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Reduction of CO_2 emissions of transport by reorganisation of urban activities

Michael Wegener

1. Introduction

It is generally believed that the private automobile has been the primary cause of the expansion of cities over wider and wider areas. However suburbanisation was not caused by the car but has been the consequence of the same changes in the socio-economic context of urban life that were also responsible for the growth in car ownership: increase in income, more working women, smaller households, shorter work hours and a consequential change in lifestyles and housing preferences towards quality of life, leisure and recreation. Under these conditions, the car and low fuel prices brought low-density suburban living within the reach of not only the rich, with the result that for the last thirty years the growth of cities has occurred primarily in the suburbs. Offices, light industry, services and retail started to decentralise later following either their employees or their markets or both taking advantage of attractive suburban locations with good accessibility, ample parking and lower land prices.

However, while this deconcentration process clearly reflects the preferences of the majority of the population, its negative side effects are more and more becoming apparent: longer work and shopping trips, increasing rush-hour congestion and less and less acceptable levels of noise, air pollution and traffic accidents. In particular the high energy consumption of transport in low-density cities has become an issue of growing concern. The fear of diminishing fossil fuels and the threat of long-term climate changes due to greenhouse gases have sharpened the awareness that present energy prices do not nearly cover the environmental and social costs of energy use and that the level of energy consumption in affluent countries represents a gross unfairness against developing countries which can never be allowed to rise to the same standards. At the United Nations conference on the global environment in Rio de Janeiro in 1992 many governments pledged to substantially reduce their use of fossil energy and emissions of carbon dioxide (CO_2). The German government promised to reduce CO_2 emissions from all sources by 30 percent compared with 1987 by 2005. As transport represents a major share of primary energy consumption, serious attempts to lower the energy use of urban transport are necessary to achieve this goal.

There have been numerous proposals to respond to this challenge. The majority of them follow the hypothesis that energy use of urban transport is a direct function of settlement density and suggest a return to mixed-use, compact land-use patterns. The most frequently quoted support of this hypothesis is the study by Newman and Kenworthy (1989), who analysed 32 cities in four continents and found a significant negative statistical correlation between residential density and transport-related energy consumption per capita (see Figure 1, top). In many European countries the reliance on this hypothesis has led to policy recommendations such as the following:

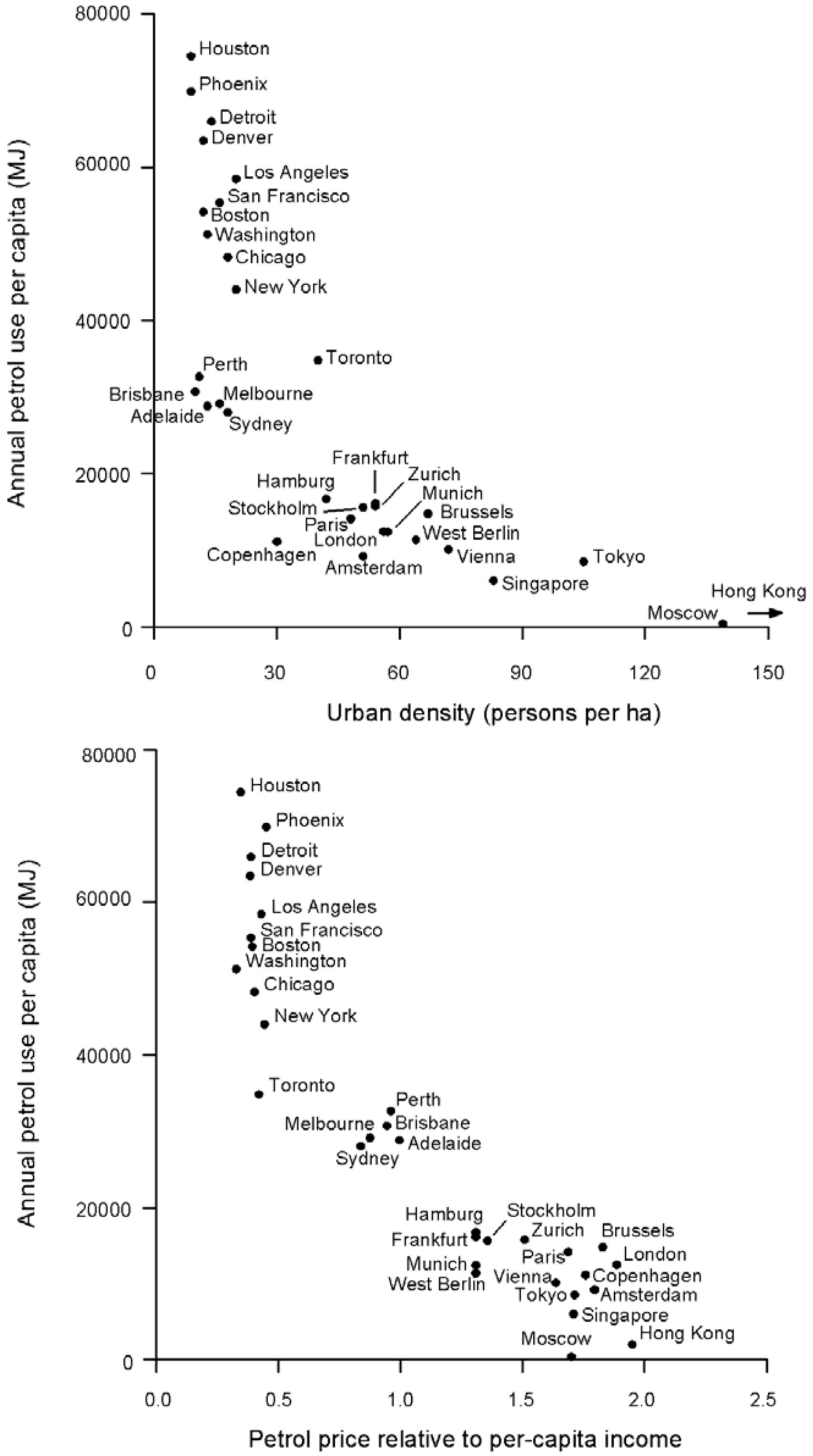

Fig. 1. Petrol use v. urban density (top) and petrol price (bottom), 1980. Source: Newman and Kenworthy (1989)

> *"[Local governments are advised] to apply a policy of short distances which reduces the length of trips between residences, workplaces and public and private facilities in order to avoid car traffic and increases the attractiveness of public transport, cycling and walking."*
>
> German Council of Cities: Ten Points to Improve Urban Transport (1989)

