

ASSESSMENT OF SUSTAINABLE TRANSPORT POLICIES WITH AN ENERGY-ECONOMY-ENVIRONMENT MODEL

T. ZACHARIADIS

Economics Research Centre, University of Cyprus
P.O. Box 20537, 1678 Nicosia, Cyprus
e-mail: zach@hol.gr

EXTENDED ABSTRACT

Sustainable development is widely accepted as an important ingredient in formulating long-term strategies, and transport is recognised as a priority area in sustainability discussions. Because of the inherent complexity of this sector in comparison to most other branches of economic activity due to the millions of travellers involved, policy measures often have to be taken at local scale and respecting local particularities.

In order to respond to requirements of a European research study, an appropriate assessment tool had to be used. Based on the experience collected so far, a new model was developed, which is described in this paper. The model covers the whole transport sector (road and rail transport, inland shipping and aviation) in the 15 countries that were EU Member States in the beginning of 2004. It attempts to bridge the gap between top-down energy-economy models, which address the transport sector in an aggregate fashion, and bottom-up technological models, which provide sufficient technological coverage but often cannot simulate the effect of behavioural changes induced by changing costs and income. It covers the major sustainability issues associated with the transport sector, i.e. emissions of air pollutants and greenhouse gases, energy intensity, congestion, road accidents and noise. Its underlying database is consistent with those of EU institutions such as the European statistical service (Eurostat), the European Commission and the European Environment Agency, a feature that ensures acceptance by policy makers at national and international level.

Starting from a simulation of the economic behaviour of consumers and producers within a microeconomic optimisation framework and the resulting calculation of the modal split, the allocation of the vehicle stock into vintages and technological groups is modelled. In a third step, a technology-oriented algorithm, which incorporates the relevant state-of-the-art knowledge in Europe, calculates emissions of air pollutants and greenhouse gases as well as appropriate indicators for traffic congestion, noise and road accidents. The paper describes briefly the methodological approach, which has been presented elsewhere. Its main focus is the presentation of assumptions and results of several alternative scenario runs that attempt to simulate individual policies aiming to promote sustainable transport. Examples of such policies are: urban road pricing, early implementation of stricter vehicle emission standards, road infrastructure investments as well as economic subsidies for encouraging public transport, using alternative fuels and scrapping old cars. A major conclusion drawn from the results is that individual policy measures cannot respond sufficiently to the diverse sustainability concerns associated with transportation. Therefore, a suite of policies combining promotion of advanced 'conventional' technologies and alternative fuels with economic and regulatory interventions to reduce demand for transport would be most appropriate.

Key words: optimisation, microeconomics, emissions, congestion, noise, accidents

1. INTRODUCTION

Sustainable development is a concept that for a long time had been accepted as an important ingredient in formulating long-term strategies. Apart from atmospheric pollution concerns in urban areas as well as climate change, the emergence of a great number of additional sustainability concerns in recent years (concerning bio-diversity, transport congestion, social exclusion, regional imbalances with their attendant political risks etc.) has posed particular challenges to analysts with respect to integration and quantification of these problems. One of the major issues in this agenda is transport, which is worldwide accepted as a priority area in sustainability discussions [1], [2]. Work on sustainable transport is well in progress, both in the research field and in policy-oriented studies, concentrating primarily on emissions of air pollutants (causing health problems) and greenhouse gases (affecting climate change) and expanding to other sustainability concerns such as congestion, noise and accidents.

In order to respond to the requirements of a European research study that was wide-ranging in scope and addressed other sustainable development concerns as well (MINIMA-SUD project under the European Commission's 5th Framework Programme), a transport simulation and policy assessment tool had to be used. Based on the experience collected so far, a new model was developed, which is described in more detail elsewhere [3]. The second section of this paper provides a brief overview of the methodological approach. The third section, which is the main focus of this paper, describes the assumptions and results of several scenario runs that attempt to simulate policies aiming to promote sustainable transport. Items of future work are outlined in the concluding section.

