# ENERGY SCARCITY AND CLIMATE CHANGE: THE CHALLENGE FOR URBAN MODELS

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**Abstract:** Today integrated mathematical models of urban land use and transport are applied to a growing number of metropolitan areas. Recent developments in data availability, computer science, modelling theory and methodology have widened the range of issues that can be addressed. However, many present urban models have not yet responded to new challenges urban planning will face in the future, such as energy scarcity and climate change. The fundamental changes in the priorities and challenges of planning caused by energy scarcity and climate change will have significant impacts on the theory and method of urban modelling. The paper analyses the deficiencies of present urban models in the light of the new challenges and draws conclusions on how to overcome them – based on the conviction that at times of fundamental change rational exploration of future actions is more important than ever.

**Keywords:** Energy scarcity, climate change, urban models, modelling theory, modelling method

## 1. INTRODUCTION

Integrated mathematical models of urban land use and transport have a history of almost half a century. Today such models are applied to a growing number of metropolitan areas. Recent developments in data availability, computer science, modelling theory and methodology have widened the range of issues that can be addressed.

However, many present urban models have not yet responded to new challenges urban planning will face in the future, such as energy scarcity (alternative vehicles or fuels, decentralised energy provision, energy-efficient buildings), climate change (reduction in $CO_2$ emissions, anti-sprawl regulation, promotion of public transport, cycling and walking, travel demand management) and the resulting social conflicts (distributive effects, access to basic services). Many models do not consider travel cost in their trip generation, trip distribution or modal split components or work with elasticities estimated in times of cheap energy.

The fundamental changes in the priorities and challenges of planning caused by energy scarcity and climate change will have significant impacts on the theory and method of urban modelling: less reliance on observed behaviour, more foundation on strong theory, less statistical calibration, more plausibility analysis, less focus on choices, more attention to constraints. The paper analyses the deficiencies of present urban models in the light of the new challenges and draws conclusions on how to overcome them – based on the conviction that at times of fundamental change rational exploration of future actions is more important than ever.

## 2. NEW CHALLENGES FOR URBAN MODELS

### 2.1 History of Urban Models

Integrated mathematical models of urban land use and transport appeared first in the United States in the early 1960s. In particular the Lowry model (1964) stimulated modelling efforts in many large metropolitan areas. However, many of these efforts failed to deliver because of unexpected difficulties in data collection, calibration and computing. Moreover, the models were focused on growth allocation and transport efficiency and failed to address new problems of social and ethnic urban conflict. In addition, the synoptic rationalist planning paradigm the models were based on was replaced by incremental, participatory ways of planning.

In his "Requiem for large-scale models" , Douglass B. Lee (1973) accused the models of "seven sins": hypercomprehensiveness, grossness, hungriness, wrongheadedness, complicatedness, mechanicalness and expensiveness. The urban modelling community retreated into the basements of academia.

The requiem was premature. Some of the technical problems were relieved by better data availability and faster computers. The models became more disaggregate and were based on better theory, such as bid-rent theory or discrete choice theory and user equilibrium in urban networks. Better visualisation tools made the model results more understandable by citizens and decision makers. A new generation of models was more sensitive to issues of social equity.

The 1990s brought a new interest in urban land-use transport models: Environmental legislation in the USA triggered a new wave of applications of urban land-use transport models. In Europe, the European Commission funded a number of studies employing urban land-use transport models. Several urban land-use transport models, such as TRANUS, MEPLAN, IMREL, RURBAN, METROPILUS, UrbanSim, DELTA and PECAS, were applied to a growing number of metropolitan areas. The first urban models, TRANUS and UrbanSim, are available as Open Source software.

The early 2000s have opened a seemingly unlimited golden future for urban modelling (Wegener, 2004): Improved data availability through geographic information systems and new developments in computer science, such as parallel computing, have reduced former technical limitations. New advances in modelling theory and methodology, such as activity-based and agent-based models, have widened the range of issues that can be addressed. A global community of urban modelling experts meets at conferences, such as the World Conference on Transport Research (WCTR), the Conference on Computers in Urban Planning and Management (CUPUM) and the Annual Meeting of the Transportation Research Board (TRB).

However, not all modelling projects were successful: Many large modelling projects failed to deliver in the time available or had to reduce their too ambitious targets. Many applications of established models by others than their authors did not become operational. Many projects got lost in data collection and calibration and did not reach the state of policy analysis. Many projects remained in the academic environment and produced only PhD theses. Many applications of microscopic activity- or agent-based models ignored the pitfalls of stochastic variation and published results with illusionary precision.

In addition, most present modelling projects have not yet responded to the new challenges urban planning will face in the future.

