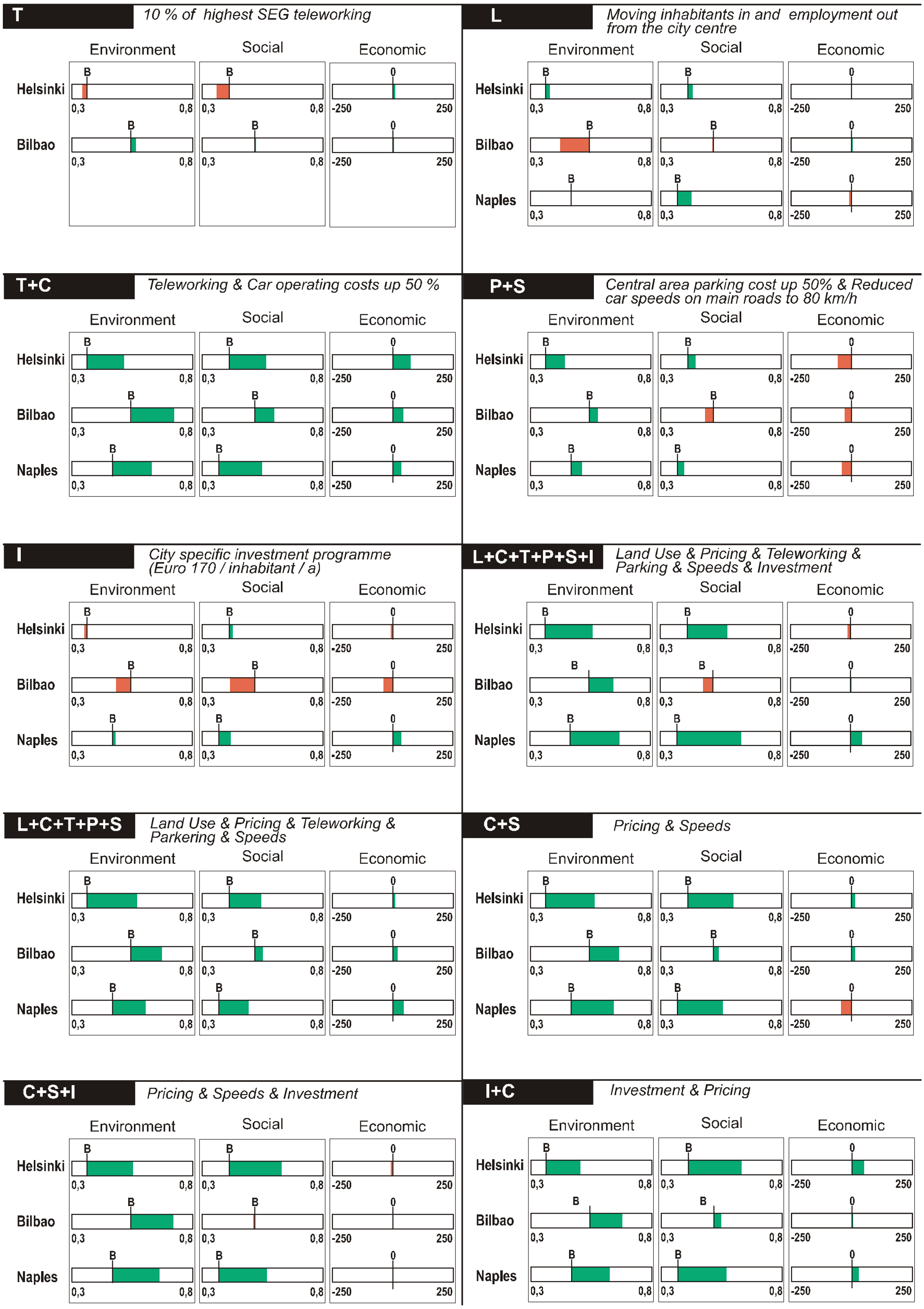


Figure 9. Environmental, social and economic indices for selected policies (LT et al., 1998).

5. Conclusions

The paper has presented a modelling system developed to simulate and evaluate the impacts of different land use and transport policies in seven European agglomerations in terms of sustainability. The system developed is unique in several respects.

The PROPOLIS urban sustainability indicator system is very distinct from most sustainability indicator systems in use. The basic difference is that other systems are based on monitoring approaches in which the quantities in question are directly observed or measured, whereas in PROPOLIS indicators are modelled, i.e. the approach is one of forecasting. Another distinction is the characteristic of many PROPOLIS indicators, that they have been 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, instead emissions or numbers of residents in the most polluted areas are used.

All land use transport models implemented are GIS integrated. All model zones and model network links have their direct correspondence in a Geographic Information System. Tools have been developed to go back and forth between model and GIS, e.g. network tools for editing link alignment and attributes in the GIS and to load them into the model. In this way the land use transport models employed follow the general trend of spatial models to be more closely linked to georeferenced data held in a geographical information system. In addition, the GIS integration is one of the basic conditions for moving ahead from traditional output indicators of land use transport models towards indicator sets like the one developed here and for linking land use transport models with new environmental modules such as the Raster Module.

