Technology versus demand regulation – strategic modelling of transport, land use and energy scenarios

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Abstract

Scarcity of oil supply is seen as one of the biggest future threats to our society. The recently finished EU-funded research project STEPs (Scenarios for the Transport System and Energy Supply and their Potential Effects) had the objective to develop, compare and assess possible scenarios for the transport system and the energy supply of the future taking into account the effects on the environment as well as economic and social viability. Two energy supply scenarios, one with and one without scarcity of oil supply, form the basis of STEPs. Furthermore two different policies are suggested to tackle the problem of scarcity of oil: a technology driven strategy and a demand regulation based strategy. This paper presents the application of these scenarios and strategies to the strategic Systems Dynamics model MARS (Metropolitan Activity Relocation Simulator) covering the metropolitan area of Edinburgh. Scenario indicators like car ownership, fleet composition and fuel resource costs were provided by the European model ASTRA and the world energy market model POLES. The first part of the paper summarises the scenarios and strategies in detail. The second part describes briefly some basics of Systems Dynamics as well as the main mechanisms underlying the model MARS. Finally the results of the scenario simulations are presented. The main outcome is that a demand regulation policy is more effective in reducing the consumption of non-renewable energy resources than a technology driven policy.

Introduction

The future framework of the transport system is intimately linked with the energy supply of the future. The relatively cheap availability of petroleum oil has allowed the expansion of the transport system over the past hundred years. This relationship between the energy supply and the vehicle technology and the characteristics of the transport system is typified by the internal combustion engine that powers much of the transport system. The wide availability of the fuel, its cheapness, and the relative simplicity of the engine itself and the storage requirements has meant that the transport system has facilitated an era of increased dispersion of activities with high levels of mobility for those with the means to purchase the vehicles. The nature of the fuel technology has been a major influence on the transport system and mobility patterns of today.

However, circumstances are changing. There is increasing concern over the environmental consequences of the fuel technology used, and concerns over the future availability of the quantities of fuel required. Driven by these two issues a wide range of new or improved fuel technologies are being proposed and developed. In response the European Union has set out its main energy policy targets to ensure the functioning of the energy market, security of energy supply, and to promote energy efficiency, energy saving and new and renewable forms of energy (European Union, 2004). In parallel the European Transport Policy (European Commission, 2001) proposed four main priorities: (i) adjusting the balance between the different modes of transport, (ii) implementing the trans-European transport network, (iii) placing the user at the heart of transport policy and (iv) managing the effects of transport globalisation; while the Green Paper (European Commission, 2000) established three major strategic priorities: (i) controlling the increase in demand, (ii) managing dependence on supply, and (iii) ensuring that the internal energy market works well.

In order to support the achievement of the European objectives as outlined above, the European Commission established several research priorities within the Sixth Framework Programme. The research presented here is based on the project STEPs (**S**cenarios for the **T**ransport system and **E**nergy supply and their **P**otential effect**S**) funded within the research priority "Sustainable Surface Transport" (Monzon and Nuijten, 2006). In STEPs different scenarios for the transport system and energy supply of the future are developed. Different models on a European and regional scale and a multi criteria analysis (MCA) are employed to compare and assess these scenarios. In this paper we report results from one of the regional case studies conducted using a strategic model of Edinburgh and its surrounding area. The following sections give an overview of the MARS model, describe the scenarios modelled, discuss the results and finally draw conclusions.

The land use and transport interaction model MARS

MARS (**M**etropolitan **A**ctivity **R**elocation **S**imulator) is an integrated strategic and dynamic land-use and transport model. The underlying hypothesis is that settlements and activities within them are self organizing systems. Hence MARS is based on the principles of systems dynamics (Sterman, 2000) and synergetics (Haken, 1983). The development of MARS was started in 2000. An early version has been described in the European Journal of Transport and Infrastructure Research (Pfaffenbichler and Shepherd, 2002). The model development continued within a PhD-thesis (Pfaffenbichler, 2003). MARS usually is implemented such that land-use is part of a dynamic system that is influenced by transport infrastructure rather than being constant. However for this case study we use land use scenarios where under the demand regulation policy strict development controls promoting brown field development and higher densities are imposed resulting in a compact city. Two person groups, with and without access to private car are considered in the transport model. The transport model is broken down by commuting and non-commuting trips, including travel by non-motorized modes. Trip generation is based on the assumption of constant travel time budgets, hence considering dynamic expansion of trip rates and distances. Car speed is volume and capacity dependent and hence not constant. The model forecasts the impacts of the transport and land use policies over a period of 30 years. For the case study presented here detailed energy and emission sub-models have been added. Speed dependent specific emission factors by different vehicle categories are utilised (DMRB, 2003; Samaras et al., 1998). The number of persons injured in road accidents is calculated using speed dependent accident rates. Future car ownership and vehicle fleet composition are outputs from the models ASTRA and POLES (TRT, 2005) which represent the impacts of transport policy, technology investments and oil prices on the fuel price and fleet composition at the European level. To date the MARS model has been applied to six European case study cities: Edinburgh, Helsinki, Leeds, Madrid, Oslo, Stockholm and Vienna and two Asian cities: Ubon Ratchathani, Thailand and Hanoi, Vietnam.