### 2.2 New Challenges

Twenty percent of mankind command eighty percent of the world's wealth and are responsible for eighty percent of energy use and greenhouse gas emissions. This inequality is growing. Since the 1970s, the per-capita income of the industrialised countries has grown by a factor of ten, whereas that of the developing countries has only tripled. But another multiplication of production, consumption and resource use of the rich countries as in the last thirty years would exceed the resources of the earth. Today it is foreseeable that if the energy consumption of the world continues to grow as in the past, the known deposits of fossil fuels will be exhausted before the end of this century. If, however, one adds the growing energy demands of Brazil, China, India and Russia, they will already be depleted in a few decades. Similar constraints apply to other raw materials.

However, only few politicians and scientists are seriously taking account of this situation. Only few countries meet the target set by the United Nations to spend 0.7 percent of their national product on development aid. Mainstream neo-liberal economic theory continues to put its stakes on further deregulation of international trade and unconstrained economic growth. There are virtually no theories, concepts or visions of how a sustainable economic order might be developed without continued material growth in the richest countries of the world.

In July of 2008 the price of crude oil rose to almost 150 US $ per barrel. During the recent world-wide financial and economic crisis it went back to below 40 US $ per barrel (Figure 1).

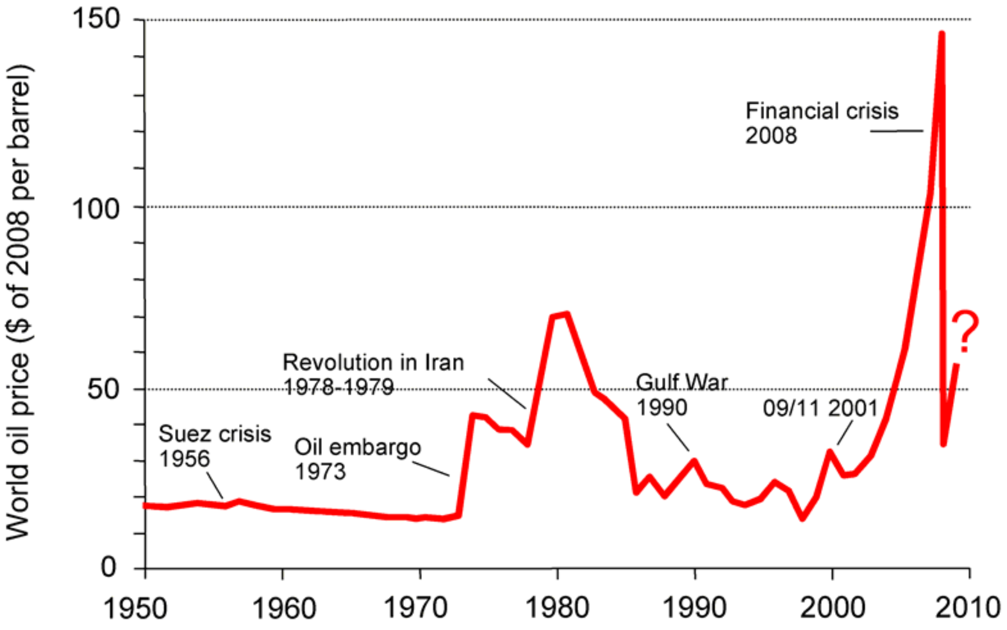

Figure 1 World oil price 1950-2009 (WTRG Economics 2007, updated)

Most experts believe that, because of the final depletion of oil resources, of political instability in the Middle East and of rising demand of fast growing developing countries, oil will continue to become more expensive. This will have significant impacts on fuel production, fuel types, fuel efficiency, location choice and mobility.

Closely related to this are the challenges of climate change. Climate researchers agree that anthropogenic greenhouse gas emissions contribute significantly to global warming and that to avoid the worst implications of global warming a reduction of greenhouse gas emissions by fifty percent world-wide is necessary. The question is how this reduction is to be achieved, Figure 2 shows total $CO_2$ emissions per year by the fifteen largest emitter countries 1990-2004.

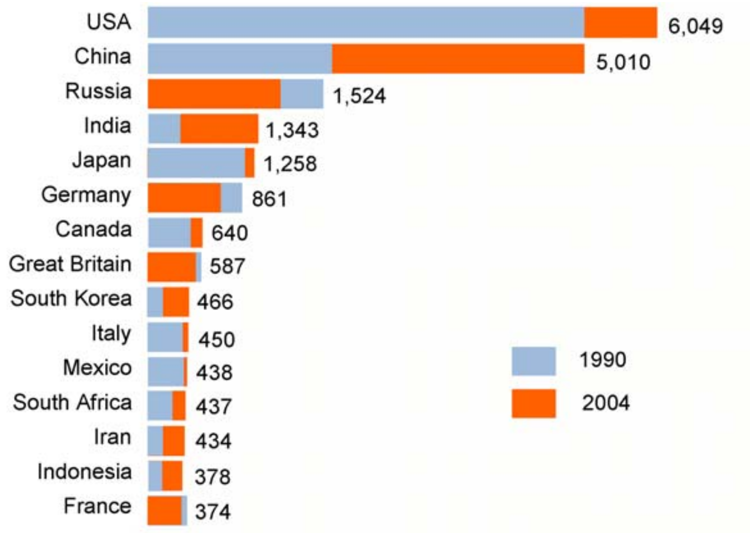

Figure 2 $CO_2$ emissions per year (million t) 1990-2004 (CDIAC, 2006)