The PROPOLIS system is one of the first attempts to address in a comprehensive modelling and evaluation framework the important question of urban sustainability and to assess the options for moving away from unsustainable urban development paths. In methodological terms the system developed moves ahead from traditional land use transport modelling by introducing also a number of interactions between the environment, land use and transport. In this way, it is one of the first comprehensive land use transport environmental modelling systems (LTE models) operational. However, it has the interaction with the environment implemented so far is a one-way interaction and the planned feedback from environment to land use and transport (Spiekermann and Wegener, 2002), i.e. the way by which changes in the environmental quality of urban locations affect location decisions of investors, firms and households and so indirectly also activity and mobility patterns, has to be postponed to a later stage of development.

The system is currently being implemented in seven European urban regions. Therefore, only typical results could have been presented in the paper. However, all case city modelling systems are expected to provide all indicators of the PROPOLIS sustainability indicator set. In all case city regions, the same set of policies will be tested. The harmonisation of output indicators achieved starting from very different case cities with partly very different land use transport models and ending with the common indicator set is the base for cross-city comparisons. These features will allow the systematic analysis of different policies and combinations of policies with respect to changing sustainability of the urban system over time. It will eventually lead to recommendations which policies should be adopted and which not in order to clearly improve urban sustainability in the long term.

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References

Aalborg Charter (1994) *Charter of European Cities and Towns Towards Sustainability.* http://www.iclei.org/europe/echarter.htm

Büttner, J., Spiekermann, K., Wegener, M. (2002): *Review Report on Environment Land Use Feedback.* Berichte aus dem Institut für Raumplanung. Dortmund: IRPUD (forthcoming).

Daly, H.E. (1991): *Steady State Economics.* Washington, D:C: Island Press.

De la Barra, T. (1989): *Integrated Land-Use and Transport Modelling. Decision Chains and Hierarchies.* Cambridge: Cambridge University Press.

Hunt, D. (1994): Calibrating the Naples land use and transport model. *Environment and Planning B: Planning and Design* **(21)**, 569-590.

Martino, Maffii, S. (1999): The integrated land-use and transport model of Naples: from the master transport plan to the EU policy tests. In: Rizzi, P. (ed.): *Computers in Urban Planning and Urban Management on the Edge of the Millennium*. Mailand: F. Angeli.

LT, ME&P, MECSA, IRPUD, TRT (1998): *SPARTACUS. System for Planning and Research in Towns and Cities for Urban Sustainability.* Final Report. Helsinki: LT Consultants (see also http://www.ltcon.fi/spartacus).

MECSA, LT, S&W (2002): Transport and Land-Use Interaction. Part B: Policy Scenarios. IPTS Report 20124 EN/2. Sevilla: IPTS. (report can be downloaded at http://www.jrc.es/cfapp/reports/details.cfm?ID=949)

Prud'Homme, R., Chang-Woon, L. (1999): Size, sprawl speed and the efficiency of cities. *Urban Studies* **(36)**, 11, 1849-1858.

Spiekermann, K. (1999): *Sustainable Transport, Air Quality and Noise Intrusion – An Urban Modelling Exercise.* Paper presented at the ESF/NSF Transatlantic Research Conference on Social Change and Sustainable Transport, 10-13 March 1999. University of California at Berkeley.

Spiekermann, K. (2002): *Linking Land Use Transport Models with Disaggregate Environmental Models.* Paper presented at the 42nd Congress of the European Regional Science Association (ERSA), Dortmund, 27-31 August 2002.

Spiekermann, K., Wegener, M. (1999): Disaggregate environmental modules for modelling sustainable urban development. In: Rizzi, P. (ed.): *Computers in Urban Planning and Urban Management on the Edge of the Millennium*. Mailand: F. Angeli.

Wegener, M. (1996): Reduction of CO_2 emissions of transport by reorganisation of urban activities. In: Hayashi, Y., Roy, J. (eds.): *Land Use, Transport and the Environment:* Dordrecht: Kluwer Academic Publishers, 103-124.

Wegener, M. (1998): *The IRPUD Model: Overview*. http://irpud.raumplanung.uni-dortmund.de/irpud/pro/mod/mod_e.htm.

Wegener, M. (1999): *Die Stadt der kurzen Wege – müssen wir unsere Städte umbauen?* Berichte aus dem Institut für Raumplanung 43. Dortmund: IRPUD.

Williams, I.N. (1994): A model of London and the South East. *Environment and Planning B: Planning and Design* **(21)**, 517-533.

WCED - World Commission on Environment and Development (1987): *Our Common Future.* Oxford: Oxford University Press.