NATIONAL SCALE LAND-USE TRANSPORT POLICY MODELLING

Günter EMBERGER, Prof., guenter.emberger@tuwien.ac.at

Anna MAYERTHALER, PhD candidate, anna.mayerthaler@tuwien.ac.at

Reinhard HALLER, PhD candidate, reinhard.haller@tuwien.ac.at

Vienna University of Technology – Institute of Transportation - Center of Transport Planning and Traffic Engineering

Financial support by FWF is gratefully acknowledged (grant number: P19282-G11)

ABSTRACT

This paper presents the dynamic land-use transport interaction (LUTI) model MARS (Metropolitan Activity Relocation Simulator) Austria and its applicability for land-use/transport policy modelling. The purpose of the model is to capture the most important feedback mechanisms between the land-use and the transport system on a national scale. The MARS model consist of a transport model, 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 emissions model.
In this paper particular attention was paid to policy scenario modelling with MARS Austria. For this purpose we have chosen three different policy scenarios and compared the results with the base run of the model. The analysis of the model results focuses on the changes in transport behaviour as well as land-use changes that might occur as reaction to the policies. Further we examine which of the tested policies are most effective in reducing CO_2 emissions in the transport sector.

Keywords: national LUTI modelling, policy scenarios, CO_2 emissions

INTRODUCTION

In the past decades, concern over transport problems has been a constant issue. These concerns recently deepened in the context of climate change because of the significant and ever increasing transport related CO_2 emissions. In Austria, CO_2 emissions from road traffic increased by a steep 83% over the period from 1990 to 2006 (Umweltbundesamt 2010). The transport sector is the sector experiencing the strongest growth in emissions in the last few years.

Interactions between transport planning, spatial planning and the economy are highly complex. For example, form and density of human settlements affect transport distances and the number of trips within a city, between neighbourhoods, home and work and home and services like city centres and shopping areas. Especially commuting distances are affected by planning of physical structures that influence location choice by firms and households.

The notion that land-use and transport are highly interrelated resulted in the development of a series of land-use/transport interaction (LUTI) models. However, the application of these models has to date been mainly limited to urban regions. While this is understandable – many related problems such as congestion, various forms of pollution and scarcity of natural land are most apparent in urban areas – there is no fundamental theoretical or empirical reason to neglect rural areas in the analysis.

The strategic land-use/transport interaction model MARS, developed at the Vienna University of Technology, is such a model (Pfaffenbichler 2003). It has been applied in a series of urban case studies.

But what are the impacts of transport and land-use policies on a nationwide scale? In a recent study MARS has been applied to a nation-wide setup for Austria. In this paper, we present the attempt to examine the impacts of these policies with MARS Austria. MARS Austria is a national system dynamics land-use/transport interaction model, applied for the whole territory of Austria with model zones mapping the level of the 120 Austrian districts (98 'Politische Bezirke' plus the 23 municipal districts of the capital Vienna). The model is design to capture the most important interrelations between transport, land-use and the economy; to this end, the mechanisms implemented in the model simulate passenger transport and the spatial distribution of residents and workplaces.

The main research question of this paper is to examine the overall effects of land-use and transport policies on the transport behaviour and on CO2 emissions taking into account feedbacks via residential, commercial and industrial land use. The district level setting of MARS Austria is very suitable in answering this question because its specific geographical setup allows both to capture certain core-periphery interactions, such as commuting flows and suburbanization, and to explicitly model rural areas as distinct entities. Furthermore, due to the significance of transport related CO_2 emissions, we want to examine which policies appear most effective in reducing CO_2 emissions from transport on a national scale.

The paper sets out with a short description of the different model components and their structure. The next sections present, in turn, the application of the model to Austria, the case study area and results for the base line scenario. This is followed by an exposition of the alternative scenarios which capture exogenous developments or policy strategies. The impacts of the individual policies on transport outcomes and CO_2 emissions follow. The paper closes with conclusions and an outlook.

THE MARS MODEL

Introduction

The MARS model is a dynamic land-use/transport interaction (LUTI) model, which is based on the principles of synergetics (Haken 1983). To date the MARS model has been applied to 10

European cities (Edinburgh, Gateshead, Leeds, Madrid, Trondheim, Oslo, Stockholm, Helsinki, Vienna and Bari), 2 Asian (Hanoi, Ubon Ratchathani) and 1 South American (Porto Alegre) city. Ongoing projects cover setting up the MARS model for Hoh Chi Minh City in Vietnam and Washington D.C. in the US.
The model description in this paper will focus on the overall model structure and some specific modules relevant for the issues addressed in this paper. For a more comprehensive presentation, we refer the reader to Pfaffenbichler (2003, 2008).

General model description

The MARS model consists of sub models which simulate passenger transport, housing development, household migration and workplace migration. Additionally accounting modules calculate assessment indicators and pollutant emissions. The overall structure of the model is shown in Figure 1. The main link between the transport model and the location choice model are accessibilities (formulated as potential to reach workplaces and shopping opportunities), which are passed on from the transport model to the location choice models and the spatial distribution of households and employment which are input from the location choice models to the transport model. The land price influences both the residential location- and the workplace sub model whereas these two sub models change the availability of land.

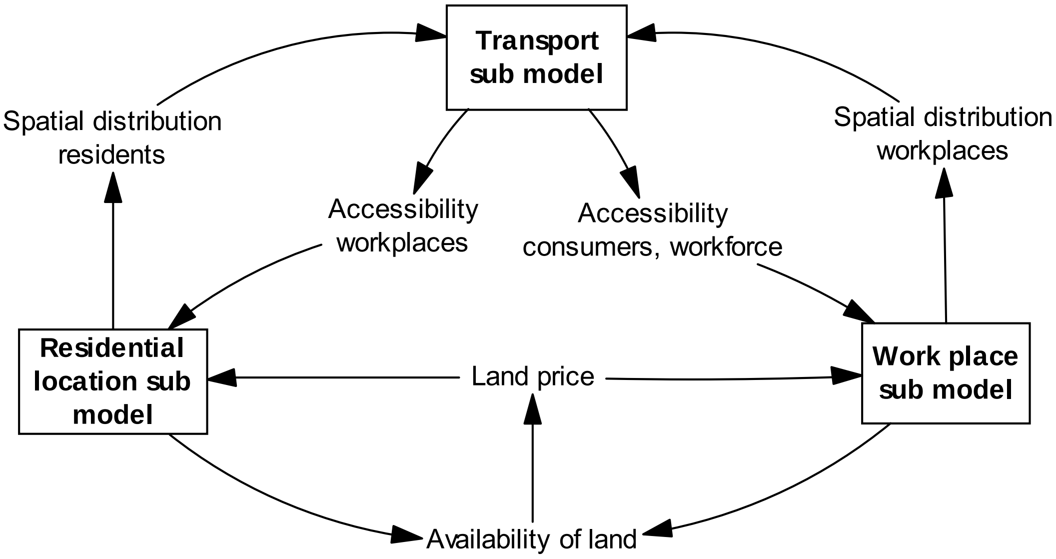


Figure 1 - Subsystem diagram with the three main sub models

Time dynamics

Changes in transport and migration behaviour proceed at different rates. MARS captures the difference between high speed of adaption in the transport system relative to the relatively slow reaction in migration. Transport users react immediately to changes in the transport system. Residents who want to change their location need available housing space in the zone of destination (the time to build new housing units is three years). This availability of housing units is checked via three time steps, going sequentially from the first best choice to the third best choice of destination zone. Residents who could not move into their destination zone, due to the lack of available housing space are added to the potential in-movers in the next time step.