However, to demand that all countries equally reduce their greenhouse gas emissions, would prevent the least developed countries from advancing their economies. Figure 3 therefore shows $CO_2$ emissions per capita per year 1990-2004 compared to the $CO_2$ emissions considered as climate-neutral (2 t per capita per year). Now it becomes apparent that countries like the United States or Canada need to reduce their $CO_2$ emissions by 90 percent, most European countries by 80 percent and China by 50 percent in order to allow developing countries like India, Bangladesh or Rwanda to catch up in economic development.

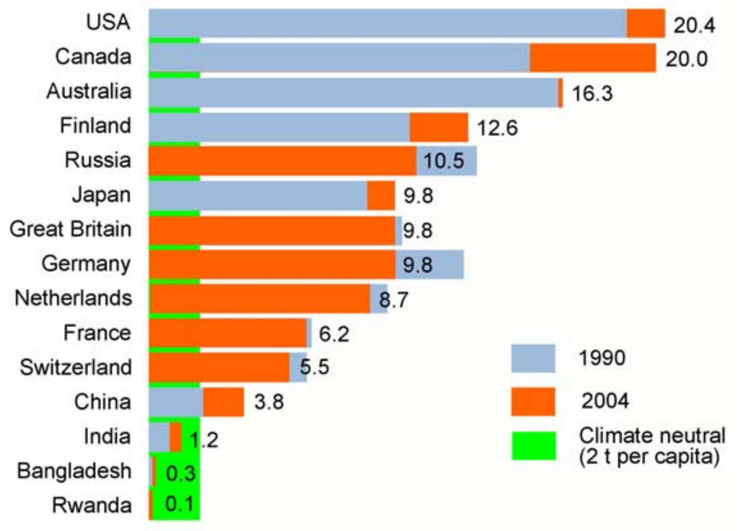

Figure 3 $CO_2$ emissions per capita per year (t) 1990-2004 (CDIAC, 2006)

The growing awareness of the seriousness of the challenge has led to the proclamation of ambitious greenhouse gas emission targets. In March 2007, the EU heads of state signed a resolution to achieve 20 percent less energy consumption, 20 percent renewable energy and 20 percent less $CO_2$ emissions compared to 1990 by 2020, and 30 percent less $CO_2$ emissions if other industrial countries join. In August 2007 the German government adopted the goal to reduce $CO_2$ emissions by 40 percent until 2020. In June 2007, the leaders at the G-8 Summit committed their countries to aim at a world-wide reduction of greenhouse gas emissions by 50 percent until 2050. In March 2007, the British Prime Minister Blair announced that Great Britain will reduce its greenhouse gas emissions by 26 percent to 32 percent until 2020 and by 60 percent until 2050. In the US presidential campaign of 2008, Barack Obama said he would aim at a greenhouse gas reduction by 80 percent below 1990 levels until 2050. Many other national, state and local governments have made similar commitments in their spatial development or transport plans.

### 2.3 Urban Models: Fit for the Task?

The policy challenges of achieving the energy transition and protecting the climate for cities are closely related. The ultimate depletion of fossil fuels and the mitigation of climate change both require the reduction of the use of carbon-intensive fossil fuels by more energy-efficient vehicles, alternative fuels and changes in mobility and location behaviour.

To achieve this will require new policies and policy packages in urban transport and land use planning, such as the promotion of alternative vehicles and fuels and alternative energy sources, such as solar or geothermal energy and the promotion of better heat insulation of buildings, the redirection of transport investment to public transport, transport demand management through road pricing, speed limits or other restrictions of car driving, the implementation and enforcement of anti-sprawl legislation, measures of flood prevention and the definition and maintenance of minimum standards of access to basic services, such as retail, health care or education, and participation in social and cultural life.

These policies are likely to generate significant distributive problems and social conflicts. Planners will therefore have to identify groups or communities affected by energy scarcity and climate change and to design and test compensation policies to assist the most affected.

What will this mean for urban models? Will they be able to adequately forecast the effectiveness and impacts of these new policies?