> *"The first fundament of sustainable mobility is a policy of concentrated development of residential and industrial areas and public facilities. In a concentrated spatial structure the distances to be travelled are shortest; the fastest transport mode is the bicycle, and good public transport can be provided."*
>
> Fourth Note (Extra) on Spatial Development in the Netherlands (1990)

> *"The strict zoning policies of the past decades which have led to the separation of land use and the subsequent development of extensive residential suburbs have in turn stimulated commuter traffic, which is at the heart of many of the environmental problems currently facing urban areas. We therefore need a fundamental review of the principles on which town planning practice has been based. Strategies which emphasize mixed use and denser development are more likely to result in people living closer to work places and the services they require for everyday life. The car can then become an option rather than a necessity."*
>
> Green Paper on the Urban Environment of the European Communities (1990)

The problem with these policy prescriptions is that there has been no evidence so far that under today's conditions, i.e. with an unconstrained transport market and present travel costs, a return to higher densities would lead to a reduction of energy consumption of urban transport. In fact there have been several studies contradicting this hypothesis:

- Rickaby (1987) found by model simulations that 'decentralised concentration' (urban areas with medium-sized secondary centres) is the most energy-efficient settlement structure.
- Banister (1992) showed that petrol consumption per capita in England declines with city size, but is higher in London than in other large cities.
- Breheny (1995) demonstrated that, if the population of England and Wales had *not* suburbanised between 1961 and 1991, total energy savings would have been less than three percent.

Moreover, even the data presented by Newman and Kenworthy can be interpreted in a different way which sheds doubt on the simple relationship between density and energy use. For instance, if one plots transport energy consumption not against urban density but against the petrol price data contained in the study, one finds the same, but even stronger, inverse relationship. In Figure 1 (bottom) annual petrol use per capita is plotted against petrol price relative to per-capita income, where 1.0 indicates the average relative petrol price of all 32 cities. Now it becomes plausible why petrol consumption in Australian cities is much lower than in cities of the United States, although Australian cities are no less dispersed than cities in the United States: because petrol is twice as expensive in Australia. One might hypothesise that urban density is only an intermediate variable and that the real cause behind a high level of transport energy consumption is the availability of cheap transport energy.

More evidence questioning the importance of urban density as a determinant of transport energy consumption is contained in Breheny (1992). However, beyond that doubt there is not much agreement about what the energy-efficient city of the 21st century should look like. The situation is characterised by Schmitz (1991):

> *"A settlement structure which is 'ideal' with respect to transport is not known today. Planning paradigms such as small-scale mixed land use, promotion of inner cities through higher densities, decentralised concentration and development axes in regional planning or the development of balanced functional urban regions still have the character of catchwords. They require first to be specified in more concrete terms and second to be assessed with respect to their efficiency and feasibility."*

In this situation computer simulation models of urban land use and transport may have a new role to play. There is a long history of ambitious efforts to introduce computer simulation techniques into planning since the appearance of the first digital computers in the late 1950s. However, with very few exceptions none of these models has made a permanent impact on the practice of planning and only few of them have survived as research tools in university departments (see Wegener, 1994). Today the environmental debate poses questions which are not likely to be handled by incrementalist, piecemeal approaches but require a fundamental review of the way cities are organised. This requires once again a comprehensive view of cities as complex systems. However, this time the models will not be used, as previously, to forecast the direction of urban *growth*, but to guide the spatial *reorganisation* of metropolitan areas towards environmental sustainability.

2. Do we need to rebuild Dortmund?

This chapter reports on a project in which a land-use transport model was used to explore the impacts of strategies to reduce transport-related CO_2 emissions by transport demand management in the metropolitan area of Dortmund in Germany.

2.1 The study area

The study area was the metropolitan area of Dortmund in Germany. Dortmund (population 615,000) is the most eastern of the cities of the Ruhr Area, the largest industrial region in Germany. It used to be one of the major centres of coal mining and steel manufacturing in Germany, but with the decline of the mining and steel industries it has been reduced to being the administrative, service and retail centre for a large metropolitan area (see Figure 2).

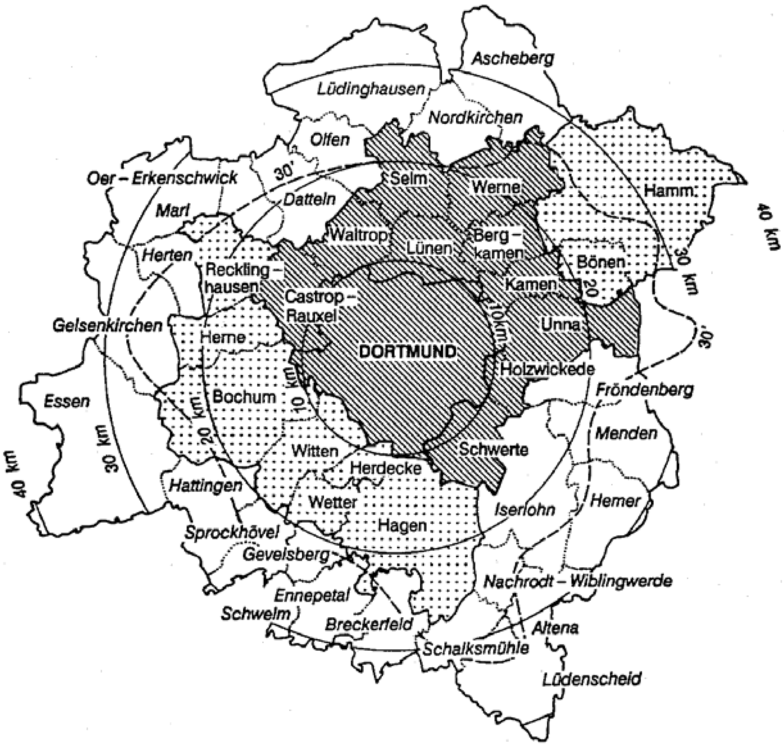

Fig. 2. The metropolitan area of Dortmund

The region represented in the model is the commuter catchment area of Dortmund containing Dortmund itself and eighteen neighbouring communities. The region is relatively compact; most of its settlements lie within the 30-minute travel-time isochrone by car from central Dortmund.

The municipalities in the hatched area are exclusively oriented towards Dortmund; the dotted areas are larger self-contained cities or communities oriented towards more than one centre. The study area has a population of approximately 2.3 million.