An analogue procedure is implemented in the workplace migration model. Before allocating workplaces to a particular zone, MARS checks whether there is enough space for workplaces in the destination zone.

Due to the inertia thus embodied in the system, policy measures affect different sub systems of MARS with different time lags. For example, a transport policy measure, such as an increase in parking fees, might have an immediate effect on transport users, say a shift in modal split to other transport modes, but may also, in the long run, change the locational patterns of residents and firms. As an example, people may choose to live closer to their workplaces to reduce the need for commuting.

Model structure

The transport sub model

The transport model in MARS simulates passenger transport and comprises trip generation, trip distribution and mode choice stages. Trip distribution and modal split are calculated simultaneously by a gravity (spatial interaction) type model.

The modes considered in the model are slow, car, public transport (PT bus) and public transport (PT rail). The slow mode represents the non-motorized modes walking and cycling. Due to the zone size in the MARS Austria model, this mode is almost exclusively relevant for intrazonal trips. The only significant exceptions are inter-zonal trips in Vienna where the model zones represent municipal districts.

The trip generation stage calculates the number of trips originating from a particular model zone. Trip distribution and mode choice in the MARS model are calculated per origin-destination (OD) pair. Due to the heterogeneity of the case study area, as described below, we had to improve further the possibility of modelling commuting trips distribution for intrazonal trips. The original model setup was appropriate for the urban case studies, but the wider geographical scope made some changes in the structure of it necessary.

Therefore we extended the model zones for intrazonal distance classes (Mayerthaler, Haller, and Emberger 2009). Each of the 120 model zones is split into five distance classes and trips are allocated separately to each distance class.

The land-use sub model and its modules

The residential location model

In the urban MARS model, migration is modelled in a three step approach: first, out-migration per model zone is estimated. Second, migrants were pooled over the whole case study. In a third step, the migrants are distributed to destination zones.

The choice of influencing variables considered (accessibility by car and public transport, level of housing costs and share of recreational green land) is based on several different lines of argument: Firstly, they repeatedly rank among the most important determinants of migration in empirical migration research (ODPM 2002). Secondly, own empirical studies focusing in particular on Vienna confirmed this importance (Pfaffenbichler 2003). Thirdly, each of the variables is highly endogenous especially from a land-use/ transport perspective.

An earlier attempt to implement the model for Austria without structural changes revealed the inappropriateness of this structure for a larger spatial scale (Haller, Emberger, and Pfaffenbichler 2007). One major shortcoming was that the observed length distributions of migration were not reflected in the model output: whereas domestic migration in Austria (and elsewhere) is largely short-distance, the model predicted significant population shifts from the West to the East of the country, i.e. over a couple of hundred kilometres.

In order to account for the overwhelming importance of distance while changing model structure as little as possible, we implement a two stage migration model (Mayerthaler, Haller, and Emberger 2009): First, the number of out-migrants per zone is estimated following the approach of the existing urban MARS model. Second, a migration destination choice model distributes the out-migrants (which it takes as an exogenous input from the out-migration model) over the possible destinations based on characteristics of the destinations and the distance between two zones.

The model takes the form of the well-know gravity or spatial interaction model. In general terms, the number of migrants between origin *i* and destination *j*, M_{ij}, is modelled as

$$M_{ij} = O_i \frac{exp\left(\alpha_0 + \alpha_1 X_{1,j} + \alpha_2 X_{2,j} + \ldots + \alpha_n X_{n,j} + \gamma_n Y_{ij}\right) d_{ij}^{\beta}}{\sum_j exp\left(\alpha_0 + \alpha_1 X_{1,j} + \alpha_2 X_{2,j} + \ldots + \alpha_n X_{n,j} + \gamma_n Y_{ij}\right) d_{ij}^{\beta}}$$

Formula 1 General form of the formula for calculating migration flows from zone i to J

where O_i represents the number of out-migrants of origin *i* (given exogenously to the distribution model); $X_{1,j} \ldots X_{n,j}$ a set of n attributes relating to destination *j* with the associated parameters $\alpha_0 \ldots \alpha_n$; Y_{ij} an origin-destination pair specific (dummy) variable with the associated parameter γ; d_{ij} the distance between origin *i* and destination j.

Workplace location sub model

The workplaces migration sub module has a structure, very similar to the residential migration model. In the current version it consists of two parts: one for the production sector and one for the service sector.

At the moment the relative attractiveness of a zone for potential workplace migration considers:

- The zone’s potential for activity participation (accessibility);
- The abundance of building land;
- The cost for building in a zone and
- The average household income.

Access attractiveness, formulated as potential to reach workplaces and shopping opportunities, presents the zones potential for activity participation. The possibility to build in a zone is restricted by the limits of land availability in a zone. The cost of building in a zone is approximated by the land price. The average household income is a signal for firms whether there is consumption potential and is a proxy for labour cost.

For the out-moving model an average time workplaces move has to be defined, identified in empirical studies. The total number of workplaces in the study area multiplied by the reciprocal of the average time workplaces move gives the total number of out-movers in the study area.

In a next step the attractiveness to move out a certain zone is calculated with the above mentioned influence factors, except for the land availability which of course is just relevant for the in-moving sub model. This is modelled again as exponential function of the form, separately for each sector:

$$Attr_j^{out} = e^{(\alpha_1 * ACC_i + \alpha_2 * Land\_price\_attr_{i,\sec tor} + \alpha_3 * HHI_i)}$$

Formula 2 Attractiveness to move out for workplaces

$Attr_j^{out}$	Attractiveness to move out zone j
$\alpha_1 \ldots \alpha_3$	Parameters
ACCi	Access attractiveness in model zone i
Land_price_attr.i,sector	Land price attractiveness per zone i and sector (production/service)
HHIi	Household income in model zone i

The workplaces, which want to move in, are defined similar to the out-moving workplaces, but an external growth rate is added, which can be negative or positive depending on the sector. Then MARS calculates the amount of space available for business use and allocates the total potential re-allocating and newly developed workplaces to the different locations using a LOGIT model (see Formula 1)

Housing development model

In the MARS model developers decide whether, how much and where to build new housing units. Their decision is based on four factors:

- The rent they can achieve after the housing units are ready for occupation. It is assumed that this is the rent paid in the year of the development decision;
- The land price in the decision year;
- The availability of land in the decision year;
- The demand from potential in-movers in the zones.

The potential for new domiciles is distributed to the zones according to the attractiveness to build in a zone, which is dependent on the above mentioned factors. These will be ready to be occupied after an externally defined time lag of three years. MARS checks whether there is enough land for the planned developments. If not, the number of developments in the certain zones is constrained. There is currently no redistribution process to other locations in the development sub model. Changes in the available land influence land price and rent.

THE APPLICATION OF THE MODEL TO AUSTRIA

Study area and model zones

The study area for the setup of MARS Austria comprises the whole territory of Austria, 120 model zones which are based on the district subdivision ('politische Bezirke') of Austria plus the 23 municipal districts of Vienna. A first attractive feature of the district structure is that it includes the so-called 'Statuarstädte' (cities with their own statute) which are administratively separated from their hinterland districts. Hence, it is possible to represent core-periphery interactions (such as commuting flows and urban sprawl) for these districts in the model. Secondly, for many statistics, the district level is the most detailed level for which data are available.

There are two important features of the case study worth mentioning. Firstly, the model zones are very heterogeneous amongst each other (see Table 1 and Figure 2).

It comprises highly urbanized, service-sector oriented zones with highly positive commuting balances; sparsely populated zones with significant agricultural production and high out-commuting rates; mountainous regions influenced by tourism where settlement areas are concentrated or constrained by alpine valleys to name just a few examples. All in all, diversity is much greater than in usual urban agglomeration models.

