IMPACTS OF FUEL CONSUMPTION TAXES ON MOBILITY PATTERNS AND CO_2 EMISSIONS USING A SYSTEM DYNAMIC APPROACH

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ABSTRACT. Current transport behaviour leads to increasing congestion of the infrastructure, growing dependence on fossil fuels, increasing energy demand, and growing CO_2 emissions. Policies based principally on increasing system speed and in particular car speeds will lead to greater urban sprawl with increases in average trip lengths. Time saved by speed increases are traded for more distance. This trend is not sustainable in the longer term. Transport policies based just on time savings for citizens may not be the basis for our city planning strategy. The same happens with transport cost. With underpriced transport, the market undervalues land use location, which again may lead city to sprawl and could induce greater trip lengths. In this study, the efficiency of a fuel consumption or CO_2 tax policy is analysed as a policy to internalise externalities of transport in a fair travel cost. Based on system dynamics theory, an integrated land use and transport model is proposed in order to assess the effects and impacts of such policy in the short, medium and long term. Different scenarios related to clean vehicles are incorporated. This model is applied to three cities Madrid, Vienna and Leeds and compares their results.

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INTRODUCTION

The recently published communication "GREEN PAPER–Towards a new culture for urban mobility" (COM (2007) 551) clearly says that "*European towns and cities are all different, but they face similar challenges and are trying to find common solutions*": for making our cities sustainable. This is not a minor task. Over 60% of the population lives in urban areas and 85% of the EU's gross domestic product is created in urban areas (COM (2007) 551, Eurostat). This means that they are essential for the economic performance but at the same time should be developed taking into account the quality of life of the majority of the EU population.

All around Europe, increased traffic, both in the city centres and the metropolitan area is a common phenomenon. These circumstances create an increasing adverse situation where externalities measured in terms of delays, pollution, stress, inequities, etc, drive our cities into a spiral of degradation: 1% of the EU's GDP, are lost every year as a result of congestion; Urban traffic is responsible for 40% of CO2 emissions and 70% of emissions of other pollutants arising from road transport (COM (2007) 551).

On the other hand, Climate change is recognised as an international problem where all are involved. On the Kyoto Agreement signed in 1997, developed countries approved reducing their overall emissions of six greenhouse gases (GHG) to 5.2% below 1990 levels over the period 2008–2012. European Member States have, under this target, started to deploy different strategies and measures in order to achieve their GHG emission targets, as a response to European Directives or as individual initiatives. In this context, the big issue which maintains the tension, especially in the transport sector, is the predominance of oil as the main means of energy. The CO_2 emission reduction commitment is also competence of the cities as well. Despite advancement in car technology, the increase in traffic and the 'stop-go' nature of driving in urban areas implies that cities are becoming a major, and growing, source of CO_2 emissions which contribute to climate change.

Thus, the sensitivity to a "greener" urban environment is continuously growing, and transport is on the agenda of every policy maker. National and Urban governments show considerable interest in formulating policies for a more sustainable transportation sector. Some of them have been named as "Transport Demand Management" (TDM) policies, where a change of travel behaviour is desired. Policies, among others, such as "fuel taxes", are under this concept as a transport policy. Implications of this policy are presumed to be not just about mode choice, but, in the long term, the city structure as well.

It is generally assumed that higher speeds, allow people to cover longer distance within their time and money constraints. These spatial opportunities will increase including the distance between their residence and job locations, resulting in the dispersion of residences and jobs. Under this presumption, and the opposing argument, it suggests that increasing the cost of travel will result in people gravitating back towards the centre, or multi-centres, thus gradually changing the dispersed city back into compact mono or poli-centric ones.

In this article fuel taxes will be evaluated as an important instrument for the environment and urban sustainability on three different European cities, showing the effectiveness of the measure. The methodology presented, in order to assess the effects on the long term in an urban area, is based on the System Dynamic (SD) approach in order to integrate within the assessment the interrelation between land use and transport, that otherwise (traditional transport models) would be omitted.

The objective of this study is to analyse how the energy taxation policy can contribute to the climate policy. Many arguments justify this exercise. Among others, the Directive 2003/96/EC where the implementation of the EU minimum energy tax policy in the Member States is stabilised. This implies that there will be changes on this regulation as a process of harmonization between the different Member States. Others are related to Kyoto target and the different national commitments.

So in order to asses, from a regional and local point of view, what are the implications and impacts of this policy, different scenarios are tested and evaluated. Changes are assessed for different urban areas in terms of emissions and mobility patterns. The scenarios tested take into account, as relevant exogenous variables:

- First, different CO_2 fuel tax policies.
- Second, different fuel market prices.
- And third, different evolutions of vehicle technologies into the future.

FUEL TAX POLICY AND SCENARIO ASSUMPTIONS

Once the worrisome transport emission trends was acknowledged through its observation since 1990 (base year for the Kyoto protocol), and in order to help achieve Kyoto targets the European Commission established in 2001 the first European Climate Change Programme (ECCP), with the transport sector included. A wide range of measures was identified and introduced in the Member States (MS) in the following years thanks to this programme. Most of these transport measures could be categorized under the following themes:

- Taxation (fuel taxes / vehicle taxes / fuel tax exemptions / registration taxes)
- Infrastructure charging
- Vehicle efficiency
- Logistics and combined transport
- Promotion of public transport

The second ECCP I report of April 2003 (European Commission (2003)) identified additional measures in order to achieve new CO_2 savings. Among others were: community strategy on CO_2 from passenger cars where not just technology improvements had to be met, but also fiscal measures would be undertaken; environmentally enhanced vehicles (Directive COM (2005) 634, Council of the European Union (2005)); Framework Directive Infrastructure Use and Charging; or fuel taxation. Under this last item, the Commission agreed the directive on the taxation of energy products and electricity (2003/96/EC, Council of the European Union, (2003)). The directive modernised and extended the community energy tax framework, and raised the minimum rates of taxation for transport, and the use of fiscal incentives for environmental or transport policy purposes was introduced (public transport, renewables). This is a change in the orientation of the fuel tax instrument at the EU level.