2.2 The model

The Dortmund model is a model of intraregional location and mobility decisions in a metropolitan area (Wegener, 1983; 1985; 1996). It receives its spatial dimension by the subdivision of the study area in thirty *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 walking and cycling and all past and future network changes. It receives its *temporal* dimension by the subdivision of time into fifteen time periods of three years' duration.

Figure 3 is a schematic diagram of the major subsystems considered in the model and the interactions between them and of the most important policy instruments. 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).

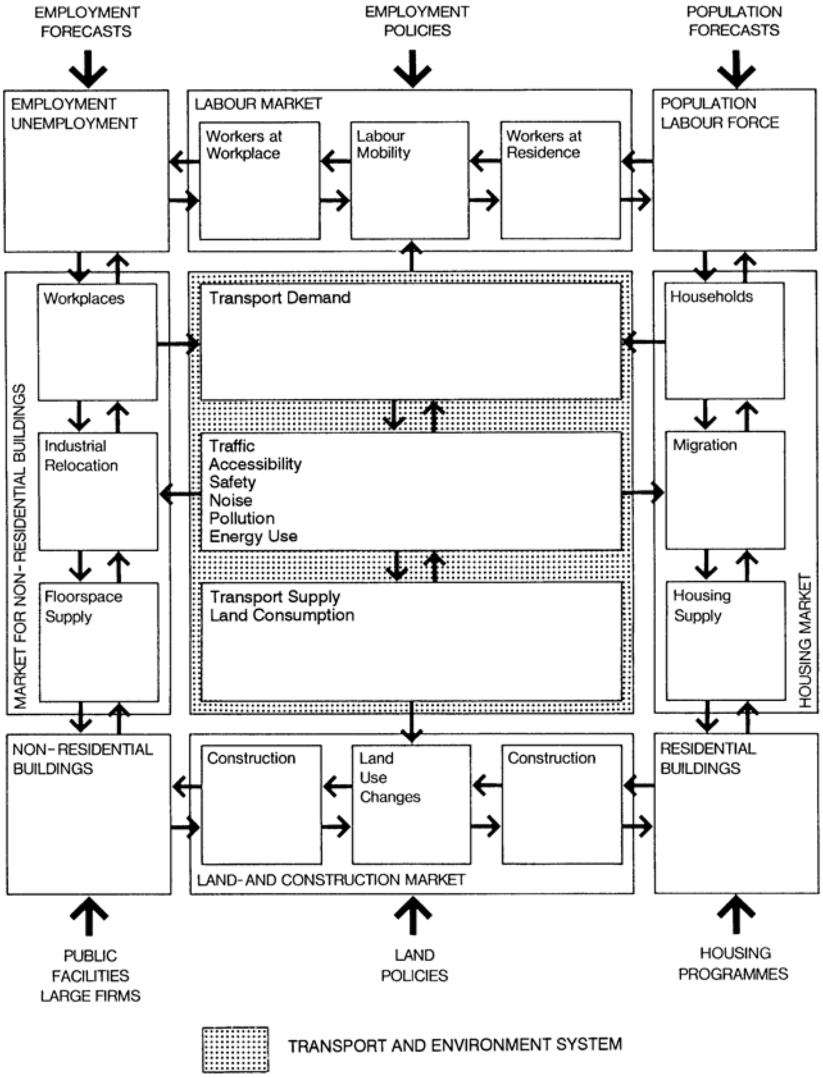

Fig. 3. Major subsystems of the Dortmund model

The actors representing these stocks are *individuals or households*, *workers*, *housing investors* and *firms*. These actors interact on five *submarkets* of urban development. The submarkets and the market transactions occurring on them are:

- the *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 and their consequences: changes of accessibility, road accidents, traffic noise, air pollution and energy use.

For each submarket, the diagram shows supply and demand and the resulting market transactions. Choice in the submarkets is constrained by supply (jobs, vacant industrial or commercial floorspace, vacant housing, vacant land, network capacity) and guided by attractiveness, which in general terms is an actor-specific aggregate of *quality* 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.

With this model structure the Dortmund model is one of the few operational urban models in which the two-way interaction between land use and transport in urban areas is explicitly modelled (Webster et al, 1988; Wegener, 1994). Figure 4 summarises these interactions: The distribution of *land uses*, such as residential, industrial or commercial determines the location of households and firms and so of human *activities* such as living, working, shopping, education or leisure. The distribution of *activities* requires spatial interactions or trips to overcome the distance between them. These trips occur in the *transport system* in a sequence of choices: decisions to own a car, to make a trip and to select destination, mode and route. These decisions result in flows in the networks and congestion and increases in travel times, distances and costs. Travel times, distances and costs create opportunities for spatial interactions and can be measured as *accessibility*. The distribution of *accessibility* in space, together with other attractiveness indicators, determines location decisions of investors and so results in new construction, modernisation or demolition, i.e. changes to the *land-use* system, which in turn determine the location decision of users and hence the location of activities.

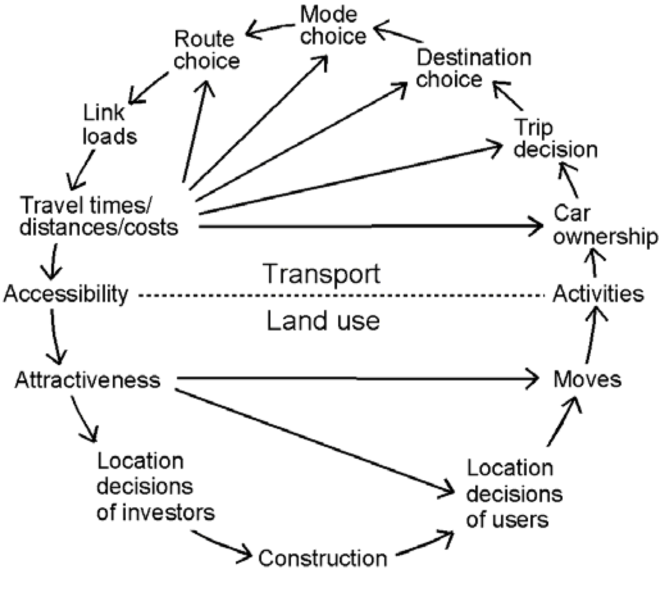

Fig. 4. The 'land-use transport feedback cycle'

Figure 5 portrays the same interrelationships in a format proposed by Brotchie (1984). The 'Brotchie Triangle' represents the universe of possible constellations of spatial interaction and spatial structure in an urban area. Spatial structure is represented on the horizontal axis as spatial dispersal (for instance, mean travel distance of employment from the centre of the region), spatial interaction on the vertical axis as some measure of total travel such as mean travel distance to work.