The answer is that, except for empirical and modelling studies at the frontier of research (e.g. Ettema, 2009; Ettema *et al.,* 2008; 2009; Ferdous *et al.*, 2009), most transport and integrated land use and transport models applied in the planning practice have not yet responded to these new challenges. Many current urban models cannot model the impacts of significant energy price increases as their travel models do not consider travel cost in their trip generation, trip distribution or modal split models. But even models that consider travel costs in the form of "generalised travel cost" do not predict induced or suppressed travel demand because they work with fixed trip rates. Many land-use and transport models work with elasticities estimated in times of cheap energy which may not be valid after significant fuel price increases. Many urban models do not consider household budgets for housing, transport and other expenditures and do not model car ownership as a function of household incomes or travel budgets.

This is surprising because there is a broad range of theoretical approaches in urban economics and geography that offer feasible and empirically tested ways of modelling changes in mobility and location behaviour in response to energy scarcity and fuel price increases. One of them is the action space concept of time geography (Hägerstrand, 1970).

An action space is the set of spatial opportunities available to an individual subject to *capacity* constraints, such as money and time budgets, *coupling* constraints to the linking of activities and *institutional* constraints, such as opening hours or entrance fees. Using the framework of action space theory, Zahavi *et al.* (1981) proposed the following hypotheses based on travel data of more than 100 urban regions:

(1) Households consider in their daily travel decisions monetary and time budgets.

(2) Monetary and time budgets available for transport change only very slowly.

(3) Within their monetary and time budgets households maximise spatial opportunities (i.e. travel distances).

In particular the third hypothesis is in contrast to most travel demand models used in the planning practice which assume that trip rates are fixed and travellers try to minimise travel time and travel cost to perform these trips. It implies:

- If travel becomes *faster* or *less* expensive, people will make *more* and *longer* trips.
- If travel becomes *faster* or less expensive, people will choose *more distant* locations.
- If people will get *more affluent*, they will make *more* and *longer* trips and choose more distant locations.
- If people have to work less, they will make *more* and *longer* trips and choose *more distant* locations.
- If all this happens together, people will make *more* and *longer* trips and choose *more distant* locations ...

... and if travel becomes *slower* or *more expensive*, the reverse will happen.

The behavioural assumptions underlying the action-space model are founded not on subjective preferences of individuals but on the options they have to perform their mandatory and discretionary activities in time and space subject to monetary and time constraints. It can therefore be expected that the behaviour so predicted will be relatively robust and remain stable over time,

## 3. THE STEPs PROJECT

In this section it is demonstrated how the impacts of significant energy price increases on urban mobility and location behaviour can be modelled based on concepts of time geography. The example is taken from the EU 6th RTD Framework project STEPs (Scenarios for the Transport System and Energy Supply and their Potential Effects). In STEPs five urban models were applied to forecast the long-term economic, social and environmental impacts of scenarios of fuel price increases and infrastructure, technology and demand regulation policies (Fiorello *et al.*, 2006). Here the results for the urban region of Dortmund are summarised.

### 3.1 The IRPUD Model

For this the IRPUD model developed at the Institute of Spatial Planning of the University of Dortmund (IRPUD) was used (Wegener, 1998). The IRPUD model is a simulation model of intraregional location and mobility decisions in a metropolitan area. 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 IRPUD model has a modular structure and consists of six interlinked submodels operating in a recursive fashion on a common spatio-temporal database:

- The *Transport* submodel calculates work, shopping, service, and education trips for four socio-economic groups, and three modes: walking/cycling, public transport and car.
- The *Ageing* submodel computes all changes of the stock variables of the model (employment, population and households/housing) which result from biological, technological or long-term socio-economic trends.
- The *Public Programmes* submodel processes a large variety of public programmes specified by the model user in the fields of employment, housing, health, welfare, education, recreation and transport.
- The *Private Construction* submodel considers investment and location decisions of private developers, i.e. of enterprises erecting new industrial or commercial buildings, and of residential developers who build flats or houses for sale or rent or for their own use.
- The *Labour Market* submodel models intraregional labour mobility as decisions of workers to change their job location in the regional labour market.
- The *Housing Market* submodel simulates intraregional migration decisions of households as search processes in the regional housing market. Housing search is modelled in a stochastic microsimulation framework. The results of the Housing Market submodel are intraregional migration flows by household category between housing by category in the zones.

Figure 4 shows how the submodels work together. The two top corners of the diagram show the main actors of the model, employment (firms) and population (households). The two bottom corners show the corresponding residential and non-residential buildings. Between the four boxes there are markets: the regional labour market, the regional housing market, the regional market for non-residential buildings and the regional land market. They are linked by the transport market in the centre.

The *Transport* submodel determines a user-optimum set of flows where car ownership, trip rates, modal split and route choice are in equilibrium subject to congestion in the network and household budgets for travel time and travel expenditures. These budgets change over time as a function of demographic and household formation trends, labour market dynamics and the growth in household incomes due to increasing wealth. Equilibrium between budget constraints is achieved by adjusting car ownership and the number of discretionary trips after each iteration in the assignment procedure. In addition, the budget constraints are modified by substitution elasticities between different domains of time and money expenditures. Figure 5 shows the main steps and feedbacks in the transport model.