Fuel taxes were not initially designed for environmental purposes, but their consequences are certainly environmental. Historically, externalities had played a small role in the motivation of a fuel tax. In fact, probably there is not, or was not, a belief that climate change is a serious problem. Hence, the stated motives for fuel taxes vary considerably from one place to other (Parry and Small (2005)). But nowadays, fuel taxes could play a crucial role in order to motivate a change, but still it is difficult to raise fuel taxes as policies are shaped by economic interest and the growing dependence and ownership of cars among the population makes them unpopular with the electorate and politicians (Hammar et al. (2004)).

Fuel taxes are much higher on average in Europe (even the lowest) compared to the US. This is one of the reasons that explains the difference on fuel uses and energy consumption (Kenworthy (1999)), and probably on mobility patterns as well. US annual gasoline consumption per capita is at 1,300 litres. Most European countries use less than a third of this amount (Germany 360l, France 240l, UK 360l, Italy 300l) (IEA, 2006). What would have happened if the EU had followed the same path as the US? Probably if the EU had followed a similar tax policy to that in the US, aggregate carbon emissions would have been substantially higher and cities more dispersed.

The problem is not a short term problem rather than a long term one. Action made, or not made, will have consequences on the long term future. This makes the matter much more complicated but now is the time to decide what type or model of urban, technology, behaviour or structure we will have for the next one or two decades, since the actions carried out now, will determine the intensities of energy and environment use for the next years to come.

One can suggest that the oil market by itself will balance the demand, or that just technology improvements will solve the issue. CO_2 emissions from new passenger cars sold in the EU have decreased by 12.4% between 1995 and 2004, following a voluntary agreement between the European Commission and industry. However, despite these improvements, environmental conditions are still not satisfactory: local authorities are facing serious problems to meet the requirements on air quality, such as the limits of particulates and nitrogen oxides in ambient air which have a negative impact on public health. Various demand-oriented tools like fuel taxation, vehicle taxation, and infrastructure charging have to be implemented but at the same time be carefully investigated.

By combining the policy dimension with the energy-availability dimension, a scenario framework was created which consists of scenarios for the future of the European Transport and Energy system up to 2030. From the point of view of energy availability, two groups of scenarios have been identified:

- Scenarios Type A. Based on the “optimist” energy supply forecast. In the following, these scenarios will be named ‘low oil price growth scenarios’ or just ‘scenarios A’
- Scenarios Type B. Are based on the assumption of energy scarcity. In the following, these scenarios will be named ‘high oil price growth scenarios’ or just ‘scenarios B’.

At the same time, from the energy demand policy dimension there are also two groups:

- Policy Strategy Type 1. Focused on technology improvements. In the following, these scenarios will be named ‘technology investment scenarios or just ‘scenarios 1’.
- Policy Strategy Type 2. Concentrating on demand regulations related to fuel tax measures. In the following, these scenarios will be named ‘Fuel Tax Regulation’ or just ‘scenarios 2´.

Table 1. Scenarios for Measure Assessment

		Energy demand		
		Business as Usual	Technological Investment	Fuel Tax Regulation Rate
Energy availability	Optimist forecast	A0	A1	A2
	Worst case forecast	B0	B1	B2

Main characteristics for the baseline and all scenarios are summarised in Table 2. These are based on the scenarios contemplated in STEPs (Scenarios for the Transport System and Energy Supply and their Potential Effects) project (Monzón, A., Nuijten, A. (2006)).

Table 2. Specification for the Baseline Scenarios

Measure	Indicator	Scenario 0	Scenario 1	Scenario 2
		Business as usual (BAU)	Technological Investment	Tax and Prices Regulation
Socio-Economic and Cultural Sub-system		**Annual change in %**		
Mobility management	Car ownership	+ 1,0%	+ 1,0%	+ 1,0%
Travel cost change due to fuel taxes	Car (General car cost)	+ 0,5%	+ 0,5%	+ 0,5%
	Air (General air cost)	- 0,5%	- 0,5%	- 0,5%
Diffusion of Telework	Commuting trips saved per year	0,0%	0,0%	0,0%
Fuel Tax and Prices Policies		**Annual change in % A/B scenarios**		
Fuel Prices	Gasoline/litre	+1.0% / +4.0%	+1.0% / +4.0%	+1.0% / +4.0%
	Diesel / litre	+1.0% / +4.0%	+1.0% / +4.0%	+1.0% / +4.0%
	Electric/unit	+0.0% / +0.0%	+0.0% / +0.0%	+0.0% / +0.0%
	CNG/unit	+1.0% / +4.0%	+1.0% / +4.0%	+1.0% / +4.0%
	Hybrid/unit	+0.0%/ +4.0%	+0.0%/ +4.0%	+0.0%/ +4.0%
	Hydrogen/unit	+1.0% / +0.0%	+1.0% / +0.0%	+1.0% / +0.0%
Fuel Tax	Gasoline fuel tax/ litre	+1.5%	+1.5%	+4.7%
	Diesel fuel tax/ litre	+0.7%	+0.7%	+4.7%
	Electric fuel tax/unit	+0.0%	+0.0%	+0.0%
	CNG fuel tax/unit	+0.0%	+0.0%	+0.7%
	Hybrid fuel tax/unit	+0.7%	+0.7%	+4.7%
	Hydrogen fuel tax/unit	+0.0%	+0.0%	+0.0%
Transport Energy Sub-System		**Annual change in %**		
Improving energy efficiency for car	Car fuel efficiency (gasoline fuel consumption/car)	- 0,5%	- 2,0%	- 0,5%
	Car fuel efficiency (Diesel fuel consumption/car)	- 1,0%	- 3,0%	- 1,0%
Investments in alternative vehicle technologies	Emission factors	- 8,1%	- 16,0%	- 8,1%
	Car fleet (growth/share)	Conventional (gas/ dsl): -1% / 72% Hybrids: +12,5% / 15% CNG: +10% / 10% Electric: +3% / 1% Hydrogen: +3% / 2%	Conventional (gas/ dsl): -2,1% / 55% Hybrids: +13,5% / 20% CNG: +2% / 15% Electric: +7% / 5% Hydrogen: +7,8% / 5%	Conventional (gas/ dsl): -1% / 72% Hybrids: +12,5% / 15% CNG: +10% / 10% Electric: +3% / 1% Hydrogen: +3% / 2%