Table 1 - Descriptive statistics on the case study area

Indicator	**Population**	**Pop. density [inhab./km²]**	**Total workplaces**	**Service sector employment [%)]**
Total	7,795,786	–	2,933,438	–
Minimum	1,696	20	522	41
Maximum	237,810	25,345	145,137	91
Average	64,428	93	24,243	64
Indicator	**Total area [km²]**	**Undeveloped area [% of total]**	**Land price (EUR/m²)**	**Housing rent (EUR/m²/month)**
Total	83,859	–	–	–
Minimum	1	7	14	1.63
Maximum	3,270	98	577	4.02
Average	693	89	204	2.60

Secondly, as the case study covers the entire Austrian territory, it is apparent that the model area is polycentric and, additionally, comprises several levels of central places. The polycentric structure can be shown by the representation of the commuting catchment areas in Figure 2. The blue encircled area shows Vienna, the red surrounded areas represent the provincial capitals and the yellow encircled areas other regional centres, with their main commuting catchment areas.

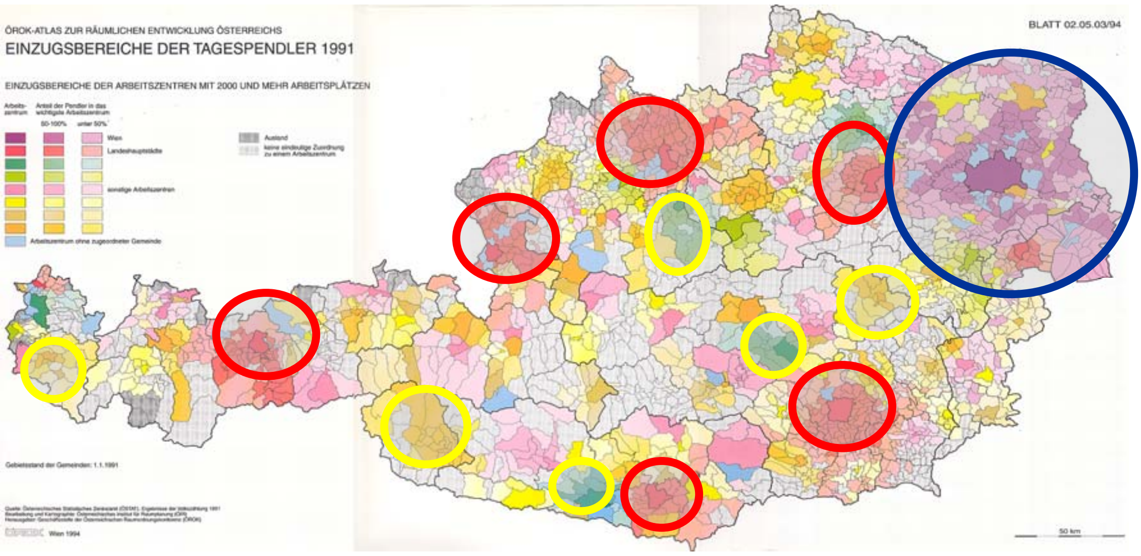


Figure 2 - Polycentric structure of Austria depicted by its commuting catchment areas.

We set up the model with data from 2001 for all available data, which makes 2001 the start year for all simulation runs. Due to some lack in data expert guesses were necessary. This concerns first and foremost guesses in data for the transport model, like parking place search time, parking fees, etc. For the average rent in EUR/m^2 data covers just the year 1991.

BASELINE SCENARIO

With the calibrated model a first long term model run (30 years) was completed. In the following the description of the base line scenario (the main underlying model assumptions) and the results of the transport model, the residents' migration and the workplaces migration model are presented.

Description of the scenario

For the population model a growth in population of 0.3 % per year is assumed. Assumptions for the workplace model are a slight decrease for the production sector (-0.55 %) and a growth for the service sector (+2.56 %) per year. The energy prices model assumes, that resource cost rise approximately 0.5 % - 1.6 % and fuel duty between 0.6 % - 1.3 % per year, depending on the fuel type.

Table 2 – Average fleet development until year 30

Vehicle type	Average change rate per year [%]
Petrol	-0.24
Diesel	1.33
Hybrid	17.17
CNG	6.68
Electric	6.63
Fuel Cell	19.05

Embodied in MARS is a fleet development model which was developed in the EU STEPs project (Shepherd and Pfaffenbichler 2006), Table 2 shows the average change rates per year for the different vehicle types implemented in MARS Austria. In total the number of cars is assumed to increase by approximately 0.8% per year.

MARS is based on the concept of stability of travel time budgets. There are numerous studies and household surveys that show that travel time budgets are stable over time as well as across cities, countries and even continents (Mokhtarian and Cao 2008; Schafer 2000; Schafer 1998) Trip rates per capita and day are assumed to be constant for peak (commuting) tours. MARS uses a constant trip rate for trips in peak time. Because of the stability of travel time budgets and the constant trip rate for peak (commuting) trips, changes in trip generation only take place at off-peak times.

Baseline forecast

Transport development

For the transport model part, there are no substantial changes in the modal split and trip distribution compared to the start year, which would be the expected result considering the implemented developments mentioned in the section above.

Table 3 – mode split base run t=30

Modal split year 30	*peak [%]*	*off-peak [%]*	*total [%]*
car	63.9	48.9	54.3
bus	11.0	9.8	10.3
rail	7.0	6.3	7.4
slow	18.1	35.0	28.9

Figure 3 shows the trip length distribution in off-peak for the whole case study area. Slow modes are dominant in the first two distance classes (0-10 km), for all the other distance classes car is the most important mode. The trip length distributions for the public transport modes are in general less steep than for the mode car.