Scenario definition and simulation strategy

Scenarios are used to derive conclusions about likely impacts of policies in the fields of technology, infrastructure, pricing and regulation under different assumptions about the evolution of energy supply. Six different scenarios have been defined, analysing three policy strategies in two different contexts of energy supply (Table 1). A0 is the reference scenario to which the results of the other scenarios will be compared.

The energy supply scenarios are basically represented by the oil price assumptions. The generally accepted supply forecast resulted in an increase in oil prices of 2 % p.a. over the next 30 years while in the worst case prices are increased at 7 % p.a. These increases were put through the energy model POLES which equilibrates demand and supply for various energy sectors in a World Market model. The results of the POLES runs meant that the increases in oil prices were translated into increases in resource costs of fuel of 1 % and 4 % p.a. over the next 30 years. The policy variable assumptions were derived from an analysis of current and future policy trends at both the European and urban/regional scale. A detailed description of the scenario definition can be found in (SenterNovem, 2005) and (Monzon and Nuijten, 2006). A brief summary key attributes of the scenario assumptions is given in Table 2. The policy variables at the regional level include bus priorities, bus speeds, fare changes, car ownership and operating costs including fuel taxes and cordon charges, telework rates and land use planning restrictions. In addition there are other assumptions about technology improvements, energy use and emissions which affect how the fleet composition develops over time. This has been modelled in more detail at the European level using the interactions between the POLES/ASTRA models. The Edinburgh model MARS has taken the resulting fleet composition and emission factors from the POLES/ASTRA runs for each scenario. Fleet composition responds not only to the technology assumptions but also to a lesser degree to the other policy and scenario variables such as fuel price and car ownership costs.

Impacts of the scenarios

This section discusses the performance of the scenarios against a set of outcome indicators to be used in a multi criteria analysis. Here we look at total energy consumption in tons of oil equiva-

Table 1: Energy supply and policy scenarios as defined in the project STEPs.

	Business as usual	Technology investments (infrastructure, alternative fuels etc.)	Demand regulation (taxes, toll, etc.)
Generally accepted energy supply forecast	A0	A1	A2
Worst case energy supply forecast	B0	B1	B2

Table 2: Overview of scenario variables.

Policy/Scenario variable	Business as usual (A0/B0)	Technology Investments (A1/B1)	Demand Regulation (A2/B2)
Fuel resource cost	A0 +1% p.a. B0 + 4% p.a.	As A0 As B0	As A0 As B0
Fuel tax	Petrol +0.7% p.a. Diesel +1.5% p.a.	As A0/B0	Petrol +4.7% p.a. Diesel +4.7% p.a.
Public transport speeds	+0.3% p.a.	+1.1% p.a. (peak) As A0/B0 (off-peak)	As A0/B0
Public transport fares	+0.8% p.a.	As A0/B0	-1.7% p.a.
Road pricing -Double cordon	-	-	€2 rising to €5 by year 30
Telework	No change	As A0/B0	+0.3% p.a. work trips saved
Land use controls on new developments	As in structure plan	As A0/B0	Development split 30/70/0 (CBD/urban/extra urban)
Fleet shares derived from POLES/ASTRA (Year 2030)	A0 : 86/8.2/0.6/0.1/4.8 [a] B0 : 74/13.5/0.3/0.3/11.6	A1 : 69/17/0.1/0/13.8 B1 : 51/20/0.1/0/28.6	A2 : 86/9/0.5/0.1/5.4 B2 : 76/13.4/0.4/0.2/10.2
Car ownership growth rate [b]	A0 : 1.20% p.a. B0 : 1.12% p.a.	A1 : 1.21% p.a. B1 : 1.15% p.a.	A2 : 1.02% p.a. B2 : 0.76% p.a.
Energy use [c]	Petrol -0.5% p.a. per km Diesel -1.0% p.a. per km	Petrol -2.0% p.a. per km Diesel -3.0% p.a. per km	As A0/B0
Emission factors [c]	-8.1% p.a.	-16% p.a.	As A0/B0

a) Share of conventional/hybrid/CNG/electric/hydrogen

b) The car ownership growth rate is based on UK TEMPRO projections for A0 and the relative changes in ownership rates from POLES/ASTRA are applied to the other scenarios.