2. METHODOLOGICAL OVERVIEW

The model covers the whole transport sector (road and rail transport, inland shipping and aviation) in the 15 countries that were EU Member States in the beginning of 2004. It covers the major sustainability issues associated with the transport sector and is designed so as to enable integrated policy exploration jointly with models addressing different aspects of sustainability. Its underlying database is consistent with those of EU institutions such as the European statistical service (Eurostat), the European Commission and the European Environment Agency (EEA). It links the choice of transport mode and technologies with economic variables such as income and generalised transport costs, but at the same time is technology-rich so as to simulate sustainability impacts in a sufficiently precise manner. Depending on the values of exogenously set policy variables such as taxes, regulations or infrastructure investments, the demand and supply modules interact in order to reach an equilibrium, where generalised prices satisfy demand and supply for transport services. The outcome of this iterative process is the determination of the overall demand for passenger and freight transport, travelling speeds and associated costs. These variables are then fed in the next modules, where the vehicle stock is calculated and allocated into vintages, technology shares are assessed and the sustainability-related impacts are determined.

A major assumption made in the model is that the choice of transport mode, both for consumers (as regards passenger transport) and for producers (as regards freight transport), is based on economic considerations. More specifically, a microeconomic optimisation framework is assumed: consumers will allocate their income expenditures for passenger mobility to different transport modes so as to maximise their overall welfare (or utility). Similarly, producers will allocate their expenditures for the transport of goods to different freight transport modes so as to minimise their total costs. Consumer and

producer choices are described as a series of separable choices, which create a nesting structure (decision tree). All utility/cost functions of the decision tree, which describe the behaviour of economic agents, were assumed to have constant elasticities of substitution (CES functions).

Having determined the transport activity evolution by transport mode, vehicle size and road type and the associated costs, the model becomes more detailed for road transport. It calculates the evolution of the road vehicle stock and the distance travelled annually by vehicle type and size and by road type. This stock is further decomposed into age cohorts, according to an initial exogenous age distribution in the base year and assumptions on the evolution of scrapping rates. Following the assessment of the age distribution for a given year, technology shares are calculated. These depend both on European emissions legislation and technology-related parameters such as total vehicle travel costs, availability of a given alternative technology/fuel and policy measures assessed in a specific scenario. The model includes the 113 technology classes of the COPERT III methodology [4], which is the state-of-the-art methodology for vehicle emissions calculation in Europe, as well as several alternative road vehicle technologies/fuels. Air pollutants covered are CO, NMVOC, NO_x, PM, SO₂ and lead. Greenhouse gases addressed are CO₂, CH₄ and N₂O. Simpler approaches are applied for non-road transport modes. Sustainability indicators other than air emissions are assessed with the aid of simple methodologies, as large-scale transport policy assessment studies often do not require more detailed coverage of these issues.

3. SIMULATION OF SUSTAINABLE TRANSPORT POLICIES

In order to assess the impact of policies on transport-related sustainability indicators, a number of policy instruments were selected, shocks (i.e. large 'doses' of each instrument) were applied and their impact on these indicators was evaluated. Ten scenarios were selected so that: i) several types of policy instruments are examined and ii) the applied instruments sometimes yield conflicting impacts on sustainability indicators.

In *Policy 1*, vehicles powered with CNG and fuel cells are subsidised by 50% of their pre-tax purchase cost. This applies to cars, light and heavy trucks alike. At the same time, fuel supply is assumed to progress considerably in order to respond to the increasing demand for CNG and methanol. In *Policy 2*, the tax imposed on diesel fuel used by private vehicles (i.e. cars and trucks) is doubled, a measure directed primarily towards curbing PM emissions. According to *Policy 3*, from 2006 onwards, 'Euro V' emission standards are implemented in cars and light trucks instead of 'Euro IV' ones, but their purchase and maintenance costs are 40% higher because of their 'premature' introduction in the market. 'Euro V' vehicles are assumed to be 10% more fuel efficient and to emit 24%-50% less NO_x, NMVOC and PM than the corresponding 'Euro IV' technologies. The justification for assuming the corresponding fuel economy improvements and increases in car purchase prices is provided in [3]. *Policy 4* assumes that investment expenditure for road infrastructure doubles throughout the outlook period; this applies to both the urban and non-urban road network. In *Policy 5*, fares of all public transport modes (buses, trams, metro and trains) are subsidised by 50%. According to *Policy 6*, all automobile trips in urban areas are charged on average with additional 3 Euros (in 2000 prices); the latter measure would correspond e.g. to an increase of 5-10 Euros of car parking prices per day (depending on the fraction of cars that have to pay for their parking space in each city), or to a charge of 3-8 Euros per trip in a road pricing scheme (depending on the share of residents of urban areas who may not be affected by such a charge). *Policy 7* assumes that, in an attempt to accelerate scrapping of old cars

and renew the vehicle fleet, the pre-tax purchase cost of all new passenger cars that replace old ones is subsidised by 50%.