Baseline scenario | **Trip length distribution - off-peak, year 30**

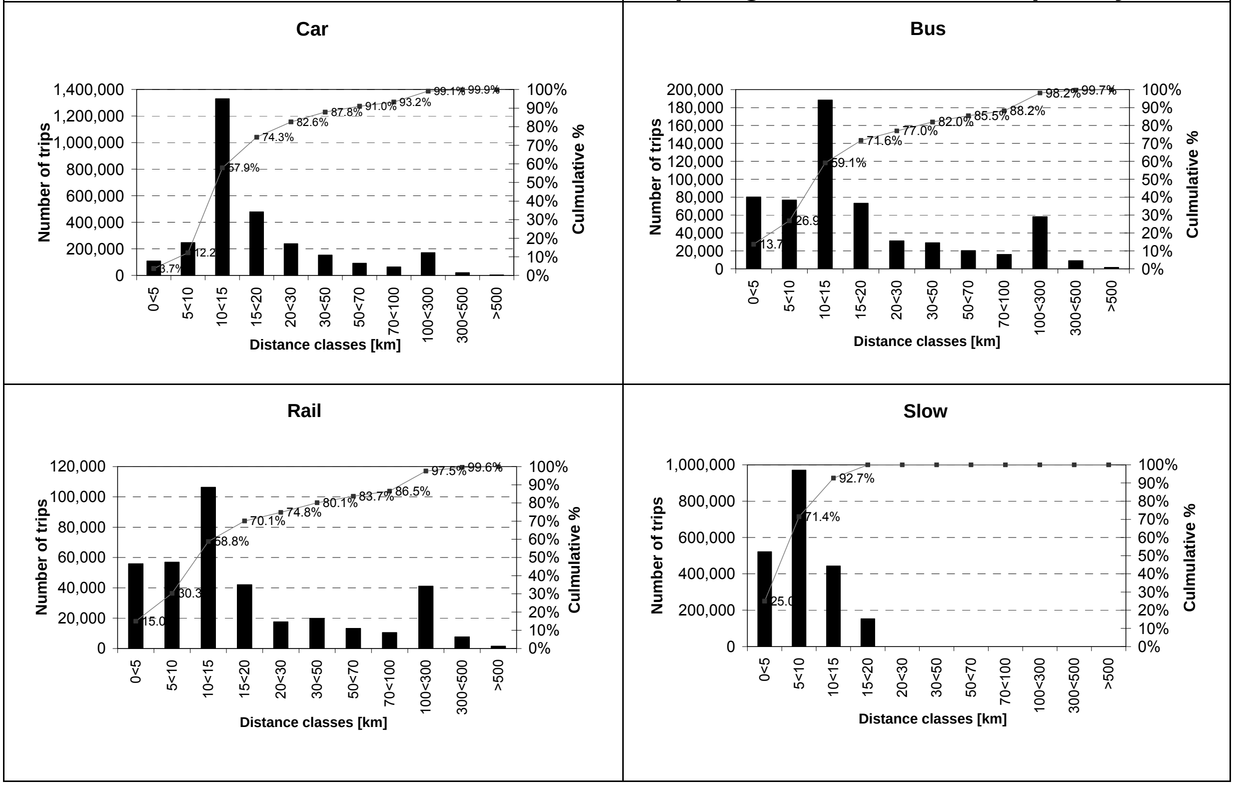


Figure 3 – Trip length distribution base line scenario off-peak

Land-use development

Figure 4 shows the population development by district from the year 1991 to 2001 from empirical data. In this period a suburbanization process for almost all provincial capitals can be observed as well as significant population losses in the province of Styria, due to structural economic changes. These districts had been dominated by heavy industry.

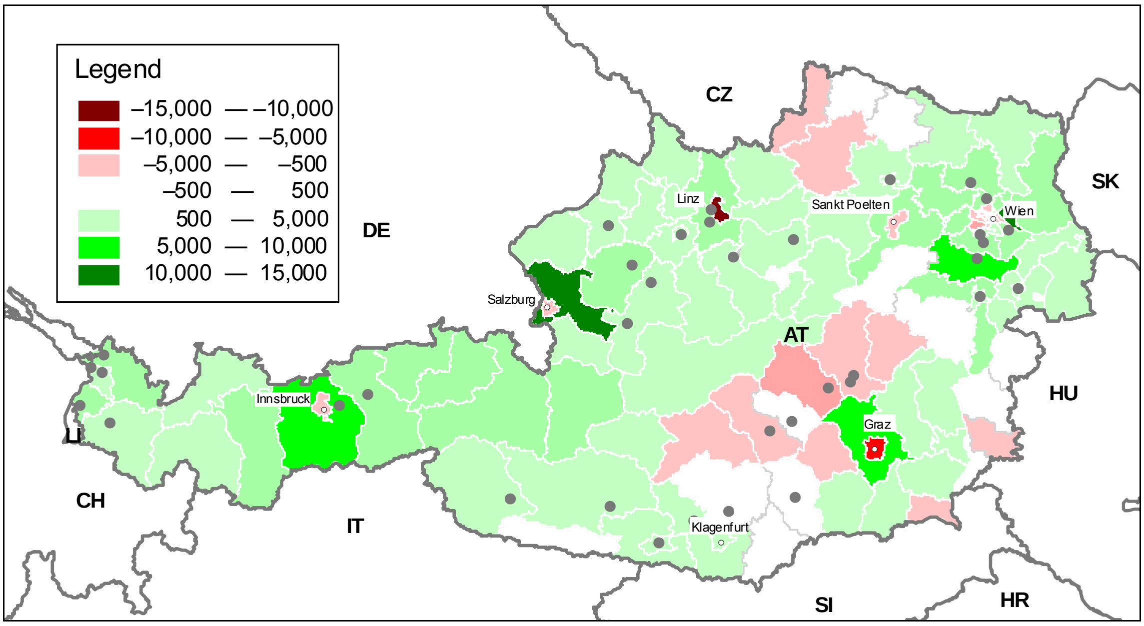


Figure 4 – Change in population by district 1991-2001 (data), provincial capitals are labelled. Source: (Statistik Austria 2002)

Figure 5 presents the predicted population development after a forecasting time of 30 years. All major agglomerations are now winners in absolute population values compared to the start year 2001. This development is reasonable due to the implemented population growth mentioned above. Vienna experiences an ongoing suburbanization process, like some other major agglomerations.

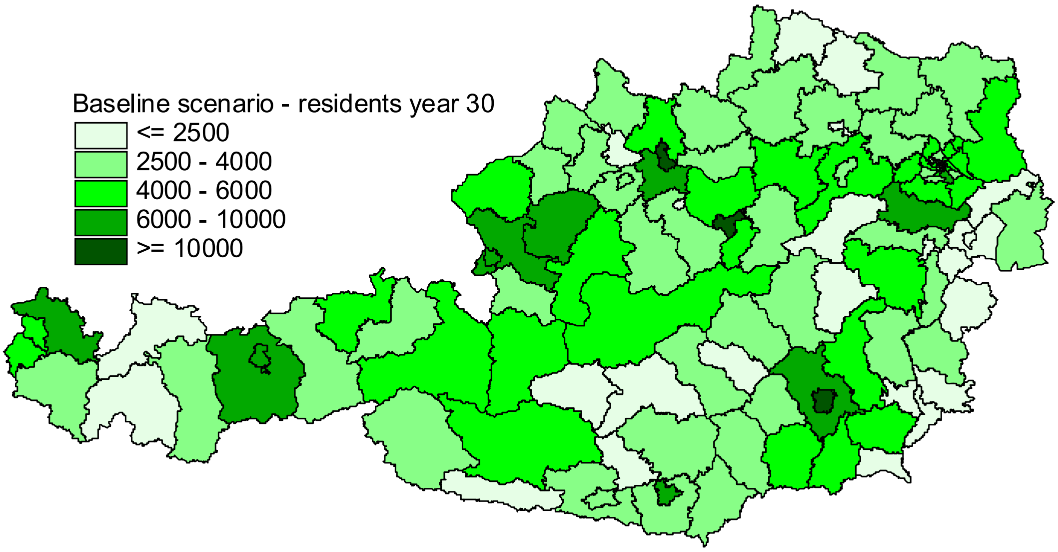


Figure 5 - Predicted population changes after a forecasting time of 30 years (year 2031) compared to base year 2001.

In the following the predicted workplace development of the two sectors (production and service) are presented. Figure 6 shows the development of the workplaces in the production sector after a forecast of 30 years. All capital cities loose workplaces in the observed sector, except for Innsbruck. This development follows an overall observed Austrian trend of the last years. Growth rates over the whole case study area in the production sector are assumed to be slightly negative as mentioned above.