Any city will lie between three hypothetical points in the diagram: point A represents a situation in which all jobs are at the centre, i.e. dispersal is zero. Both points B and C represent regions in which all jobs are as dispersed as the population. Point B represents a situation in which workers choose their residence without regard of distance, point C a situation in which they walk to work. The model answers the question in which direction the real city, point D, will shift: a shift up or down indicates reorganisation or *moves*, a shift to the left or right indicates *construction*, or rebuilding the city.

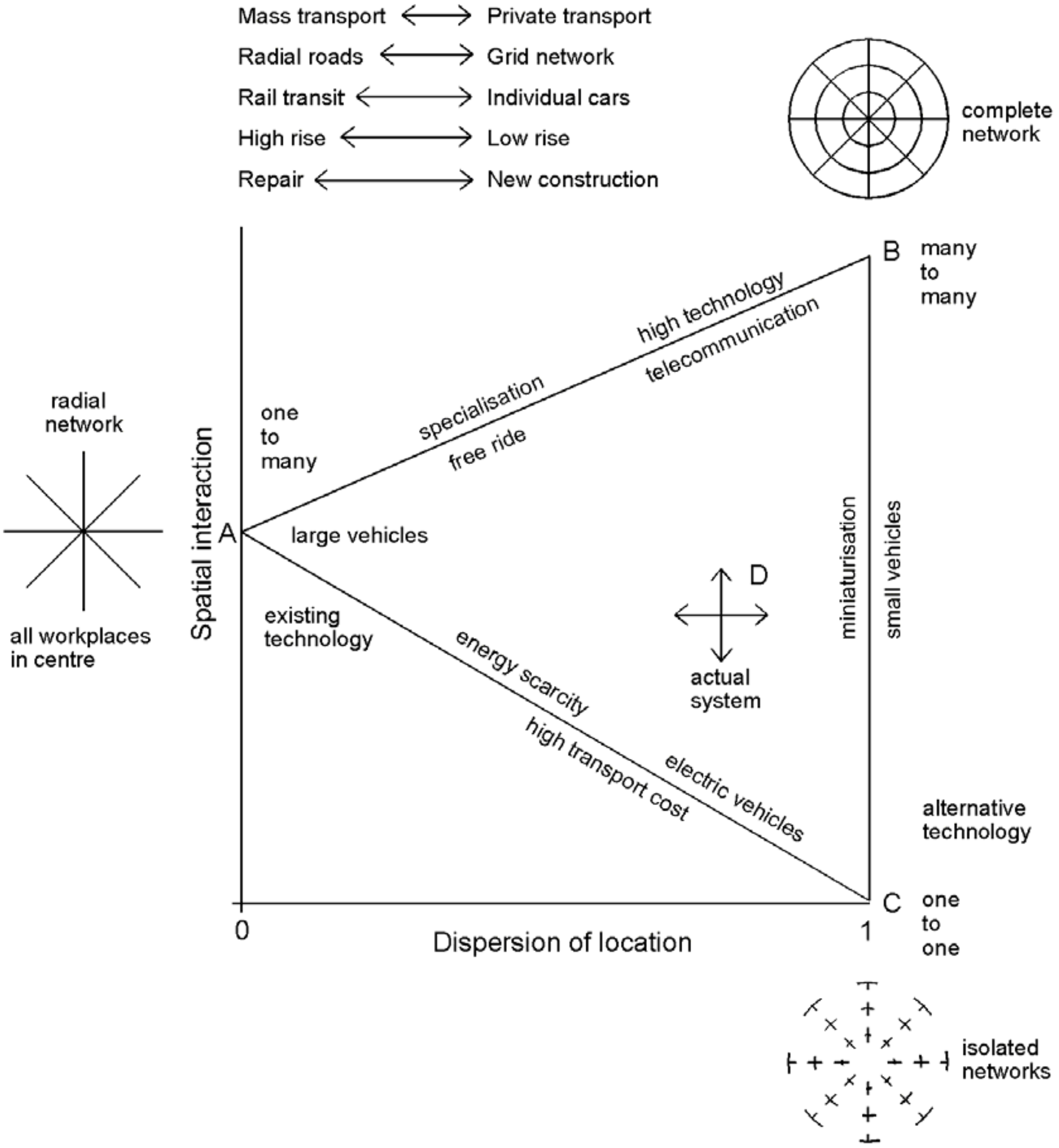

Fig. 5. The 'Brotchie Triangle'. Source: Brotchie, 1984

2.3 The scenarios

Three types of scenarios were simulated: scenarios of travel cost changes, scenarios of travel speed changes, and scenarios in which changes of both travel costs and travel speeds were combined. Table 1 shows the list of scenarios and their specification. The first two groups of scenarios are similar to the policy tests conducted by the International Study Group on Land-Use Transport Interaction (ISGLUTI) (Webster et al, 1988); the combination scenarios go beyond ISGLUTI. Scenarios 30 and 40 were defined differently from their ISGLUTI counterparts. In Scenario 30 a much faster increase of petrol price was assumed (all price increases include inflation), but the scenario was made more realistic by assuming that car manufacturers would respond to significant increases of fuel price by offering more energy-efficient cars. In Scenario 40 public transport was not only made faster but also having more trains and busses to accommodate additional ridership.

Table 1. Scenarios

Scenario	*Specification*
Base scenario:	
00	Base scenario.
Travel cost scenarios:	
30	Increase petrol price incrementally to 12 DM/l by 2015 and reduce average petrol consumption of cars incrementally to 5 l per 100 km by 2015.
32	Increase inner-city parking charges incrementally, after 2000 quintupled.
33	Reduce public transport fares incrementally, after 2000 free.
35	Increase public transport fares incrementally, after 2000 doubled.
37	Increase all transport costs incrementally, after 2000 doubled.
Travel speed scenarios:	
40	Make public transport faster (25 %) and reduce headways (50 %) and make cars slower (40 %).
46	Make public transport and cars faster (25 %).
47	Make public transport and cars slower (40 %).
Combination scenarios:	
53	'Promotion of public transport': scenarios 30+32+40.
54	'Reduction of mobility': scenarios 30+32+35+47.