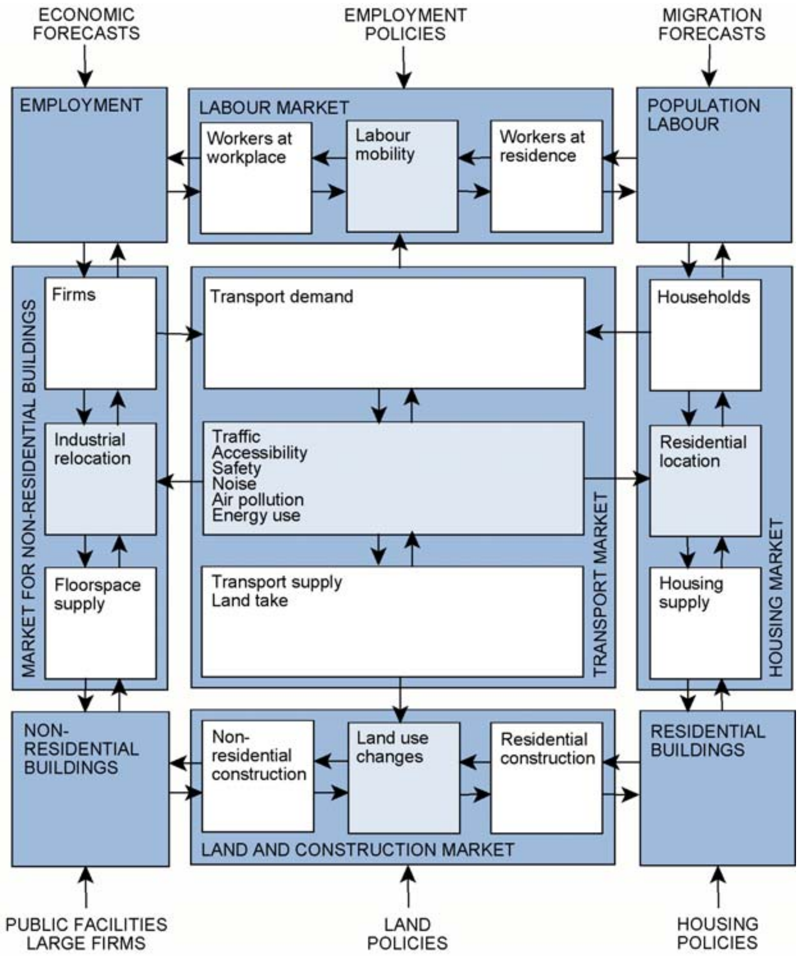

Figure 4 The IRPUD model

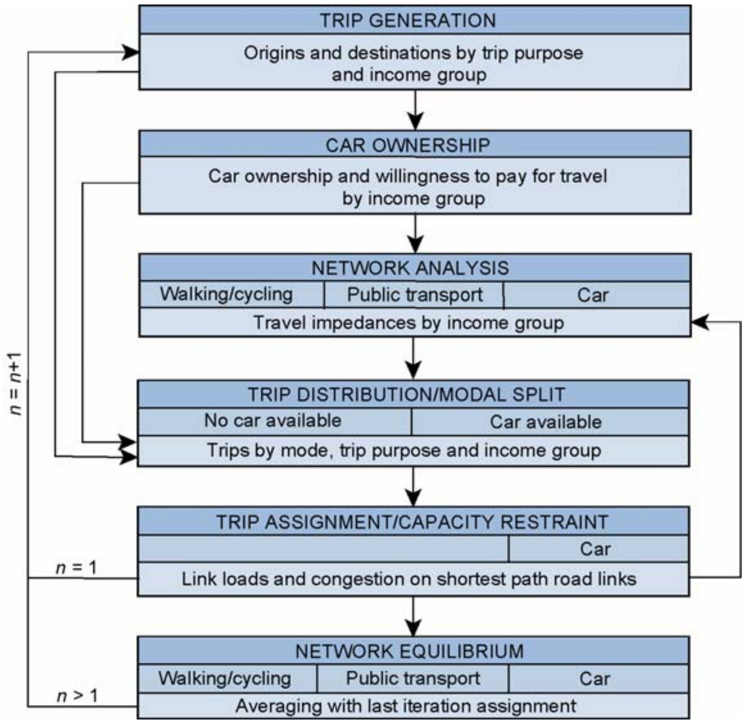

Figure 5 The transport submodel of the IRPUD model

### 3.2 Scenarios

The STEPs scenarios combined three rates of consumer fuel price increases with three sets of policies (Table 1):