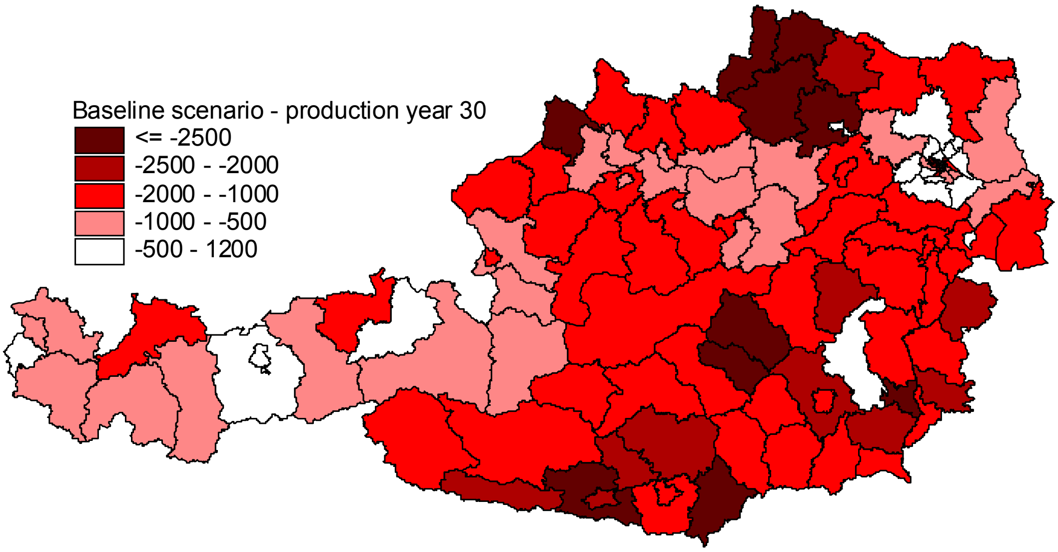


Figure 6 - Workplace development of the production sector

The development of the workplaces in the service sector shows quite the opposite development compared to the production sector (Figure 7). All capital cities experience gains in the number of workplaces, this development is in line with observed Austrian trends; the service sector gained workplaces in the last years. The pattern which emerges in figure 7 is a concentration effect for this sector. Districts which already used to have a high number of workplaces in the service sector are experiencing the largest increases.

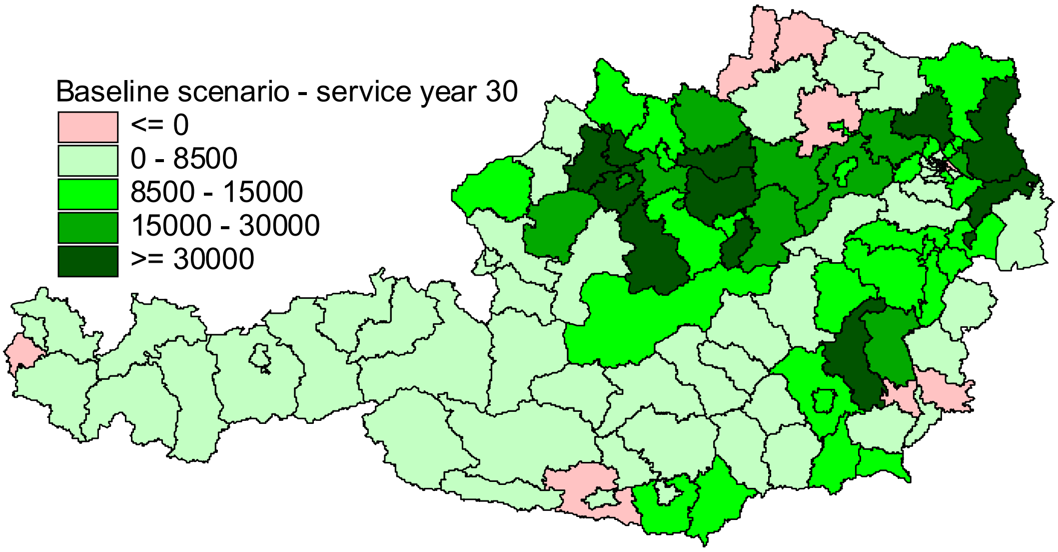


Figure 7 Workplace development of the service sector

ALTERNATIVE POLICY SCENARIOS

At the moment 19 different policy profiles are implemented in MARS Austria. The variety of possible policy instruments covers “pure” transport policies, as well as land-use policies or measures to increase the awareness of public transport and changes in the share of telework. For each policy, it is possible to define a start and end point as well as the magnitude of the policy. One main feature of the policy input module is that not only single policy instruments can be tested but also the effects of policy combinations over time can be examined.

The following descriptions of the outcome of the implemented policy measures are always compared to the baseline scenario at year 30. Each policy starts in year 5 and remains constant in magnitude until the year 30.

In our analysis of the travel behaviour we will focus on mode shifts, destination change and trip generation that may occur as consequence of the policy measure.

Description of the scenarios

All policies are assumed to start in year 5, given the base year equivalent to 2006, and remain stable until the final year 30 (or 2031).

Fuel price scenario

The first scenario deals with a major increase of the oil price. We assume that fuel prices including taxes rise from roughly 80 or 90 cents, for diesel and petrol respectively, to 2.60 and 3.40 Euros. The increase can be interpreted as the result of either a 500 % increase in fuel taxes, a steep increase in the resource costs of fuel or any combination of these two. The most obvious trigger for such a rise in the resource costs of fuel is a strong, sustained increase in the world price for crude oil brought about by the progressive depletion of economically exploitable oil resources (‘peak oil’). The difference between the two cases is of course that a fuel tax duty raises significant revenues which can used for transport or other purposes, while an exogenous increase in fuel price does not.

The behavioural reactions to higher fuel prices may include changes in the use of cars, such as a switch to more fuel efficient vehicles or alternative technologies, changes within the scope of the transport system, such as modal shift or the choice of alternative destinations for rather unconstrained trips, but ultimately also changes in the location choice of both households and firms.

Reviewing the empirical literature, Goodwin (1992) concludes that automobile travel is rather inelastic with respect to fuel prices. Furthermore, fuel costs account for only about a quarter of the total cost of driving.

Parking regime scenario

This scenario considers an increase in the parking fees charged for parking at locations visited on a regular basis such as the job and residential location (‘long term parking’). The average charge for such parking increases by 30 and 50 %, up from a level of currently 5 Euros per stay.

The policy is assumed to be implemented on an area-wide basis in the capital Vienna and the eight provincial capitals in Austria (all considered as separate zones in the model), as well as in small and medium sized towns in rural or suburban districts (model zones).

Public transport fare scenario

The demand for a substantial decrease in public transport fares is raised time and again in the public discussion on transport policy. Proponents often make the claim that, given the pre-existing incidence of subsidization in public transport, public transport fares could be significantly reduced or abolished altogether via relatively moderate increases in subsidies. One particular example can be found in the Greenbook on Energy Efficiency published by the Austrian regulatory agency for electricity markets (Energie-Control GmbH 2008). The policy is motivated by the expectation that significantly cheaper or free public transport will induce a large-scale shift towards public transport use.