The results of the simulations are summarised in Figures 6 to 8. In each of them the evolution of the urban system between 1970 and 2015 is represented by trajectories of one variable for each of the simulated scenarios. Until the mid-1990s, all scenarios coincide because the policies specified in Table 1 are introduced after 1993; this serves to visualise the development in the past. The trajectory of each scenario is indicated by its number as in Table 1; Scenario 00 is the 'base scenario' defined as the trend scenario without policy changes.

Figure 6 (top) shows the effect of the various policies on average trip length. It can be seen that in the base scenario average trip length increases from 8 to 13 kilometres between 1970 and 2015, and that policies to reduce travel cost (Scenario 33) or increase travel speed (Scenario 46) result in longer trips. Increasing travel costs (Scenarios 30, 37) and making travel slower (Scenarios 40, 47) result in shorter trips, but this effect is diluted after 2000 by growing affluence and greater fuel efficiency of cars. The reduction effect is strongest in the combination scenario which penalises mobility altogether (Scenario 54), whereas in the combination scenario which promotes public transport (Scenario 53) the loss of mobility is much smaller. Figure 6 (bottom) shows that the impact of the combined policies is even stronger if only car travel is considered. Here Scenario 53 shows its superiority because it results in a much stronger reduction of car-km travelled than Scenario 54, in which no attractive travel alternatives by public transport exist. Indeed the total distance travelled by car in the region is more than halved in Scenario 53.

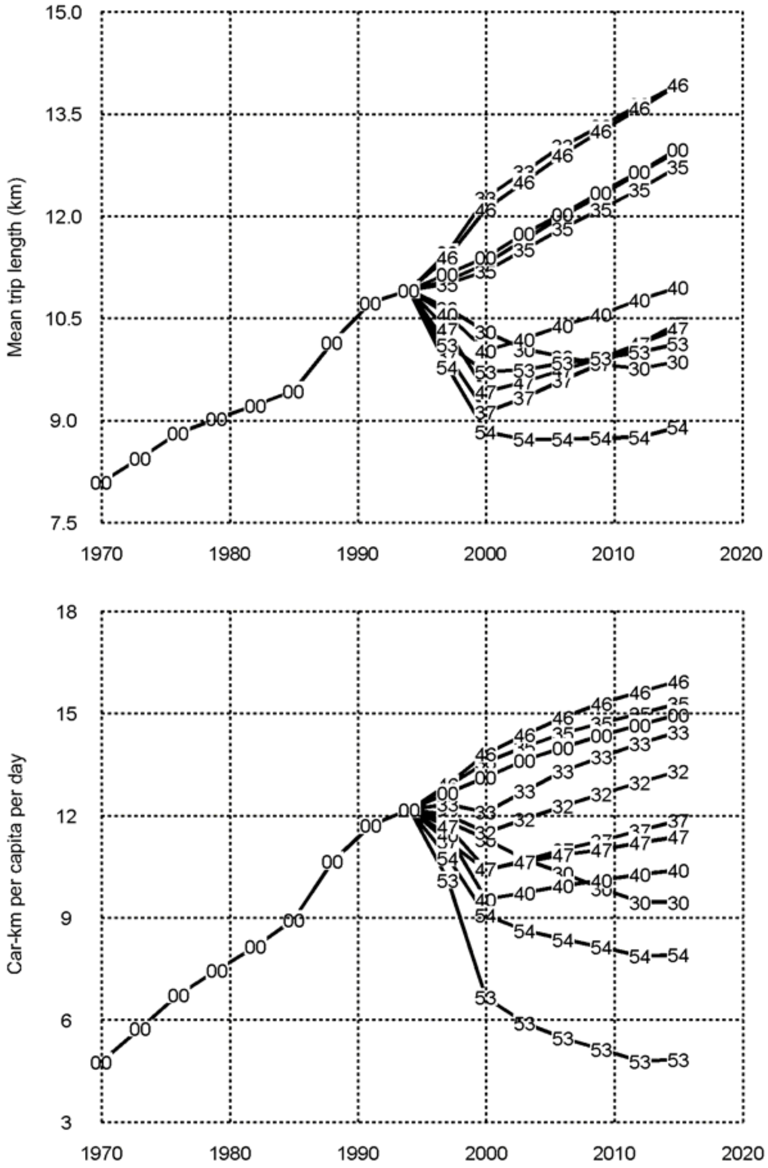

Fig. 6. Mean trip length (top) and car-km per capita per day (bottom)

Figure 7 (top) shows that this is due to the substantial modal shift occurring in the region in that scenario. It can be seen that public transport has declined from 30 percent of all trips in 1970 to less than 20 percent today. One can see that neither massive investment in public transport at the expense of car traffic (Scenario 40) nor making public transport free (Scenario 33) will result in substantial increases in ridership. Nor will an increase in the out-of-pocket cost of car travel (Scenario 30) help to revitalise public transport; in combination with increased fares (Scenario 54) it will even discourage public transport use. However, if the improvement of public transport is combined with monetary disincentives to car travel (Scenario 53), the effect is a dramatic rise in public transport use to over forty percent of all trips.

All this translates into significant savings in energy use and CO_2 emissions as shown in Figure 7 (bottom). The diagram shows the savings in energy use and CO_2 emissions by all transport, including the additional busses and trains necessary for the growing number of passengers. Despite the growth in car ownership and travel distances, CO_2 emissions per capita are likely to decrease after 2000 because of greater energy efficiency of cars. However, without intervention the goal to reduce CO_2 emissions by 30 percent compared with 1987 cannot be achieved. None of the policies meets this target except those in which car travel is made significantly more expensive. Of these Scenario 53 implies the smallest sacrifice in mobility.