Besides these exercises, three additional scenarios were applied with combinations of some of the above instruments. *Policy 8* is a combination of road pricing and advanced emission standards (i.e. of scenarios 3 and 6). *Policy 9* assumes, on top of *policy 8*, subsidies on CNG and fuel cell vehicles, thus combining scenarios 1, 3 and 9 by assuming that revenues raised from road user charges are used in order to boost the use of alternative propulsion systems and fuels. Finally, *policy 10* combines road pricing (scenario 6), advanced emission standards (scenario 3) and subsidies on bus and rail fares (scenario 5), thereby assuming that revenues collected by discouraging private vehicle use are directly utilised to support public transport modes.

Some impacts of these policies on sustainability indicators, expressed as percentage changes from the baseline run, are shown in Table 1 (results of the baseline run were presented in [3]). The following paragraphs provide some comments on these results.

Policy 1 causes negligible changes in generalised prices, aggregate transport activity and speeds. The major change is observed in the fuel mix after 2010, with CNG and fuel cell vehicles emerging dynamically. By 2020, alternative fuel vehicles will account for about 3%, 18%, 11% and 29% of the total fleet of cars, buses, light trucks and heavy trucks respectively. This results in reduced consumption of conventional fuels and increases in demand for CNG and methanol. The decline of CO₂ emissions is projected to be limited. NO_x emissions are expected to fall slightly; emissions of other pollutants will decline much more as neither CNG nor fuel cell vehicles emit NMVOC, PM, SO₂ or lead.

Despite the considerable rise in the costs of diesel vehicles, *Policy 2* causes overall an increase of less than 2% in user costs of passenger cars and 2-10% in those of trucks. Passenger kilometres of diesel cars decrease by 3-14% (mainly under urban peak driving conditions), but gasoline cars benefit most from this decline, so that total pkm of cars fall negligibly. As the use of trucks is largely inelastic to cost increases, road freight tkm decrease by only 2-7% to the benefit of rail. Energy demand and CO₂ emissions decline slightly due to the higher transport price. Because of the increase in gasoline vehicle use, NMVOC and lead emissions increase, whereas NO_x, PM and SO₂ emissions decrease.

The accelerated introduction of 'Euro V' technology (*policy 3*) at higher purchase costs is projected to make car travel more expensive, particularly in non-urban areas, where capital costs account for the major part of total costs. This will slightly improve congestion levels, which is expected to affect particularly freight transport where time costs dominate. Buses and rail in urban areas are projected to gain about 4-5% after 2020. In non-urban transport, high-speed rail and aviation are expected to benefit most. Energy consumption will fall substantially, with some switch to alternative fuels. Air pollutant emissions (particularly NO_x and PM) will also fall significantly due to lower 'Euro V' emission levels and the shift towards public transport.

In *Policy 4*, driving becomes somewhat cheaper and time spent in urban driving declines by about 6% throughout the outlook period. The effects are not as pronounced as might be expected because of a 'rebound effect': improved congestion conditions reduce time and fuel costs, make car driving more attractive and lead to even higher passenger and freight transport intensity and energy demand. Pollutant emissions change very little. Despite higher driving speeds, which would normally lead to more road accidents, better infrastructure improves road safety, so that the number of deaths from road accidents remains about the same as in the baseline.

Table 1: Results of policy scenarios, expressed as relative change in sustainable development indicators compared to the baseline scenario in the year 2020.