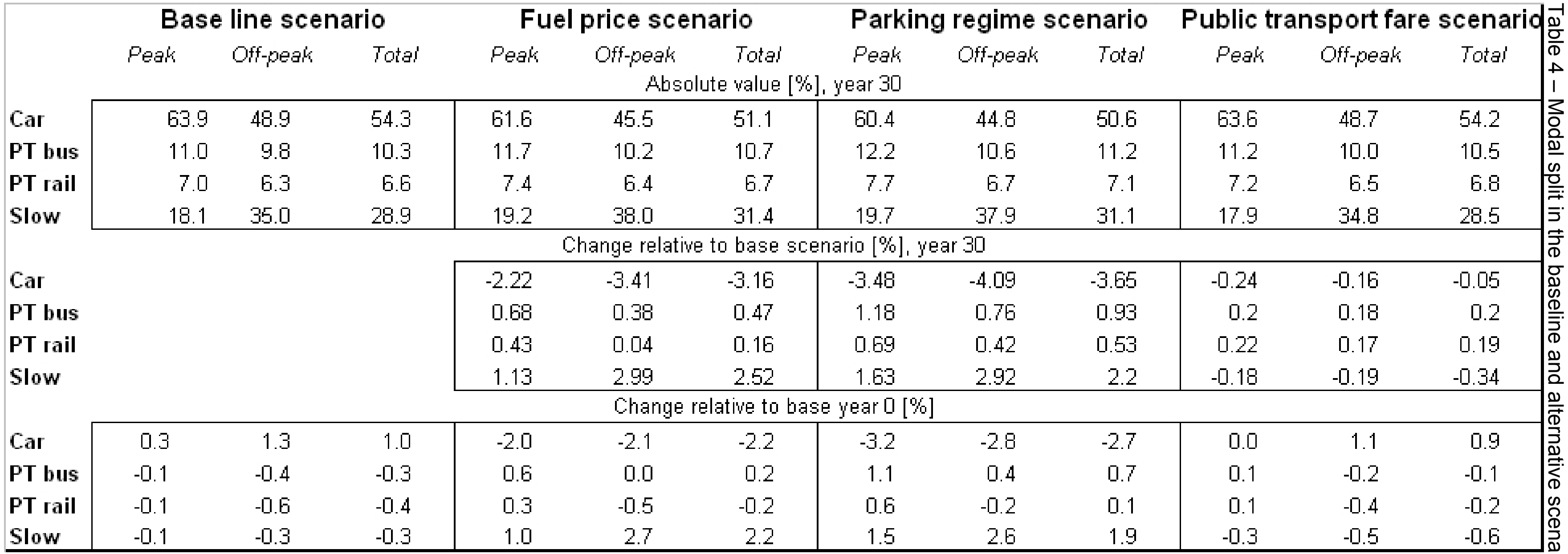
In order to assess the impact of such policies, this scenario considers an across-the-board decrease in public transport fees. Bus and rail fares are assumed to decrease by 50 % relative to their current level of 7 Euro-Cents per kilometre.

Behavioural reactions may include a mode shift, changes in destination and, in the medium to long term, changes in the location of people and firms (Wegener and Fürst 1999).

Transport impacts of the scenarios

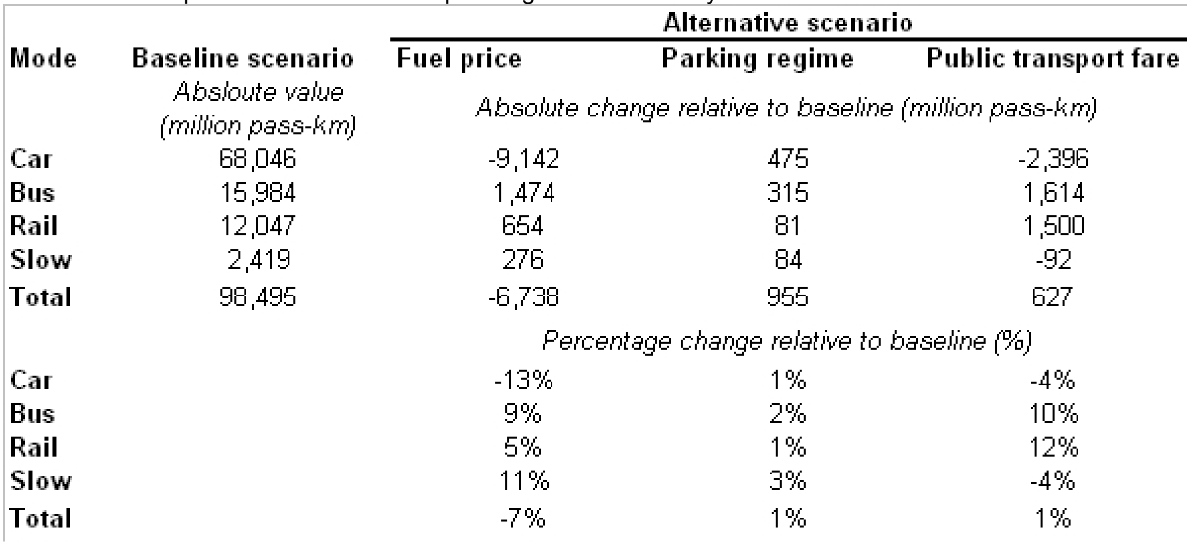
This section presents the impacts of the alternative scenarios on key travel indicators in year 30 of the simulation. These impacts are the combined result of direct reactions in travel behaviour, and of medium and longer term reactions through the scenarios' impacts on location decisions. The discussion focuses on the impacts of the alternative scenarios relative to the baseline scenario.

Table 4 – Modal split in the baseline and alternative scenarios, year 30



	Base line scenario			**Fuel price scenario**			**Parking regime scenario**			**Public transport fare scenario**		
	Peak	*Off-peak*	*Total*	*Peak*	*Off-peak*	*Total*	*Peak*	*Off-peak*	*Total*	*Peak*	*Off-peak*	*Total*
	Absolute value [%], year 30											
Car	63.9	48.9	54.3	61.6	45.5	51.1	60.4	44.8	50.6	63.6	48.7	54.2
PT bus	11.0	9.8	10.3	11.7	10.2	10.7	12.2	10.6	11.2	11.2	10.0	10.5
PT rail	7.0	6.3	6.6	7.4	6.4	6.7	7.7	6.7	7.1	7.2	6.5	6.8
Slow	18.1	35.0	28.9	19.2	38.0	31.4	19.7	37.9	31.1	17.9	34.8	28.5
	Change relative to base scenario [%], year 30											
Car				-2.22	-3.41	-3.16	-3.48	-4.09	-3.65	-0.24	-0.16	-0.05
PT bus				0.68	0.38	0.47	1.18	0.76	0.93	0.2	0.18	0.2
PT rail				0.43	0.04	0.16	0.69	0.42	0.53	0.22	0.17	0.19
Slow				1.13	2.99	2.52	1.63	2.92	2.2	-0.18	-0.19	-0.34
	Change relative to base year 0 [%]											
Car	0.3	1.3	1.0	-2.0	-2.1	-2.2	-3.2	-2.8	-2.7	0.0	1.1	0.9
PT bus	-0.1	-0.4	-0.3	0.6	0.0	0.2	1.1	0.4	0.7	0.1	-0.2	-0.1
PT rail	-0.1	-0.6	-0.4	0.3	-0.5	-0.2	0.6	-0.2	0.1	0.1	-0.4	-0.2
Slow	-0.1	-0.3	-0.3	1.0	2.7	2.2	1.5	2.6	1.9	-0.3	-0.5	-0.6

Table 5 – The impact of the scenarios on passenger-kilometres in year 30



		Alternative scenario		
Mode	**Baseline scenario**	**Fuel price**	**Parking regime**	**Public transport fare**
	Absloute value (million pass-km)	*Absolute change relative to baseline (million pass-km)*		
Car	68,046	-9,142	475	-2,396
Bus	15,984	1,474	315	1,614
Rail	12,047	654	81	1,500
Slow	2,419	276	84	-92
Total	98,495	-6,738	955	627
		Percentage change relative to baseline (%)		
Car		-13%	1%	-4%
Bus		9%	2%	10%
Rail		5%	1%	12%
Slow		11%	3%	-4%
Total		-7%	1%	1%

The impact of the three policies on travel flows measured in passenger-kilometres is relatively modest; none of the policies considered implies a double-digit decrease in passenger kilometres. The comparatively highest reduction of roughly 6,738 million passenger-kilometres or seven percent follows from the fuel price scenario, followed by the parking regime and the public transport fare scenario both with a 1 percent reduction (

Table 5).

As is to be expected, car pass-km decrease in the fuel price and the public transport fares scenario relative to the baseline scenario. The parking regime scenario leads surprisingly to an increase in passenger km for the mode car. The extent of the reduction in car travel differs a lot between the scenarios, the reduction in pass-km in the fuel price scenario is nearly four times that of the public transport fares scenario (see Table 4). Public transport ridership in passenger kilometres significantly increases in the fuel price and public transport fare scenarios, where the increase by 14 and 22 percent respectively, while the impact of the parking regime scenario slightly negative.