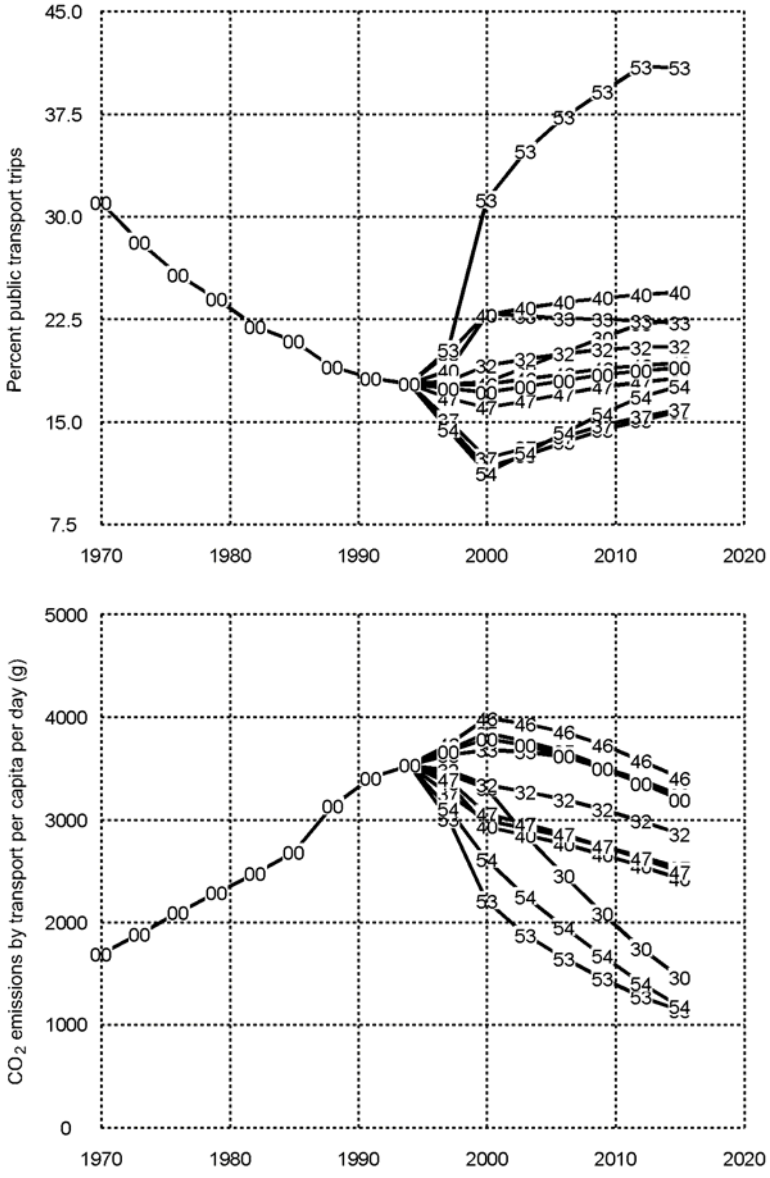

Fig. 7. Percent public transport (top) and CO_2 emissions of transport (bottom)

How much of this effect is due to changes in land use rather than travel behaviour? Figure 8 gives some idea. The top diagram shows the 'Brotchie Triangle' of the Dortmund region between 1970 and 2015. It is apparent how the region is drifting apart in the base scenario both in terms of workplaces and residences. The lower diagram is a blow-up of the highlighted area in the top diagram with the trajectories of the other ten scenarios added. The vertical lines at right indicate the line B-C of the Brotchie Triangle, i.e. dispersion of population.

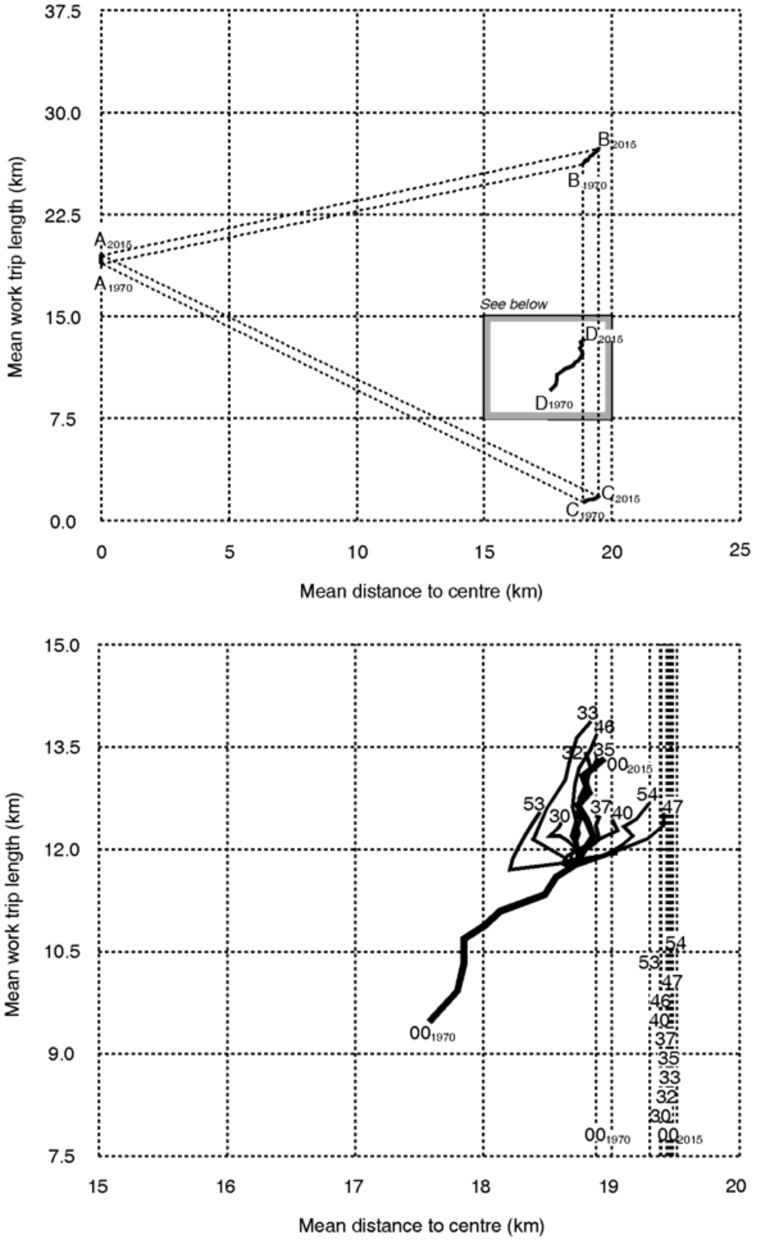

Fig. 8. The 'Brotchie Triangle': base scenario (top) and all scenarios (bottom)

In all scenarios the spatial structure of the region moves towards more dispersal and more travel. Changing the cost of travel (Scenarios 30, 32, 33, 35, 37) has only little effect on location, but substantial effect on distance travelled. If travel speeds are changed (Scenarios 40, 46, 47), the impact on location is stronger. In both cases the direction of change is related to the share of public transport trips (see Figure 7, top). Higher shares of public transport (Scenarios 30, 32, 33, 53) are associated with a more compact city, whereas car-dependent cities (Scenarios 37, 47, 54) tend to be more dispersed. Workplace location responds stronger to transport changes than housing. If travel speeds are reduced (Scenarios 40, 47, 54), workplaces move outward to be closer to residences. This explains why Scenario 40 (in which public transport becomes faster and car travel slower) combines a gain in public transport with more dispersed employment. If car travel costs rise in conjunction with higher public transport use (Scenarios 30, 53), both workplaces and residences centralise. Scenario 53 leads to the most compact cities of all scenarios both in terms of workplaces and residences.