Indicator	Impact of Policy Exercises on Sustainable Development Indicators in the Year 2020 (%)									
	Policy 1	Policy 2	Policy 3	Policy 4	Policy 5	Policy 6	Policy 7	Policy 8	Policy 9	Policy 10
Passenger Transport Intensity (pkm/GDP)	0.1	-0.5	-3.6	1.2	2.1	-2.6	0.0	-6.1	-9.2	-3.6
Freight Transport Intensity (tkm/GDP)	0.0	-2.5	-0.2	2.2	0.1	-0.1	0.1	-0.4	-0.3	-0.4
Energy Intensity of Transport (toe/GDP)	-1.8	-1.2	-8.2	1.9	0.8	-3.8	-0.1	-11.7	-14.6	-10.7
CO2 Emissions of Transport (Mt)	-1.5	-1.4	-8.3	1.9	0.4	-3.8	-0.1	-11.7	-14.2	-11.1
NOx Emissions, Total (kt)	-2.0	-3.6	-7.8	0.6	1.0	-1.9	-0.6	-9.8	-11.9	-11.3
NOx Emissions, Urban (kt)	-3.6	-4.6	-12.6	-1.4	1.8	-6.4	-0.9	-18.0	-23.2	-15.4
NMVOE Emissions, Total (kt)	-4.6	1.3	0.8	0.4	0.1	-4.6	-0.7	-4.4	-11.7	-4.2
NMVOE Emissions, Urban (kt)	-3.3	1.6	1.6	0.8	0.1	-6.1	-0.8	-5.1	-11.5	-5.0
PM Emissions, Total (kt)	-5.7	-7.8	-12.6	1.0	0.2	-5.0	-0.7	-17.5	-26.5	-17.0
PM Emissions, Urban (kt)	-6.0	-8.9	-13.6	-2.3	0.2	-9.7	-0.7	-22.1	-32.2	-21.5
SO2 Emissions, Total (kt)	-0.7	-4.4	0.3	-2.8	0.3	-0.4	-0.1	0.1	-0.2	0.6
SO2 Emissions, Urban (kt)	-7.4	-1.2	-10.2	-0.8	0.4	-9.1	-0.1	-18.2	-28.0	-17.4
Lead Emissions, Total (kt)	-2.2	3.3	-12.6	1.9	-0.8	-8.2	-0.1	-20.0	-26.9	-20.7
Lead Emissions, Urban (kt)	-2.6	4.0	-11.6	-0.5	-1.2	-15.0	-0.1	-24.9	-31.0	-25.9
Urban Road Congestion travel time in hours)	-0.1	-0.6	-1.3	-5.7	-0.1	-3.5	0.0	-4.7	-5.9	-4.7
Noise Emissions in db(A)	0.0	-0.1	-0.5	1.6	0.0	0.0	0.0	-0.5	-0.9	-0.5
Fatalities from Road Accidents (000)	-0.1	1.1	3.5	-2.0	0.9	15.5	0.0	19.6	24.0	20.8

Heavy subsidies of public transport fares (*policy 5*) render these transport modes much more attractive, but this induces an overall increase in the use of trains and buses without affecting the use of cars significantly. Although pkm of buses and rail increase in total by 11-16% and 27-29% respectively over the outlook period, pkm of cars decline only by approximately 1%. Here again, the 'rebound effect' is evident: improved congestion conditions encourage private car travel, so that the overall impact on car use is very small. Emissions remain essentially unchanged.

Imposing urban road user charges (*policy 6*) produces more remarkable effects in the first years of implementation. Urban travel costs rise considerably, thus reducing congestion by over 4% and increasing transport activity of urban buses and tram/metro by more than 25% and 15% respectively in the 2010-2020 period. A marked improvement is forecast for peak-hour driving speeds, which leads to fuel savings and to a reduction of 4.4% in energy demand and CO₂ emissions by 2010. In the absence of measures to reduce emissions from diesel bus engines, pollutant emissions are projected to fall moderately.

Policy 7 does not affect travel costs, car ownership and car use, as the subsidies address only those cars that enter the market in replacement of old ones. However, it causes a significant acceleration in the renewal of the car park, so that scrapping rates increase by 15-20%. As a result of the faster penetration of 'Euro IV' cars, energy use and pollutant emissions decrease particularly in the 2006-2015 period. The overall effect is limited though as the subsidies apply to passenger cars only; emission levels of trucks and aviation remain unchanged.