Source: Based on STEPs EU Co-funded R&D Project

For the fuel tax regulation scenarios (scenarios 2) several assumptions were set up. There are not specific transport targets. The role of transportation in reducing GHG emissions needs to be determined and targets need to be specified. In this study, some hypothesis has been settled in order to evaluate the reliability of the fuel tax instrument in order to achieve the Member State Kyoto Targets.

The scenarios 1 increase the technology investment with share of "clean" technologies significantly. The demand regulation scenario 2 results in only small changes in fleet composition. Furthermore the B scenarios which have higher fuel prices promote a further shift away from conventional fuels in the base case with similar but less exaggerated shifts than under the technology scenario and as before only small shifts for the regulation scenario.

The main target of this study is to evaluate the efficiency of the tax measure under different conditions and policies, not just for the CO_2 emission level achieved, but also for the general transport and territory equilibrium. Thus, every scenario will have a different tax policy and a different fuel price policy trough the years along the study, and also different kinds of vehicles fleet compositions.

Wide variations in geography, population density, cultural aspects and affluence affect the success of various policies and measures. Such differences need to be accounted for especially when attempting to promote behavioural changes and raise awareness. This is the reason that the same measures are implemented on three different urban areas with three different characteristics to compare the transferability of the results obtained.

METHODOLOGY

There are several economic literatures based on the topic of searching for the optimal carbon-tax system to achieve some certain abatement objectives and sustain the macroeconomic welfare (Nordhaus (1991), Dean and Hoeller (1992)). Azar and Schneider (2002), Weber et al. (2005), some of them, particularly the more recent papers, started to use models where endogenous changes were taken into account. Not too many integrated economy-climate models have been developed using a system dynamics approach. Some good examples are Kunsch and Springael (2008), Piattelli, et al (2002). This simulation technique stresses feedback dynamics of stocks and flows and the associated time delays in achieving objectives and learning mechanisms.

In the case of our study, the SD approach was used to take into account the dynamic interaction between transport and territory or land use systems. The model assumes that land-use is not a constant but is rather part of a dynamic system that is influenced by transport infrastructure, this interaction process is modelled using time-lagged feedback loops between the transport and land-use sub-models over a period of 30 years.

The model used for this study is based on the MARS (Metropolitan Activity Relocation Simulator) model (Pfaffenbichler 2003). MARS is a strategic, interactive land-use and transport interaction (LUTI) model. The MARS model includes a transport model which simulates the travel behaviour of the population related to their housing and workplace location, a housing development model, a household location choice model, a workplace development model, a workplace location choice model, as well as a fuel consumption and emission model. All these models are interconnected with each other and the major interrelations are shown in Figure 1. The sub-models are run iteratively over a 30 year time period.

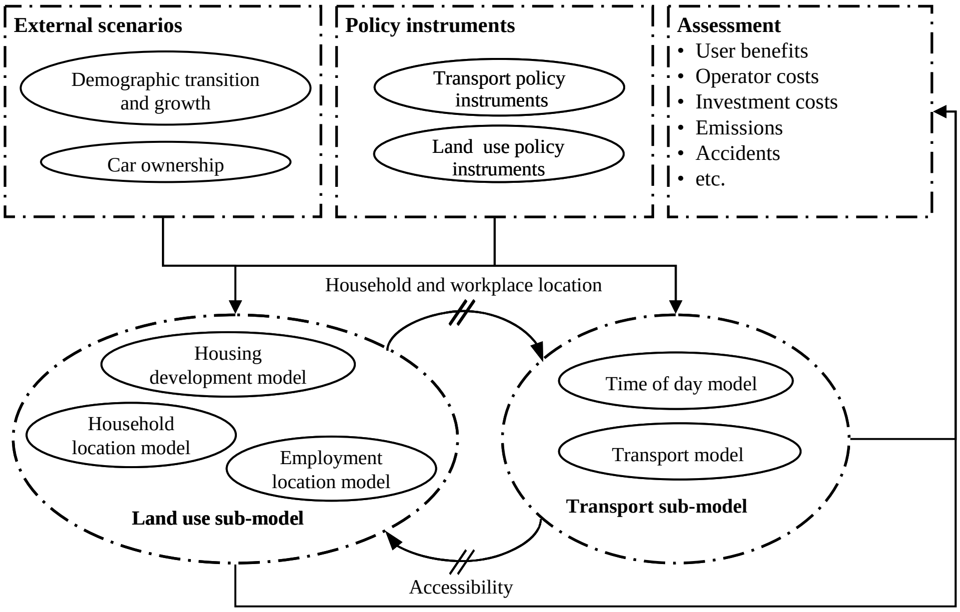


Figure 1. Basic structure of the MARS sub-models (Pfaffenbichler, 2003)

The transport model is broken down by commuting and non-commuting trips, including travel by non-motorized modes. Car speed in the MARS transport sub-model is volume and capacity dependent and hence not constant. The energy consumption and emission sub-models of MARS utilize speed dependent specific values. The land-use model considers residential and workplace location preferences based on accessibility, available land, average rents and amount of green space available.

The concept of Casual Loop Diagrams (CLD) is used to explain the cause and effect relations variables in the model. Figure 2 show a part of the transport sub-model: the variables which affect the number of commute trips taken by car. We start with loop B1, negative loop, what means that is a balancing feedback loop, commute trips by car increase as the attractiveness by car increases which in turn increases the search time for a parking space which then decreases the attractiveness of car use (hence the balancing nature of the loop). Loop B2 represents the effect of congestion, as trips by cars increases, travel speed by car decrease. Loop B3 adds to the model the commute cost by fuel costs. In a urban case, as speeds increase fuel consumption is decreased, and here, we have a new equilibrium feedback.