The impacts on mean work trip length are as expected. Higher speeds (Scenario 46) lead to longer work trips, whereas slower speeds (Scenarios 40, 47, 53, 54) result in energy savings. Because of their limited adjustment potential, the savings of worktrips are small compared with those of all trips (see Figure 6, top); this suggests that the largest savings are made with respect to 'voluntary' trips to shopping and leisure. Remarkably, the moderate Scenario 53 has shorter work trips than the radical Scenario 54.

It is frequently argued that increasing the fuel tax as in Scenario 53 would be socially unfair as it would restrict automobility to the rich. Figure 9 (top) looks into that issue. It shows car-km per household per day for four household income groups for Scenario 53. As one might expect, poor households (1) drive less than the middle-class (2) or the more affluent (3-4), but all households increase their distance travelled by car during the 1970s and 1980s. The drop in all four trajectories illustrates that all households are affected by the policies of Scenario 53, but that the more affluent households give up more in absolute terms, with the effect that after 2000 the ratio of car travel between the four household groups is rather more balanced than in the 1970s and 1980s, though on a lower level.

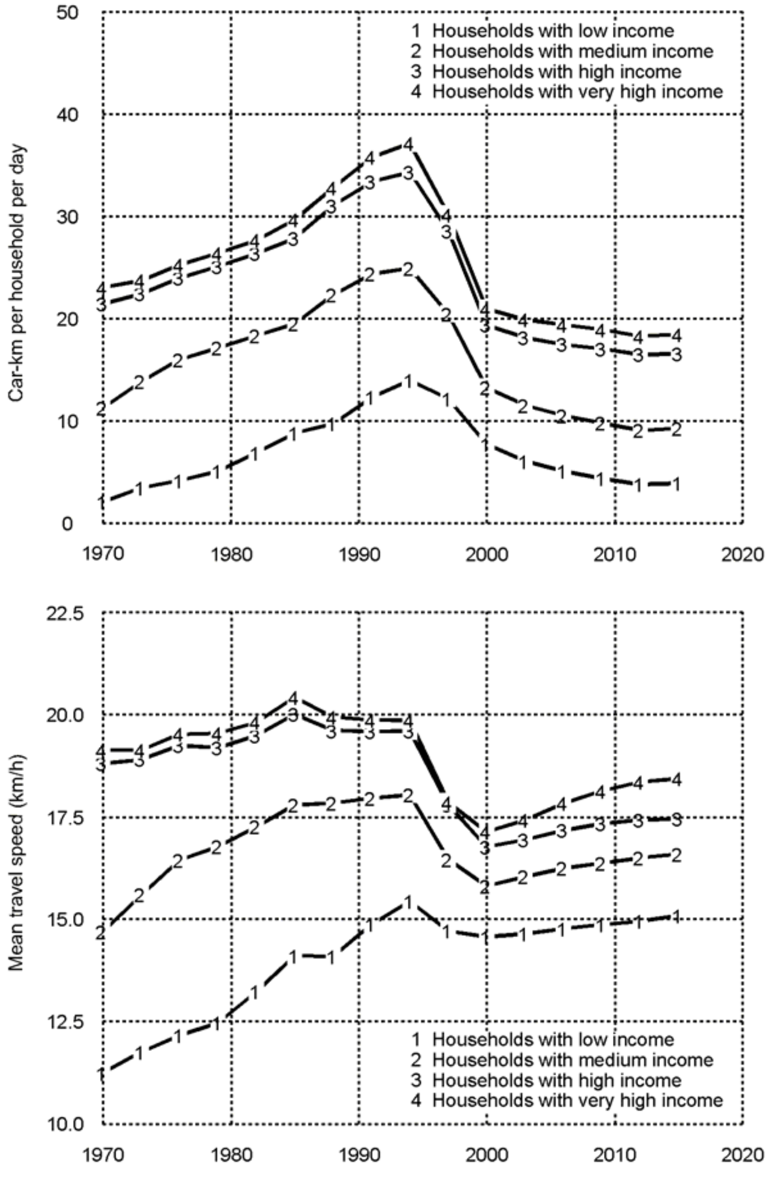

Fig. 9. Car-km per household per day (top) and mean travel speed (bottom) in Scenario 53

Figure 6 (bottom) shows average travel speeds of all trips by household income group. The two top income groups, because of their level of car ownership, already in the 1970s enjoyed high average travel speeds. From the mid-1980s even for them no further increases in travel speed have been possible because of increasing road congestion. Households with medium or low incomes, however, have been able to increase their average travel speeds by buying more cars. After Scenario 53 becomes effective, all income groups travel more by public transport and hence more slowly, but when more energy-efficient cars become available after 2000, gradually return to more car travel. As above, the ratios between the travel speeds of the four groups are more balanced after the introduction of the policies of Scenario 53 than before.

A final argument against Scenario 53 might be that the money required to improve public transport as substantially as assumed in the scenario would be unaffordable to local governments. A simple calculation as the one shown in Table 2 demonstrates that, despite the decline in car-km travelled, the additional revenue from the increased fuel tax would be sufficient to more than double the annual expenditure of the regional public transport authority. In combination with the expected increase in fare revenue, this would allow them not only to accommodate the additional passengers by running more trains and buses, but also to significantly improve the quality of service by more comfortable vehicles, more attractive rail stations and bus stops and better passenger information.