The impacts of scenarios 3 and 6 are effectively added up in the case of *policy 8*. More substantial improvements in energy intensity and CO₂ emissions (-12% from 2020 onwards) and pollutant emissions (up to -25% for urban PM and lead emissions) are achieved in this way. However, as average speeds rise, the impact on accident rates is also added up: road fatalities are 20% more than in the baseline.

Policy 9 is an additional step further: all sustainability indicators except road fatalities improve more than in scenario 8. Passenger transport intensity becomes 9% lower after 2015. After 2020, penetration of alternative fuels will result in over 20% lower energy demand and CO₂ emissions. The improvement is more pronounced in emissions of PM, SO₂ and lead. On the other hand, lower congestion levels are expected to give rise to more accidents and fatalities than in the baseline. Figure 1 illustrates the cumulative impact of the three distinct policy instruments that have been simulated in this scenario on transportation energy demand and NOx emissions. It is evident that the introduction of

'Euro V' standards accounts for the largest part of the improvements compared to the baseline, whereas road pricing and alternative fuel subsidies yield together about as much improvement as 'Euro V' standards on their own.

Finally, the effectiveness of *policy 10* is somewhat lower than that of policy 9, because the use of passenger cars falls less remarkably due to the 'rebound effect' mentioned in the case of scenario 5.

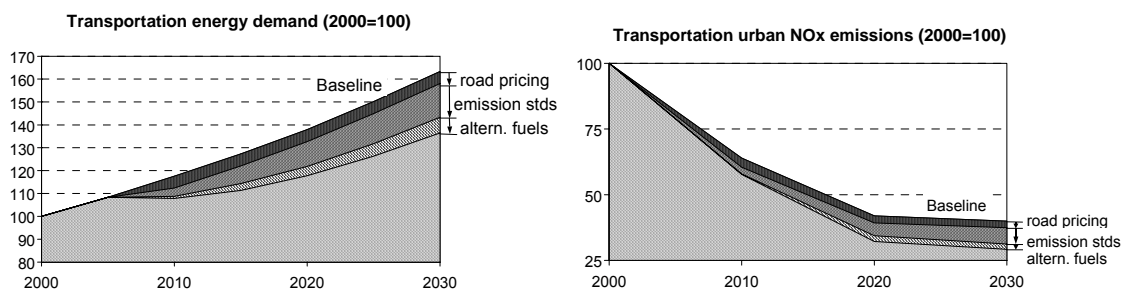


Figure 1: Cumulative impact of road pricing, emission standards and alternative fuel subsidies on the evolution of energy demand and urban NOx emissions, 2000-2030.

4. CONCLUSIONS AND OUTLOOK

The policy scenarios presented here reconfirm the widely expressed assertion that individual policy measures cannot respond sufficiently to the diverse sustainability concerns associated with transportation [1], [2]. In order to achieve improvements in energy intensity, CO₂ emissions, congestion and air pollutant emissions, packages of measures are necessary. Strategies that promote advanced technologies can mainly affect air pollution and to a lesser extent energy demand, whereas traffic-related measures can primarily improve congestion and thus energy intensity and emissions as long as appropriate clean technologies are in place. Therefore, a suite of policies combining promotion of advanced 'conventional' technologies and alternative fuels with interventions to reduce demand for transport would be most suitable to address the variety of sustainability issues.

For a comprehensive analysis of policy options, the social cost of measures has to be assessed with the aid of appropriate economic methods (such as the welfare losses or gains because of changes in consumer/producer surplus), and this will be the centre of research work in the immediate future.

REFERENCES

1. European Commission (2001) 'White Paper on European transport policy up to 2010: time to decide', URL: http://europa.eu.int/comm/energy_transport/en/lb_en.html
2. WBCSD (World Business Council for Sustainable Development) (2004) 'Mobility 2030: Meeting the challenges to sustainability', Geneva. URL: <http://www.wbcasd.org>
3. Zachariadis T. (2005) 'Assessing policies towards sustainable transport in Europe: an integrated model', *Energy Policy*, **33**, 1509–1525.
4. Ntziachristos L. and Samaras Z (2000) 'COPERT III – Computer programme to calculate emissions from road transport – Methodology and emission factors', Technical Report No. 49, European Environment Agency, Copenhagen. URL: http://reports.eea.eu.int/Technical_report_No_49/en