Finally, loop B4 shows the effect of congestion over other transportation modes and is actually a reinforcing loop (as trips by car increase, speeds by car and public transport decrease, which increases costs by other modes and all other things equal would lead to a further increase in attractiveness by car). These elements are car availability and attractiveness of the zone relative to others which is driven by the number of workplaces and population. The employed population drives the total number of commute trips and within MARS the total time spent (based in the travel time budget) commuting influences the time left for other non-commute trips. Similar CLDs could be drawn for other modes and for non-commute trips as MARS works on a self-replicating principle applying the same gravity approach to all sub-models.

It is this simple causal loop structure and user friendly software environment which helps improve the transparency of the modelling approaches used

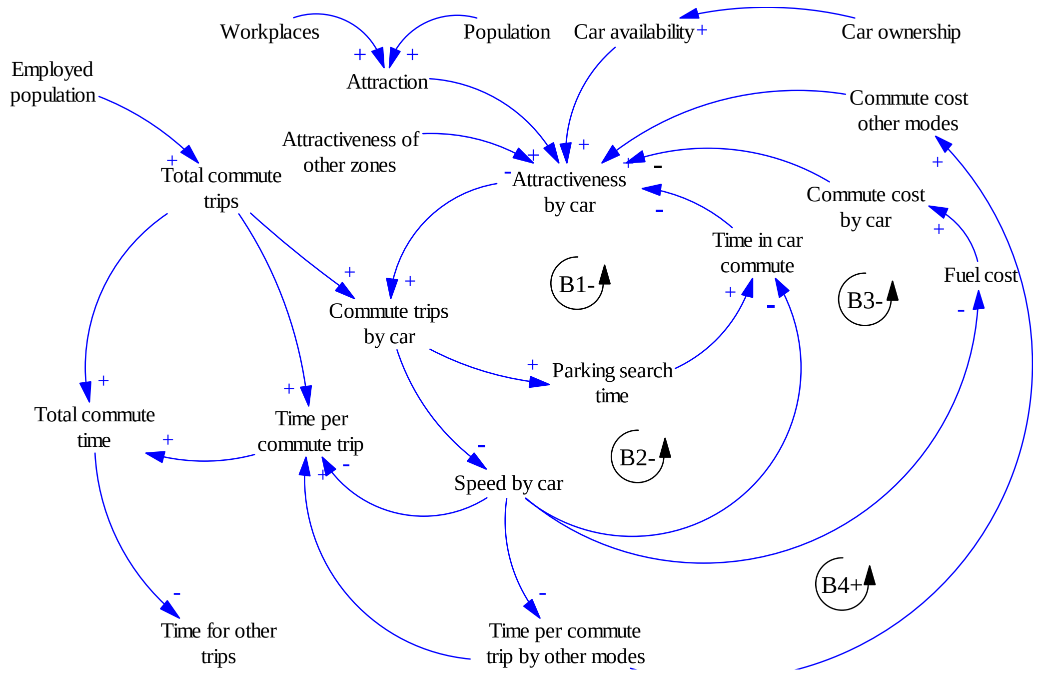


Figure 2. CLD for the Transport Model – Commute Trips by Car in MARS

It has to be said that changes on the transport system not just affect modal share and trip distribution but, in the long term, land use as well. They are linked by accessibility as output from the transport model and input to the land use model and on the other hand by the population and workplace distribution as output from the land use model and input to the transport model. A comprehensive description of MARS can be found in Pfaffenbichler (2003).

In order to implement the scenarios previously mentioned, the values of fuel duty, fuel price and vehicle fleet composition where formulated. This has been modelled in more detail at the European level using the interactions between the ASTRA/POLES models. POLES (POLES, 2000) models the world energy market while ASTRA (ASTRA,1999) is an European level transport model

The MARS models for the different cities assessed have taken the resulting fleet composition and emission factors from the POLES/ASTRA runs for each scenario. As can be seen from the following analysis the resulting 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.

Changes in the fuel prices to the end users, both due to oil market prices or fuel taxes, influences the attractiveness to use the car which will be balanced by others Causal Loops such as changes in the speed (time) due to a different level of congestion. Changes in accessibility will modify in the long term the residential and workplace location, which may also impact on the attractiveness of car use.

CASE STUDIES

Most European cities have experienced an expansion without any precedent. However, this expansion didn't correspond to the population evolution. These cities grow even further taking their limits further everyday in most of the cases based on car dependence. But car dependence is not a symbol of welfare in the cities any more. Under this situation, transportation strategies should find the point where the highest welfare is reached. A transportation system based on private car maximises mobility, but a balanced system optimises accessibility. This change in emphasis could reduce transportation costs thus reaching more efficient scenarios.

This study tries to explore the impacts of the implementation of a taxation policy as a transport policy on road fuels, and how these affect not just the $C0_2$ emissions but also the urban development and mobility patterns in the long term. Three main urban areas have been studied: Leeds, Vienna and Madrid in order to compare the results obtained.

1.1. Leeds Case Study

The total population in the study area in year 2001 is 728,000 people. The population is assumed to grow at 0.28% p.a. over the next 30 years giving a total increase of 8.75% over the period (plus 64k residents). During the same period workplaces are expected to grow by 27%. Car ownership is expected to grow at 0.50% p.a. giving a total increase of around 16% over the period.

The data for calibration of the Leeds model was adapted from a series of different sources and is based on recent data. The MARS work/commute mode share was calibrated to 20% slow modes, 28% public transport and 52% private car (this assumes no change from 2000 to 2005 data). The non-work trips were calibrated to 25% slow modes, 22% public transport and 53% private car. The other data which were used for calibration were the development data derived from the Leeds Unitary Development Plan and the Leeds Economic Handbook 2002. The calibration is more of a calibration to planned developments (in the first 5 years) rather than a calibration to development which has occurred between say 1991 and 2001 i.e. we did not use a back-casting approach.