c) The assumptions on costs of car ownership, energy use and emission factors were input to POLES/ASTRA - the fleet composition by class was then used as input to MARS which affected not only composition but also fuel consumption rates and emission factors.

lent, CO_2-emissions per person km, total CO_2-emissions, local NO_X-emissions, local particulate matter (PM) emissions, noise costs and the number of persons injured in traffic accidents. NO_X and PM emissions were calculated from pump to wheel as they impact on the local population – emissions from the production of fuel are not considered. For CO_2 we consider well to wheel impacts as it has a global impact, i.e. emissions from the production of fuel are considered. Table 3 gives an overview of the results. A more detailed presentation of the results of STEPs is given in (Shepherd and Pfaffenbichler, 2006).

Total energy in tons of oil equivalent (toe) is reduced by around 22 % over time in the BAU case (scenarios A0/B0) due to improvements in vehicle technology for both conventional and alternative vehicles. The technology scenarios (A1/B1) decrease total energy used compared to A0/B0 in year 30 by 16.4 % and 22.4 % respectively. The demand regulation scenarios (A2/B2) decrease total energy use by 4.4 % and 3.9 % for A2/B2 respectively whilst the induced shift away from car use and shorter trip lengths due to compact land use means a greater reduction in energy used per trip. In terms of energy indicators the technology policies (A1/B1) are more effective than the demand regulation policies (A2/B2). CO_2-emissions per person km are reduced despite the increase in car use in the BAU case (A0/B0) by around 18 % over the 30 year period. This is due to improved technologies and the shift from conventional vehicles. The developments in the fleet will also reduce well to wheel total CO_2 emissions but the decrease is only 2.7 % over the next 30 years which is well below the National target. Regulation (A2/B2) and technology (A1/B1) scenarios both reduce CO_2 per person-km even further, the technology policies being more effective on a per km basis. In terms of total CO_2-emissions the regulation scenario (A2/B2) outperforms the technology scenario (A1/B1) for both A and B scenarios.

In order to assess the impact of the scenarios first of all we compare changes relative to A0/B0 by year 30. In terms of total energy consumption technology scenarios (A1/B1) outperform demand regulation scenarios (A2/B2). But on the other hand demand regulation policies (A2/B2) bring a greater reduction in total CO_2 than technology policies (A1/B1) under both A and B scenarios. Local pollutants are reduced further with the demand regulation policy under the A scenario but the converse is true under the B scenario. This is due to the high proportion of Hydrogen Fuel cell technology used under B1 – caused by increased resource costs. This type of result is difficult to deal with as the policy is not robust to the external price of oil. The technology policy scenario (A1/B1) has an adverse impact on noise and accidents whereas the demand regulation policy (A2/B2) reduces these to below starting year values. The increase in resource costs of fuel between scenarios A and B obviously has an impact on the demand for car use but also on the development of the fleet over time. Nevertheless the changes in energy and CO_2 indicators are relatively small being around 3-4 % lower than in the optimistic A scenarios. There are greater reductions in local pollutants which are a result of reduced demand and improved fleet – moving more quickly to hydrogen fuel.

Conclusions

It seems that the scenario variable used to reflect the scarcity of oil supplies in the future, namely the resource cost of fuel, has little impact on the outcome indicators and hence on our policy conclusions. This is not so surprising when we analyse the impact on pump price of fuel between say A2 and B2. The pump price of petrol under scenario B2 is only 15 % higher in 2030 than under A2 (4.19 Euro/litre compared to 3.64 Euro/

Table 3: MCA outcome indicators year 0 and year 30 with relative changes as percentages.