By the very nature of the slow modes, the absolute change in passenger kilometres are limited in each of the scenarios. However, even in percentage terms, the changes are smaller numerically and ambiguous in direction. For the fuel price scenario the slow modes increase in passenger kilometres, while the reduction of the public transport fares decreases the passenger kilometres for the slow modes.

Fuel price scenario

The fuel price scenario has modest impacts on modal split given the significant increase in fuel prices underlying the scenario. The modal share of car travel in terms of trips decreases by roughly three percent; public transport takes over 2.5 per cent while slow modes take over only 0.5 percent of this reduction.

However, the aggregate figures cover significant variation at more disaggregate levels.

Peak period travel is less seriously affected than off-peak travel. The overall reduction of three percent is brought about by a 2.2 percentage points decrease in peak travel while in the corresponding decrease in off-peak travel is 3.4 percentage points.

In the peak period, both public transport modes together attract almost the same share of the former car trips than the slow modes. On the contrary, in the off-peak period, the overwhelming majority of converts opts for walking and cycling (3 percentage points) rather than public transport (0.4 percentage points).

In the peak period, the reduction in car trips is lies mainly in medium distance classes with the strongest decrease in the 20 to 30 kilometres distance class. The decrease in the shorter distance classes is taken over almost equally shared by bus and slow modes. The mode rail covers just a smaller share. People tend to travel shorter distances, the decrease of the medium distance trips of car trips is not covered by any other mode.

In the off-peak period, the modal shift is between car travel and slow modes while the impact on public transport ridership remains fairly limited. In terms of travel distances, travellers substitute short slow mode and bus trips of up to 10 kilometres for car trips in the broad range of 15 to 300 kilometres.

Comparing peak to off-peak travel, two somewhat different patterns emerge: in the peak period medium distance car trips are taken over by all other modes according to their appropriateness for covering distances, resulting in only slight decrease in distances travelled in the aggregate. In the off-peak period the modal shift towards slow modes and bus is accompanied by a significant decrease in average travel distances.

Parking regimes scenarios

The parking regime scenario has strong impact on modal split. The modal share of car travel in terms of trips decreases by roughly four percent (3.65); public transport modes take over the smaller share with 1.46 percent, while slow modes gain 2.2 percent.

Like in the fuel price scenario, the off-peak period travel is more affected than peak travel. Peak travel is reduced by 3.48, off-peak travel by 4.09 percentage points.

In the peak period, public transport modes are attracting more of the former car trips than the slow modes. In the off-peak period the mode bus is attracting the most former car trips beside the slow modes with almost 3 percent.

The reduction in car trips in the peak period lies mainly in the short distance classes (0-15 km), with the strongest decrease in the 10 to 15 kilometres distance class. Most of the short distance class trips are taken over by the slow modes and bus.

In the off-peak period almost the same pattern occurs, with the difference that the substitution effect is very small. The number of trips in the off-peak period is decreasing, most of the car trips are not covered by other modes.

Public transport fare scenario

The impact on modal split for the transport fares scenario is very little compared to the other two policy measures. The public transport modes are increasing their share by 0.4 percentage points in total.

For the peak period the magnitude of the increase is the same, with a bigger share at the expense of the mode car. The effect of the policy in the off peak period is similarly weak, with an increase of 0.35 percentage points, this time mostly to the expense of the slow modes.

In peak time period a result of the policy measure is a reduction of car trips in the distance classes 0 to 5 up to 15 to 20 kilometres. The public transport modes gain almost equally in all distance classes. Short distance trips for the slow modes are also decreasing.

In off peak period car trips are mostly reduced in the distance class 10 to 15 kilometres. For the public transport modes, there is a slight increase in long distance trips. The slow modes are loosing trips as a result to this policy measure.

Impacts on CO_2 emissions

Table 6 – Direct (pump-to-wheel) CO_2 emissions in 1,000 tonnes in year 30

	Scenario			
Mode	**Baseline**	**Fuel price**	**Parking regime**	**Public transport fare**
	Absolute value (1,000 t/year)			
Car	7,879	6,895	7,914	7,630
PT bus	194	193	193	194
Total	8,073	7,088	8,107	7,823
	Absolute change relative to baseline (1,000 t/year)			
Total		–985	34	–250
	Percentage change relative to baseline			
Car		–12.50	0.44	–3.17
PT bus		–0.05	–0.10	0.01
Total		–12.20	–0.42	–3.09

Table 6 shows the resulting CO_2 emissions for each policy scenario. The first three rows present the absolute values for the whole case study area in tonnes/year for the modes car and bus. The bottom of the table shows the relative changes compared to the baseline scenario. The most effective policy measure concerning a reduction of CO_2 emissions is the fuel price scenario. Emissions decrease by -12.20 % in total. The policy which reduced the public transport fares pays off with a reduction of -3.09 %. The parking fee scenario seems to have little effect on reducing emissions. Although there is a major reduction in short distance trips for the mode car, travellers take more medium distance trips (20 to 30 km), which almost cancels out the reduction achieved through the reduction in short distance trips.

CONCLUSIONS AND OUTLOOK

The main conclusion on the particular scenarios analysed in this study have already been highlighted in the previous section. In terms of CO_2 reductions, the fuel price scenario is most effective in that it not only dissuades car travel but also implies an incentive to make shorter trips. As to the impacts on travel behaviour, the parking regime scenario is similarly effective as the fuel price scenario even though the nature of the impact is structurally different. Finally, increasing subsidies to lower public transport fares is relatively ineffective both from a transport as well as a CO2 emission perspective.

The results also clearly indicate that transport policies should adopt strategies that combine a range of different policy measures into a larger whole. As an example, our results suggest that while changes in fuel taxation (or other distance-based instruments such as road pricing) are very effective in influencing medium to long distance car travel, their impact on short distance car trips is inferior compared with the parking regimes scenario. By contrast, parking charges are very effective in influencing short distance car travel while their effect on longer distance travel is negligible.

This result is in line with early research on urban transport strategies which emphasized the importance of an integrated strategy approach to transport policy (May, Shepherd, and Timms 2000).

In the debate about transport policies a key distinction is usually made between modal transfer, i.e. the redistribution of travel flows between modes, and traffic reduction, i.e. the reduction of the overall level of travel flows. However, neither modal transfer nor traffic reduction is a policy instrument at the discretion of transport policy makers.

The analysis in this study suggests that also actual transport policy instruments, such as changes in parking charges and public transport fares, do indeed produce different results relating to the modal transfer / traffic reduction dichotomy. In the public transport fares scenario the reduction in car passenger-kilometres (2,395 million) is completely compensated by an opposed increase in public transport passenger-kilometres (3,114 million), leaving the overall amount of travel almost unaffected.[1] The oil price scenario is somewhat of an intermediate case, with part of the car passenger-kilometre reduction (9,142 million) compensated by an increase in public transport and slow modes passenger kilometres (2,404 million ≈ 1,474 + 653 + 276 million) and part of producing a 'true' reduction in overall passenger-kilometres (6,738 million).

Another more generic conclusion emerges from the public transport fare scenario. In this scenario, commuting becomes more time-consuming in the aggregate because car travellers make longer trips and because new public transport users attracted by the lower fares accept longer travel times in exchange. As a consequence, less time is available for off-peak trips given the stable overall travel time budget. This in turn reduces the total number of trips travelled in the off-

---

[1] The overall reduction of 300 million pass-km is small compared to the total modal transfers of about 3,700 million pass-km.

peak period. This highlights that travel constraints following from overall travel budget, either in terms of available time or monetary cost, imply interdependences between commuting and other trip purposes. These links between relatively unconstrained travel to work or education and more discretionary leisure travel corroborate the case for integrated transport strategies.
The results presented in this paper give the total direct transport impacts and indirect behavioural changes due to interactions of the scenarios with residential, commercial and industrial land-use. What we did not analysis so far is the relative contribution of transport and land-use changes to these aggregate impacts. We will address this issue in future work. Doing so may also help to shed more light on the limited influence of the quite significant changes in travel costs underlying in particular the fuel price scenario.