1.2. Vienna Case Study

The trends in socio-demography and regional economy between 1991 and 2001 a significant growth in population was observed in the Viennese surroundings. During the same period the population was more or less stagnating in the city of Vienna. The economic situation in the region is different when the gross regional product is looked at relative to the average of the European Union. Vienna and its southern hinterland are above the European average while again the northern Viennese hinterland and the Burgenland are below the average.

One of the big challenges in the model development is data availability. As a consequence the transport model part was calibrated to fit aggregated modal split data and the commuting statistics from the 2001 census.

1.3. Madrid Case Study

Madrid Region is the biggest urban conglomeration in Spain and third in Europe after London and Paris. Mobility demand in Madrid grows continuously. According to the last mobility survey (2004), numbers of trips in a work day are over 14 million, that means a 40% increase over the 1996 survey. A very important explanation is the population growth, however not the only one, for instance trip per person increased 20% from 2.16 trips per day to 2.6 trips per day in 2004.

The relative weight of Madrid City Centre has been decreasing in favour of its peripheral areas as a typical urban sprawl process: Madrid municipality population grew 1.9 times in the second half of the last century, meanwhile the peripheral population grew 26.1 times. Suburbanization generates more dependence from the private vehicle.

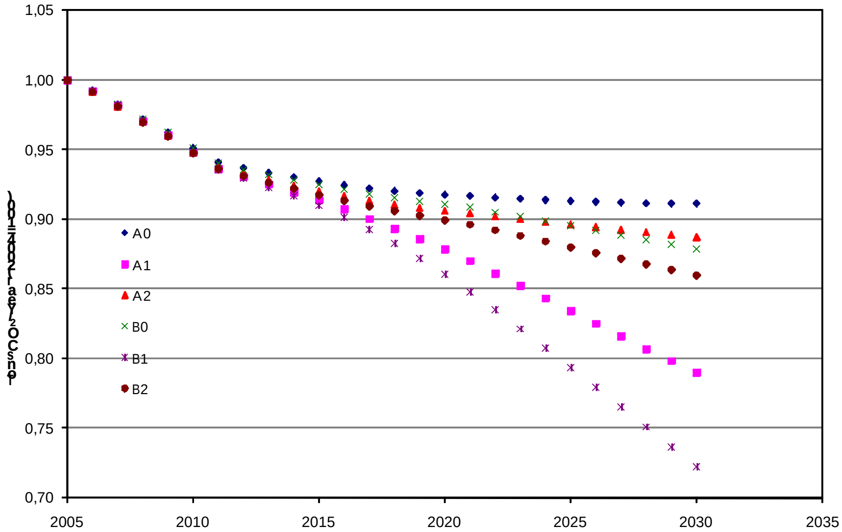
RESULTS

The results presented here are a summary of different outputs that can be extracted from the model. In this case, CO_2 emissions (wheel to wheel), modal share and trip length are shown in order to present the key aspects of this study.

CO_2 Emissions

Specific CO_2 emissions (tons per year) decrease significantly (or do not increase significantly) in all of the business as usual (BAU) scenarios. The differences between the scenarios A0-B0 and A2-B2 respectively are very small. It is clearly shown that technology improvements (A1/B1) generate high potential savings on CO_2 emissions in all cases in contrast with Business as usual (BAU) scenarios, and the impact is higher with high oil prices (B1). Thus the scenarios based on technological innovation result, in general, in the strongest reduction of the specific CO_2 emissions.

Figure 3. CO_2 Emissions in Leeds



In all cases, the scenarios B1 reduce CO_2 emissions by more than 15% compared to the BAU scenario A0. The effect of the higher fuel prices on vehicle use in the B scenarios reinforces this trend, except in the case of Vienna, where the car share is affected significantly by demand management measures in A2/B2 scenarios. The effect of car use reduction, in the Vienna case, related to CO_2 emissions is greater than the effect of the technological improvements. Whereas for Leeds and Vienna the technological investment scenarios give greater reductions than the fuel tax measures compared to the BAU scenarios. It is noticeable that for Leeds and Vienna, there is a downward trend in emissions due to technological improvements even in the BAU scenario while for Madrid, the trend is upwards as the growth in demand outweighs any efficiency gains provided by technology. Thus it can be seen that similar policies can give different results depending on the region studied.