Table 1 STEPs scenarios

| Policies | Fuel price increase | | |
|---|---|---|---|
| | 1 % p.a. | 4 % p.a. | 7 % p.a. |
| Do-nothing | A-1<br>*1.60 €** | B-1<br>*3.33 €** | C-1<br>*6.80 €** |
| Business as usual | A0<br>*1.81 €** | B0<br>*3.77 €** | C0<br>*6.05 €** |
| Technology and infrastructure | A1<br>*1.81 €** | B1<br>*3.77 €** | C1<br>*6.05 €** |
| Travel demand management | A2<br>*3.35 €** | B2<br>*6.95 €** | C2<br>*23.25 €** |
| Policy packages | A3<br>*3.35 €** | B3<br>*6.95 €** | C3<br>*23.25 €** |

** € of 2008 per litre in 2030* A-1 *Reference Scenario*

The A scenarios assume a low price increase of 1 % p.a. resulting in a fuel price at the petrol station of 1.60 € (of 2008) per litre in 2030 if no other policies are implemented. The B scenarios assume a medium rate of increase of 4 % p.a. resulting in a consumer price of 3.33 € (of 2008) in 2030. The worst-case C scenarios assume a large increase of 7 % p.a. resulting in a fuel price of 6.80 € (of 2008) in 2030.

Besides the do-nothing scenarios A-1, B-1 and C-1 and the business-as-usual scenarios A0, B0 and C0, three types of policy scenarios were simulated: Scenarios A1, B1 and C1 examine various types of technology and infrastructure policies, such as more energy-efficient cars, alternative vehicles and fuels and public transport improvements. The demand management scenarios A2, B2 and C2 examine taxation and pricing policies, speed limits, promotion of telework and land use planning. The combination scenarios A3, B3 and C3 examine integrated strategies combining technology, infrastructure and demand management policies. Table 1 shows the resulting consumer fuel prices in 2030 in each scenario. Scenario A-1 is used as the Reference Scenario for the comparison between scenarios.

### 3.3 Scenario Results

Figures 5 to 8 show selected results of the fifteen scenarios for selected transport indicators. All scenarios are identical until 2005 and then diverge due to the assumed fuel price increases or policies. The differences between the coloured lines representing the policy scenarios and the heavy black line representing the Reference Scenario A-1 indicate the effect of the fuel price increases and/or related policies. All assumed fuel price increases and policies work in the same direction: they constrain mobility – despite the fact that some policies are intended to compensate or at least mitigate the negative effects of increasing fuel prices. In no case these counter-policies are strong enough to compensate the fuel price effect.