	Total energy (toe/a)	Energy (toe/10^6 trips)	CO_2 per person-km (g/pkm)	CO_2 well to wheel (10^6 t/a)	PM pump to wheel (t/a)	NO_X pump to wheel (t/a)	Noise cost (10^6 €/a)	Number of injured persons (-)
Year 0 All	461.5	0.43	101.1	1.12	126.0	4,482	0.93	1,694
Year 30 A0	358.2	0.30	82.3	1.09	53.4	916	1.09	2,015
A1	299.4	0.25	69.1	0.93	43.7	743	1.11	2,046
A2	342.4	0.26	70.6	0.84	40.2	703	0.92	1,681
B0	345.8	0.29	78.6	1.04	46.5	797	1.09	2,002
B1	268.3	0.23	61.6	0.83	33.7	577	1.11	2,042
B2	332.3	0.25	67.6	0.80	35.5	622	0.91	1,660
Percentage change from year 0								
A0	-22.4%	-30.2%	-18.6%	-2.7%	-57.6%	-79.6%	17.2%	18.9%
A1	-35.1%	-41.9%	-31.7%	-17.0%	-65.3%	-83.4%	19.4%	20.8%
A2	-25.8%	-39.5%	-30.2%	-25.0%	-68.1%	-84.3%	-1.1%	-0.8%
B0	-25.1%	-32.6%	-22.3%	-7.1%	-63.1%	-82.2%	17.2%	18.2%
B1	-41.9%	-47.5%	-39.1%	-25.9%	-73.3%	-87.1%	19.1%	20.5%
B2	-28.0%	-41.9%	-33.1%	-28.6%	-71.8%	-86.1%	-2.2%	-2.0%
Percentage change from BAU A0/B0								
A1	-16.4%	-16.7%	-16.0%	-14.7%	-18.2%	-18.9%	1.8%	1.5%
A2	-4.4%	-13.3%	-14.2%	-22.9%	-24.7%	-23.3%	-15.6%	-16.6%
B1	-22.4%	-22.1%	-21.6%	-20.2%	-27.5%	-27.7%	1.7%	2.0%
B2	-3.9%	-13.8%	-14.0%	-23.1%	-23.7%	-22.0%	-16.5%	-17.1%
Percentage change from BAU A0								
B0	-3.5%	-3.3%	-4.5%	-4.6%	-12.9%	-13.0%	0.0%	-0.6%

litre). The dominating factor seems to be fuel tax (and VAT) in both demand regulation scenarios A2/B2. As fuel cost is only one component of the generalised cost of car use then this relatively small difference means that we may expect similar behavioural responses. One area where the oil price assumption does affect the scenarios is in the fleet composition over time – it appears that higher resource costs of fuel accelerate the move towards the use of hydrogen fuel cell technologies. In terms of policy recommendations, it appears from the analysis of the STEPs process and outcome indicators that in general demand regulation is a more effective policy than the technology policy in terms of reducing fossil fuel consumption, total CO_2, car use and hence congestion. However the technology policies are more effective in reducing total energy used and under the worst case scenario B the technology policy also decreases local emissions further than the demand regulation policy. Although the demand regulation policy appears to be better from an outcome point of view there is a price to pay both politically and by the users of the system. Basically the charges imposed on car use via the fuel tax increases and road user charges impose significant costs on car use which brings in time benefits and significant revenue streams for the Government. The fuel tax element tends to dominate the results here and we have not tested whether such levels are economically efficient via a more traditional cost benefit analysis. Finally we conclude the following:

- Both technological investments and demand regulation play a role in reducing environmental externalities - though we expect a certain level of reduction from technology developments which are already in the "pipeline" – this is based on the fact that in the BAU there are significant reductions in energy used and local emissions.
- Demand regulation reduces the externalities associated with congestion whereas technology investments do not. However we have not shown whether this "level" of regulation is efficient – other EU projects are working on the issue of optimal levels of demand regulation.
- Both technology and demand regulation can reduce total CO_2 emitted significantly but it will require some combined policy to reduce the levels by more than 20 %.
- Increased resource costs have two effects - firstly they act to suppress demand for car use, secondly they lead towards a more efficient vehicle fleet and the use of alternative fuel technologies. Thus it would seem logical that as resource costs rise the demand regulation policy could be weakened while still reducing congestion to the same levels as under A2.
- In terms of whether to accelerate the development in fleet technologies through a direct investment policy we cannot say whether these are cost effective from our tests. We can however see that they can be effective in terms of reducing energy use and local emissions.

Within the work presented here it was not possible to estimate and compare the costs of technology and demand policies. Thus it was not possible to assess the economic efficiency of the different policies. We recommend this issue is investigated in future research. Another interesting research question would be how to find the optimal combination of technology and demand policies.

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