Figure 4. CO_2 Emissions in Vienna

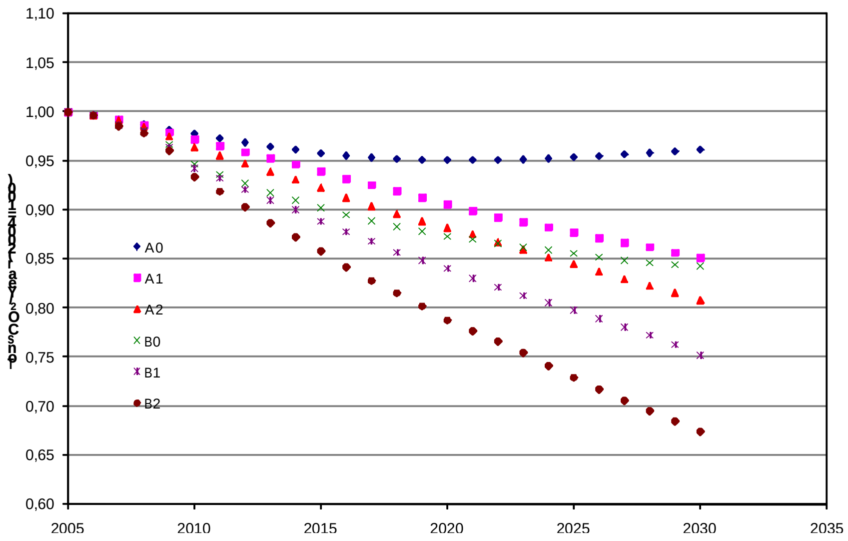
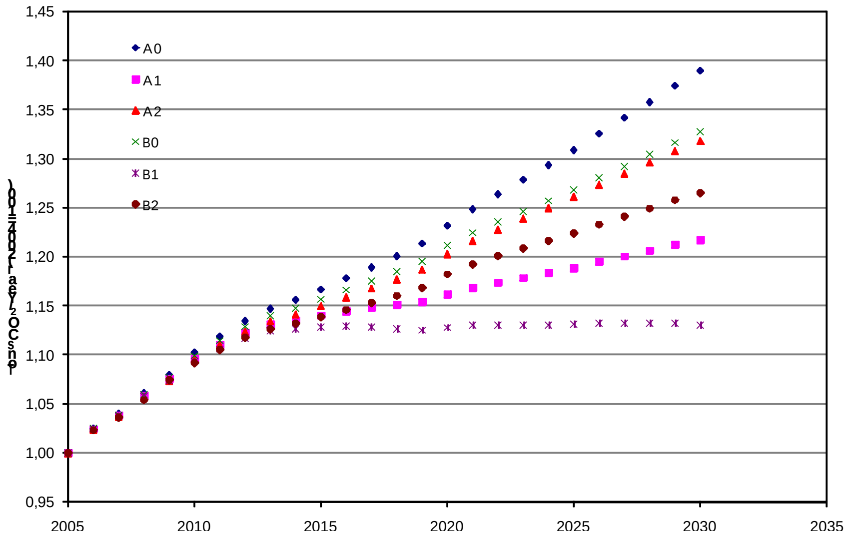


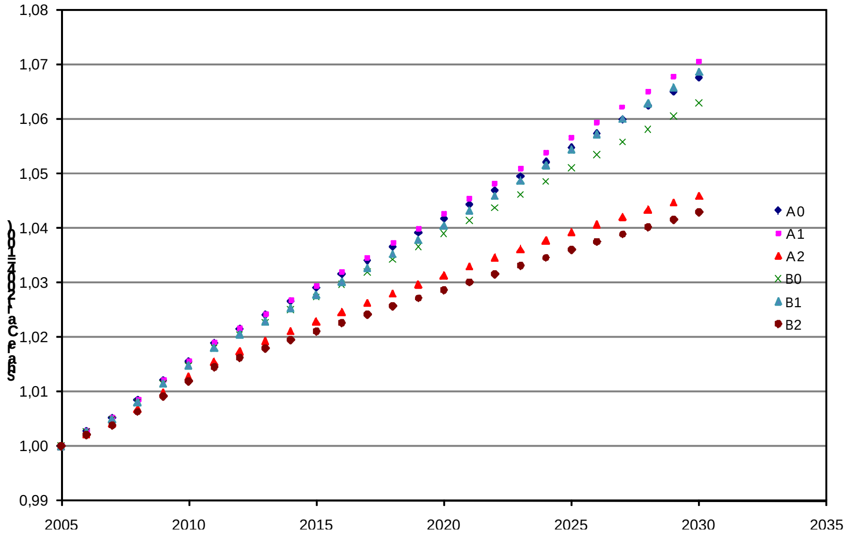
Figure 5. CO_2 Emissions in Madrid



Modal Share

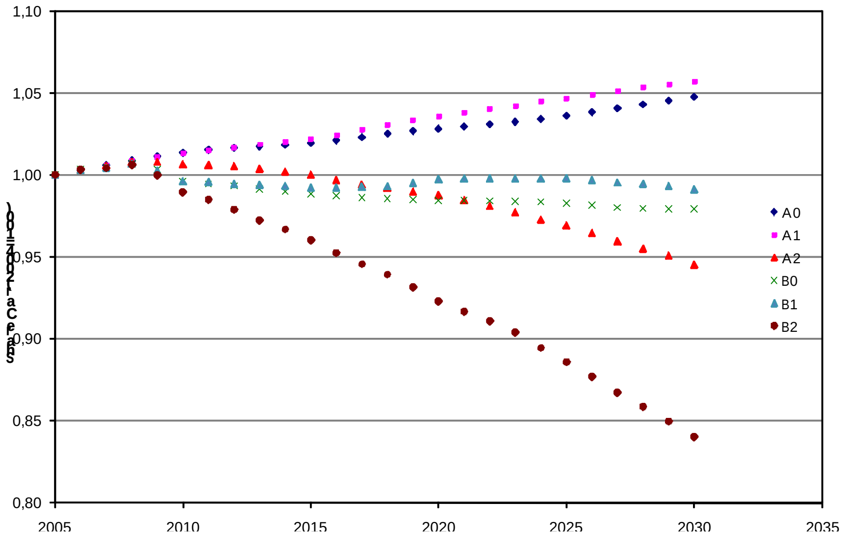
Modal split is a result of a complex interaction between urban structure, density and neighbourhood design, household status, location, and system supply among other variables. Figures 6-8 show the change in car share over time for the three cities.