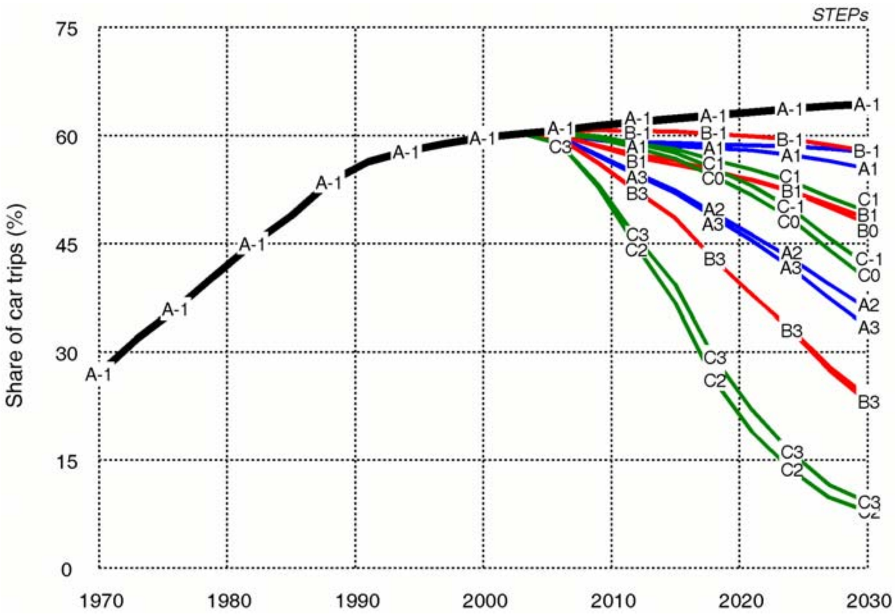

Figure 5 Scenario results: Share of car trips 1970-2030

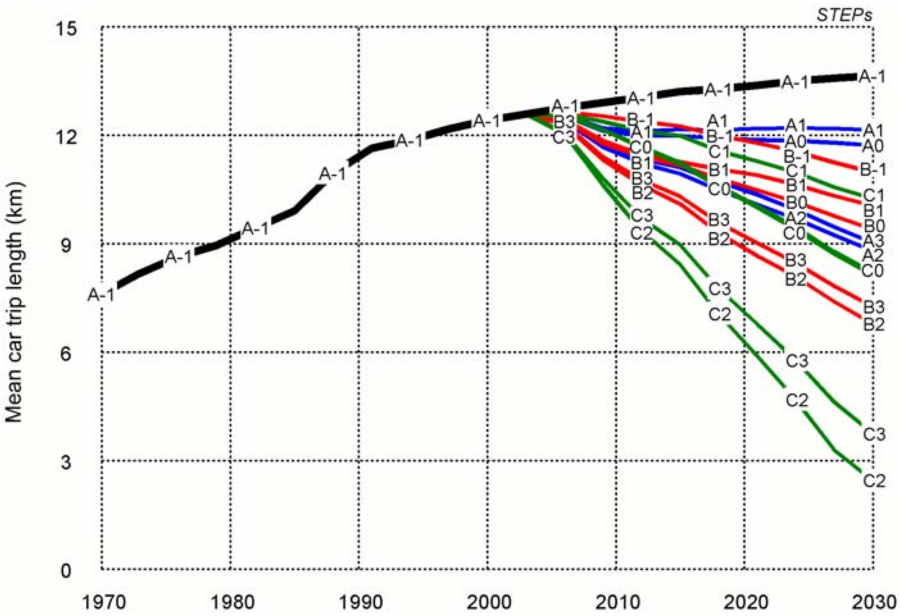

Figure 6 Scenario results: Mean car trip length 1970-2030

Figures 5 and 6 show the effects on modal shares and trip distances. The results are consistent with expectations: the higher the fuel price increase, the stronger the effects. In the Reference Scenario A-1 the share and mean length of car trips continue to increase due to cheap fuel, growing incomes and growing car ownership. As fuel prices go up, the share of car trips and distances travelled by car go down to the levels of the 1970s and 1980s. In the worst-case Scenarios C2 and C3 car travel is reduced to short-distance taxi and emergency trips. It can also be seen that with each rate of fuel price increase, the travel demand management policies in Scenarios A2, B2 and C2 reduce car travel more than the technology and infrastructure policies in Scenarios A1, B1 and C1 because they make car travel slower and/or more expensive – even more than the combined strategies in Scenarios A3, B3 and C3, in which alternative vehicles and fuels offer sustainable options of car travel.