Table 2. Financial impacts of Scenario 53

	Scenario 00	*Scenario 53*
	2015	2015
Million car-km/year	7,748	2,578
Fuel price (DM/l)	2.7	12
Fuel tax revenue (million DM)	496	1,289
... Difference (million DM)	793	
... in DM of 1990 (million DM)	380	
For comparison: VRR[a]		
Total revenues (million DM)		148
Total expenditures (million DM)		367
Deficit (million DM)		219

[a] *The Public Transport Authority Ruhr (VRR) is approximately five times larger than the study area. The numbers were scaled down accordingly.*

2.4 Relevance of the results

The main conclusion from these results is that a combination of policies to increase the cost of car travel and to improve the quality of public transport would permit a significant reduction of energy use and CO_2 emissions of urban transport without unacceptable losses of mobility, without aggravating social disparities, and without additional costs for the public authorities. Other factors not considered in the analysis, such as car sharing (increase of car occupancy), chaining of trips (reduction of number of trips), information and marketing and a potential change of values in the direction of growing environmental awareness, all work in the same direction and would contribute further to energy conservation.

This result implies that the present settlement system of European cities contains a huge unused potential for reducing trip lengths and avoiding trips without fundamentally changing the physical layout of cities. It does not suggest that rebuilding cities does not make sense, but for other, such as ecological, social or aesthetic reasons, and not for energy conservation.

3. Future work

To further test the hypothesis presented in this chapter, in a current project hypothetical *urban structures* are being compared in the light of new demographic developments, new lifestyles and new transport and information technologies, using criteria such as accessibility, total passenger-km, energy use, land requirement and other environmental indicators with respect to three objectives:

- *Equity*. The urban structure should be equitable. Social disparities should not be aggravated by the spatial organisation of the urban area. There should be no social or spatial discrimination in the distribution of accessibility, amenities or ecological disadvantages.
- *Sustainability*. The urban structure should be ecological in the sense of environmental sustainability. The consumption of non-renewable resources such as energy or land and the pollution of the environment such as noise intrusion, air pollution, water and soil contamination should be as low as possible.
- *Efficiency*. The urban structure should be efficient in that it satisfies the mobility needs of firms and households with as little effort and cost as feasible.

An urban structure is defined in the project as a combination of a *land use system* and a *transport system*:

- A *land use system* is a spatial configuration of dwellings, workplaces and public facilities within an urban area, i.e of land use categories such as high-density inner-city residential areas, large high-rise housing estates, low-density suburbs with detached houses, medium-density mixed-use areas, office parks, industrial estates or greenfield shopping centres. Land use scenarios considered for investigation are
  - 'Compact City': intensified urban density in the inner city,
  - 'Polycentric City': decentralised concentration in subcentres,
  - 'Garden City': dispersed concentration around former village cores,
  - 'Auto City': the abandonment of urban centres.

Within one land use system different patterns of activities and spatial interaction are possible. An infinite number of associations of workers and jobs via commuting is possible with the same spatial distribution of dwellings and workplaces. Also with a given distribution of shopping and service facilities an infinite number of spatial interaction patterns for shopping and service trips is possible. Which activity and interaction patterns emerge depends on the transport system connecting the locations of activities.

- A *transport system* is defined by the transport infrastructure, i.e. the road network and the public transport network, including the level of service of public transport, as well as cycling and walking. The transport system is also defined by policies that influence mobility in the form of technical standards, legal or institutional regulations, taxes and fees. Transport scenarios considered for investigation are
  - 'Star Network': radial public transport and highway network,
  - 'Grid Network': rectangular public transport and highway network,
  - 'Mixed Network': radial public transport and rectangular highway network,
  - 'Local Networks': loosely coupled local transport networks.

Each transport scenario may be combined with different levels of service and fares of public transport and levels of car ownership and car travel costs and speed limits for the road network.

There have been only very few studies in which the social and environmental impacts of different configurations of urban form have been systematically compared. The ISGLUTI study (Webster et al, 1988) examined relatively small modifications of existing land use and transport systems and contained only a minimum of environmental indicators. Rickaby (1987; 1991; Rickaby et al, 1992) used the TRANUS land-use transport model (de la Barra et al, 1984; de la Barra, 1989) to compare spatial configurations of cities with respect to accessibility and energy efficiency, yet the results were inconclusive because of a too limited set of investigated alternatives. Roy (1992), using an analytical model of a circular city, confirmed the hypothesis that spatial reorganisation (moves) can contribute much more to reducing the need for travel than increasing density (rebuilding).

The model used in the analysis is a microsimulation model as a successor to the aggregate urban simulation model described in this chapter (Spiekermann and Wegener, 1992). In the model, decisions affecting the construction of buildings are exogenous, but decisions affecting the location of activities as well as travel decisions are endogenous subject to constraints such as job availability, housing supply, transport costs and traffic constraints. An important element of the new model is its combination with a geographical information system (Spiekermann and Wegener, 1993). The GIS is used to generate artificial urban structures from a spatial database of the Dortmund metropolitan area. Each land use system so created is characterised by empirical data describing the socio-economic composition of the population, the supply of jobs and the locations of public and private shopping, education, health and leisure facilities based on actual conditions in the Dortmund region.

4. Conclusions

This chapter reported on a project in which a land-use transport model was used to explore the impacts of strategies to reduce transport-related CO_2 emissions in the metropolitan area of Dortmund in Germany.

The simulations showed that a combination of policies to increase the costs of car travel and to improve the quality of public transport would result in a significant reduction of energy use and CO_2 emissions of urban transport without substantial land use changes and without causing unacceptable losses of mobility or increasing social disparities or involving additional costs for the public authorities. This result suggests a reassessment of the widely held opinion that the only way to reduce the need for automobile travel in urban regions is a return to mixed-use, compact land-use patterns.

The urgency of the need to reduce energy use and CO_2 emissions in urban areas may grant a new lease of life to comprehensive land-use transport models. This time the models will not be used, as previously, to forecast the direction of urban *growth*, but to guide the spatial *reorganisation* of metropolitan areas towards environmental sustainability. However, if the contribution of the models is to be useful, they must have the requisite variety to respond to the new issues relevant to today's cities. First of all they need to contain the necessary submodels to forecast the impacts of transport and/or land-use policies, not only in terms of travel cost or travel time or accessibility, but also in terms of environmental indicators such as energy use, air pollution, land consumption, noise intrusion and road accidents. Second, they must be able to forecast these indicators with sufficient spatial detail to assess their implications for various social or ethnic groups in the city. Lastly, they must be capable of reproducing the potential substitution between travel and location decisions regarding the spatial pattern of daily activities such as living, working, shopping or education or recreation. Today there are only few models satisfying all of these requirements (see Wegener, 1994). However, recent advances in data availability, modelling techniques and computer memory and speed make it likely that a new generation of urban models will emerge that could live up to the new challenge.

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