Figure 6. Car Share in Leeds



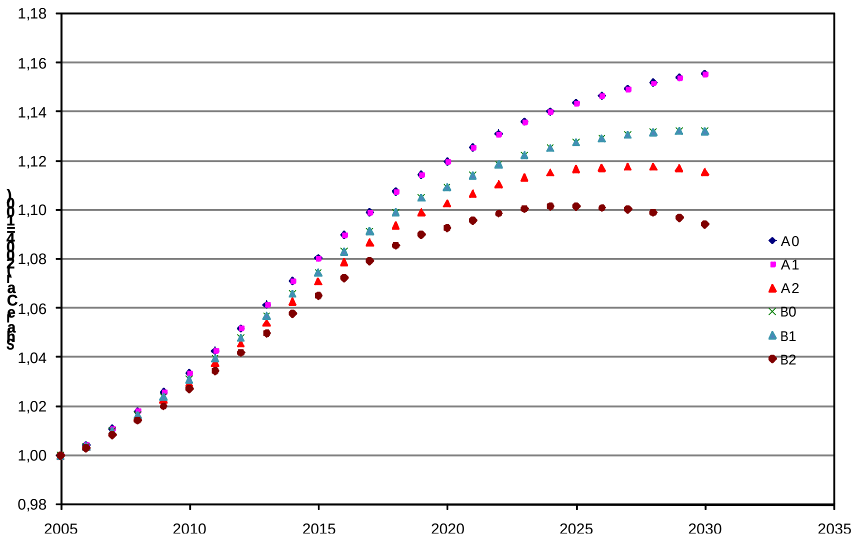
As expected, the impact on mode share can be viewed in pairs of scenarios. Obviously the demand regulation scenarios A2/B2 have the greatest impact on car share due to the significant increases in costs for car use compared to other scenarios. Similarly A0/A1 and B0/B1 scenarios are grouped together and their relative changes are small within these groupings as expected, though the technology improvements do increase car share as improvements in efficiency and a switch to lower taxed fuels means car use is slightly cheaper than in BAU.

Figure 7. Car Share in Vienna



However the effect is clearly different in each case. For Leeds and Madrid, car modal share exhibits a continuously growing trend for each scenario, whilst for Vienna, the curves are totally different. It is thought that the competitiveness of the public transport system in Vienna plays a key role here. The already high levels of service in Vienna give most OD pairs a very good alternative to car which is taken up when demand management measures are implemented. Also in Madrid, in contrast with Leeds, at year 2025 the car use presents a downward trend, especially in the scenario 2.

Figure 8. Car Share in Madrid



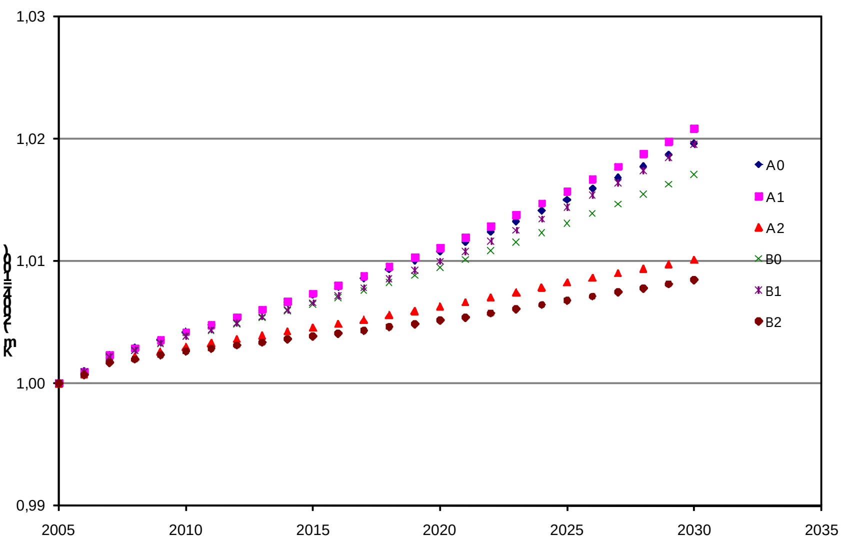
This tipping point is not in the short term for Madrid but in the medium and long term. This is explained by the public transport competitiveness mainly on long distance routes, but also by a change of urban interactions because of a relocation of activities or one urban zone being more densely populated. It may also be explained by the rapid growth in population in the outer areas which eventually causes enough congestion to cause people to shift to the metro or other long distance alternatives. For Leeds the tipping point could be brought into the medium or even short term if the public transport system were improved alongside the demand management measures.

The interaction between transport and territory is clearly shown here, where a change in a transport cost may lead to a change in the urban structure and transport infrastructure usage.

Trip Length

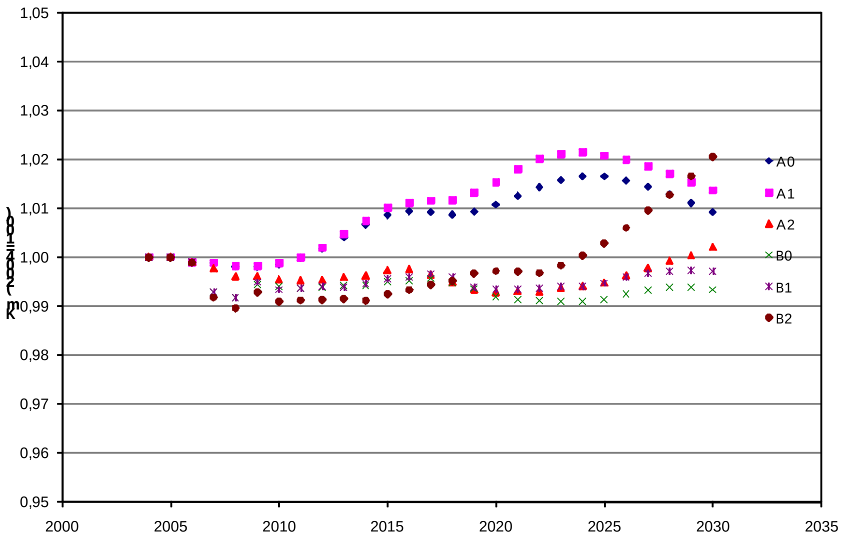
Trip length by car can be seen as a measure of the urban structure and the response of individuals in seeking to meet their needs. Under the assumption that an individual traveller attempts to travel appropriate distances by various modes such that the travel utility is optimised subject to time and money constraints different impacts are generated. Figures 9, 10 and 12 show the index of average trip lengths for the three cities over time.

Figure 9. Trip Length in Leeds



In general trip lengths are increasing over time for both car and PT use. This is due to the additional developments in the outer zones and increased car ownership levels. Just in the case of Vienna, the trip length not increasing, this trend seems to be more stable. The B0 scenario has a small impact on average car trip lengths reducing them slightly compared to A0 by 2030. The technology scenarios also have little impact but the trend is to increase trip lengths. As expected the demand regulation scenarios (A2/B2) have the greatest impact on trip length reducing car trip length significantly, in the case of Madrid and Leeds.