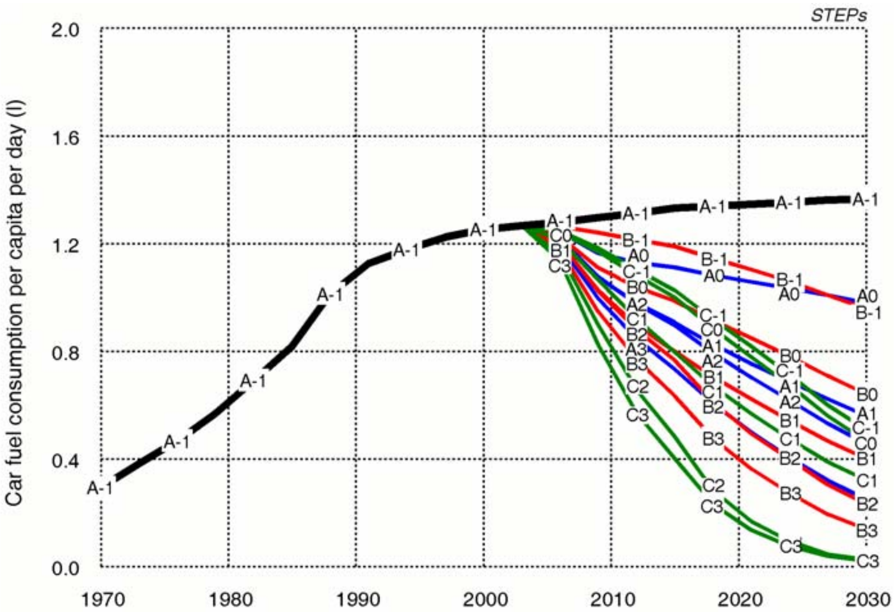

Figure 7 Scenario results: Car fuel consumption 1970-2030

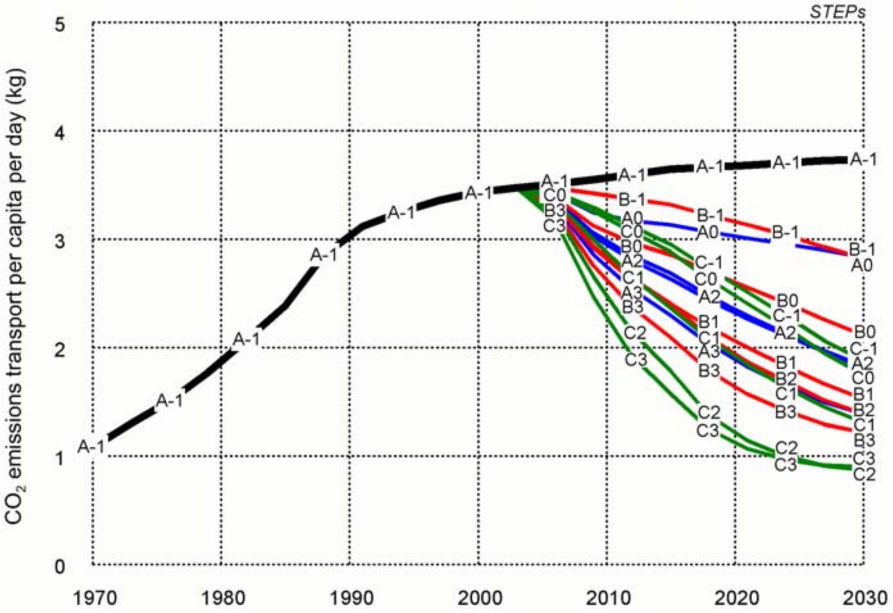

Figure 8 Scenario results: $CO_2$ emissions by transport 1970-2030

Figure 7 shows the impacts on car fuel consumption. In the Reference Scenario A-1, car fuel consumption continues to grow despite improvements in car energy efficiency because of growing car ownership and more and longer car trips (Figures 5 and 6). The reductions in fuel consumption in the policy scenarios are more or less proportional to those in the share of car trips and car trip lengths, but now the combined strategies of Scenarios A3, B3 and C3 perform better than the corresponding travel demand management policies in Scenarios A2, B2 and C2 because they use more energy-efficient cars and alternative vehicles and fuels.

Figure 8 shows the resulting $CO_2$ emissions of both car travel and public transport of all trips generated or attracted by the origins and destinations in the study area, including the parts of long-distance trips outside the study area.

The simulation results show that if travel time budgets and income-dependent travel cost budgets with appropriate elasticities and the variations in travel time and travel cost budgets between city and suburban residents are considered, the responses to travel cost increases in mobility and location decisions are higher than without such budgets. Indeed, when the results of the different urban land-use transport models applied in STEPs were compared in a meta analysis, the IRPUD model showed stronger responses than the other models (Fiorello *et al.*, 2006, 138-147). It will be a task for further research to determine which of the models are right.

## 4. CONCLUSIONS

Because of the ultimate depletion of fossil fuels and the imperatives of climate protection, energy for transport will no longer be abundant and inexpensive but scarce and expensive. This will have fundamental consequences for mobility and location behaviour in cities. The fundamental changes in the priorities of planning caused by energy scarcity and climate change will have significant impacts on the philosophy and method of urban modelling.

Urban models that were calibrated on past behaviour and/or do not explicitly consider the cost of transport and location relative to household income are not able to forecast these changes and will tend to underestimate the behavioural response of households and predict that households overspend their travel budgets.

In order to adequately deal with significantly rising energy costs of transport, urban models have to address the basic needs of households that can be expected to stay more or less constant over time, such as shelter and security at the place of residence (space, recreation, health), access to mandatory activities (work, education, retail, services) and consider the constraints of housing and travel costs in relation to household income. Action space theory taking into account both time and money budgets may be a way to achieve this.

To cope with non-marginal rather than marginal changes, models need to rely less on behaviour observed in times of cheap energy and instead pay more attention to strong theory. This implies less emphasis on choice but more emphasis on constraints, less statistical calibration and more plausibility analysis, less focus on detail and more focus on essentials.

### *A new requiem for large-scale models?*

There is again the danger that urban models are rejected because they fail to address the new challenges of energy scarcity and climate change and the resulting social conflicts. This time the "seven sins of large-scale models" would be:

- too much extrapolation of past trends
- too much belief in equilibrium
- too much reliance on observed behaviour
- too much attention to preferences
- too much emphasis on calibration
- too much effort spent on detail
- too much focus on feasible solutions

The fundamental changes in the problems and priorities of urban planning due to energy scarcity and climate change will require a change in the philosophy and method of urban modelling:

- less extrapolation, more fundamental change
- less equilibrium, more dynamics
- less observed behaviour, more theory
- less preferences, more constraints
- less calibration, more plausibility analysis
- less detail, more essentials
- less forecasting, more backcasting

Backcasting means in this context that modellers should concentrate less on policies that are politically acceptable but more on the policies that need to be implemented to cope with the challenges of energy scarcity and climate protection.

*Epilogue*

"Some may find it ironic that it requires the urgency of the environmental debate to grant urban models a new lease of life. It is indeed puzzling to see that even vigorous critics of "rational" models in planning call for just that kind of method for tackling environmental problems. However, the new respect for models is more than just another twist in the intellectual debate about rationality in societal planning. It heralds the twilight of postmodernity in the face of growing risks of ecological disaster. Urban models have a renewed chance because they stand for rationality, and rationality is again needed" (Wegener,1994, 26).

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