Figure 10. Trip Length in Vienna



It is interesting to see that in the case of Vienna, the effect is the contrary. The high impact on modal share due to the fuel prices was counter-balanced by a higher speed (figure 11) on the OD pairs as demand is reduced. There is a dynamic trade-off between cost and time which produces a higher average distance by car in Vienna for the B2 scenario.

Figure 11. Average Speed in Vienna

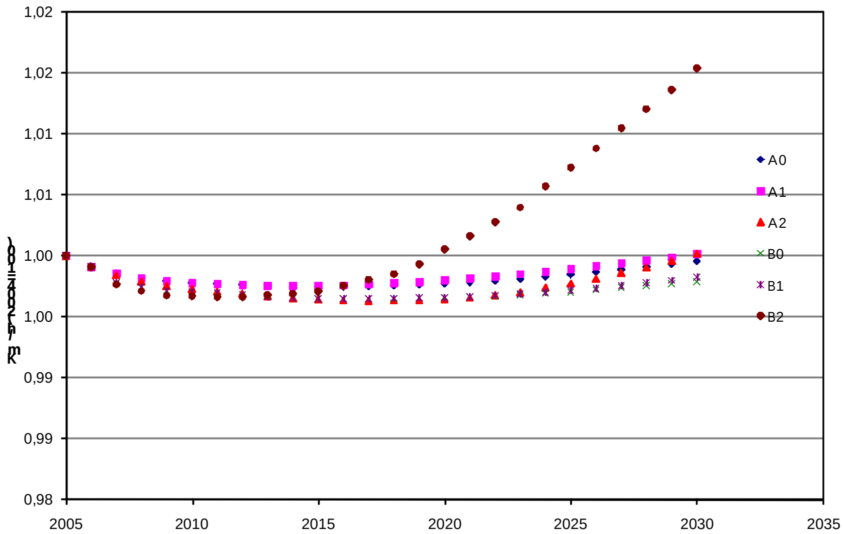
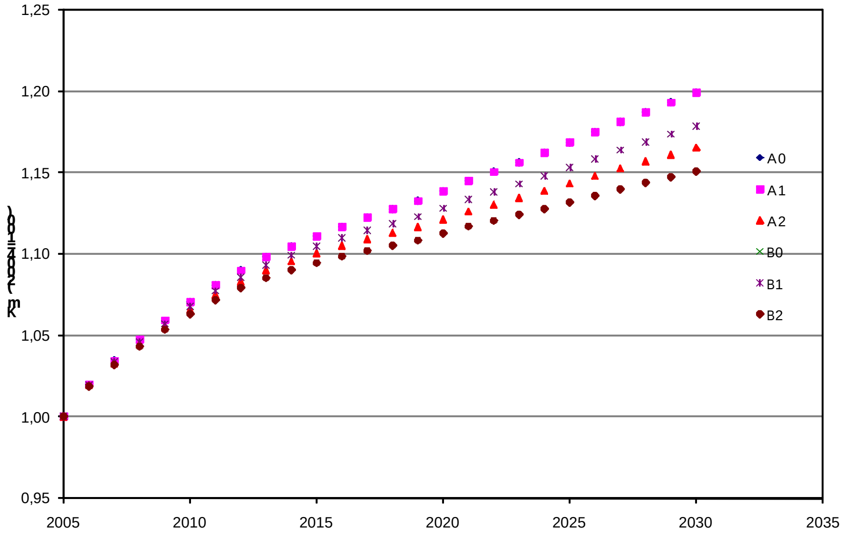


Figure 12. Trip Length in Madrid



CONCLUSIONS

The objective of this study was to explore with a land use and transport interaction model (LUTI model) what could be the impact of the implementation of an energy tax such a road fuel tax in different European urban areas in order to asses, first, its contribution to climate change, and secondly, its effectiveness under different future scenarios (technological improvements or increased oil prices).

The results suggest that from the energy and environmental criteria, the situation improves when fuel price increases, compared to BAU scenario, in all cases (Technology Improvement and Fuel Taxation measures). Fuel taxes already contribute to protecting the environment and if they are abolished or decreased in the near future, we will get an increase in emissions for sure. Fuel taxes restrain growth in fuel demand and associated carbon emissions. Until more efficient charging methods are realised, fuel taxes will continue to play an important role in setting the correct price for the road user.

From the results obtained in this study, we can conclude that

- Both technological investments and demand regulation through fuel tax can play an effective role in reducing environmental externalities.
- Demand regulation reduces the externalities associated with congestion. And also technology investments reduce these externalities, to a lesser degree.

In terms of policy recommendations we can say that both demand management and technology investments play a role in reducing CO_2 emissions but that only demand management can be used to reduce congestion and the associated externalities.

Furthermore the cross site and cross scenario comparison show that the results depend on other variables such as urban structure, transport supply, socio-economic variables, etc. This means that the effectiveness of a European Measure of, for example, raising the minimum EU energy tax will create different regional effects which requires further research.

What it is clear is that under-pricing car use (due to congestion, environmental, or other externalities) will lead us to a road based future. Setting a high price for car use appears to reduce car dependence however some comments appear in the results presented:

- There is close interaction between travel demand, system supply and urban structure which makes car use and travel behaviour be affected by:
    - o Residential location
    - o Social, demographical or cultural dynamics
    - o Spatial configuration (size, land use, transport system, neighborhood design)
- A System Dynamic approach that integrates all these "loops" is configured as an effective method for assessing different policy measures in the long term.
- Strategies for sustainable mobility cannot be based on an isolated action. No single measure will achieve sustainable scenarios for urban mobility. This suggests that further research should be done in order to explore the optimal tax policy under different situations, not just from the technological or the oil price situation, but within a strategy of different travel demand measures.

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