REFERENCES

Energie-Control GmbH. 2008. Grünbuch Energieeffizienz. Wien.

Goodwin, Phil. 1992. Review of New Demand Elasticities With Special Reference to Short and Long Run Effects of Price Changes. *Journal of Transport Economics* Vol. 26 (No. 2):pp. 155-171.

Haken, H. 1983. *Advanced Synergetics. Instability Hierarchies of Self-Organizing Systems and Devices*. Edited by H. Haken. Vol. 20, *Springer Series in Synergetics*. Berlin: Springer-Verlag.

Haller, Reinhard, G. Emberger, and P. Pfaffenbichler. 2007. National Scale Land-Use and Transport Modelling: The MARS Austria Model In *ETC 2007*. Vienna.

May, Anthony. D., Simon. P. Shepherd, and Paul. M. Timms. 2000. Optimal transport strategies for European cities. *Transportation* 27:285-315.

Mayerthaler, Anna, Reinhard Haller, and Guenter Emberger. 2009. A Land-Use/Transport interaction model for Austria. Paper read at 27th International Conference of the System Dynamics Society, 29 July 2009, at Albuquerque.

———. 2009. Modelling land-use and transport at a national scale - the MARS Austria model. In *49th European Congress of the Regional Science Assosiation International - Territorial Cohesion of Europe and Integrative Planning*. Lodz/PL.

Mokhtarian, Patricia L., and Xinyu Cao. 2008. Examining the impacts of residential self-selection on travel behavior: A focus on methodologies. *Transportation Research Part B: Methodological* 42 (3):204-228.

ODPM. 2002. Development of a migration model. London: Office of the Deputy Prime Minister.

Pfaffenbichler, P. 2003. The strategic, dynamic and integrated urban land use and transport model MARS (Metropolitan Activity Relocation Simulator). Dissertation, Institute for Traffic Planning and Traffic Engineering, University of Technology, Vienna.

———. 2008. *MARS - Metropolitan Activity Relocation Simulator. A System Dynamics based Land Use and Transport Interaction Model*. Saarbrücken: VDM Verlad Dr. Müller.

Pfaffenbichler, Paul Christian. 2003. The strategic, dynamic and integrated urban land use and transport model MARS (Metropolitan Activity Relocation Simulator). Development, testing and application. Dissertation, Institute for Transport Planning and Traffic Engineering, Vienna University of Technology, Vienna.

Schafer, A. 2000. Regularities in travel demand: an international perspective. *Journal of Transportation and Statistics* 3 (3):1-32.

Schafer, Andreas. 1998. The global demand for motorized mobility. *Transportation Research Part A: Policy and Practice* 32 (6):455-477.

Shepherd, S.P., and P.C. Pfaffenbichler. 2006. Sustainable transport policies under scarcity od oil supply. *Engineering Sustainability* 159(2):pp.63-70.

Statistik Austria. 2002. Volkszählung 2001. Hauptergebnisse I - Österreich. Wien: Statistik Austria.

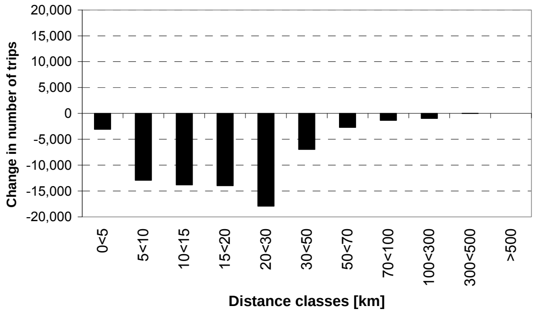
Umweltbundesamt. 2010. Austria's annual greenhouse gas inventory 1990–2008. In *Submission under Decision 280/2004/EC*. Vienna: Umweltbundesamt GmbH and Federal Ministry of Agriculture, Forestry, Environment and Water Managemen (BMLFUW).

Wegener, Michael, and Franz Fürst. 1999. Land-use Transport Interaction: State of the Art. In *Berichte aus dem Institut für Raumplanung*, edited by I. f. Raumplannung. Dortmund: Universität Dortmund.

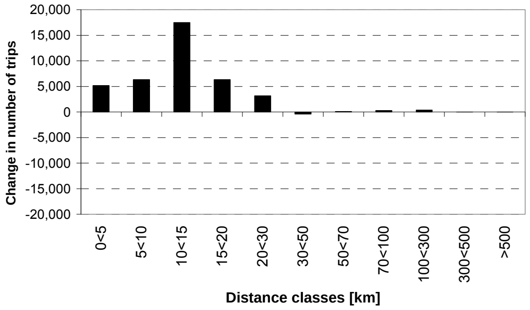
APPENDIX 1 – RESULTS BY DISTANCE CLASSES

Change in trips relative to baseline scenario: fuel price scenario, peak period, year 30

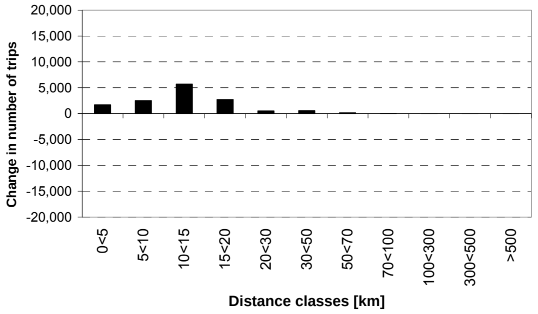
Car



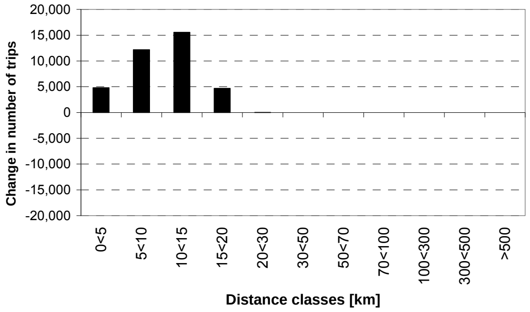
Bus



Rail

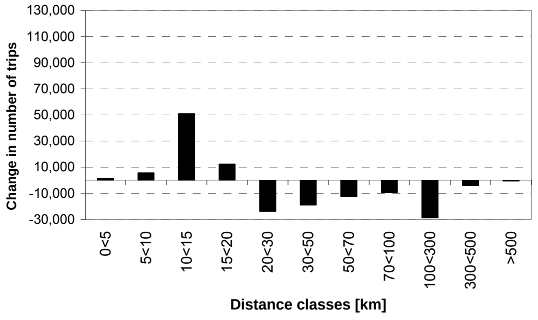


Slow

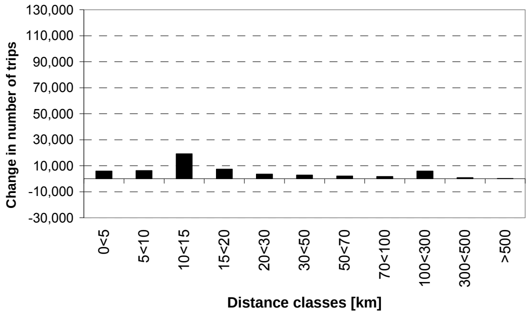


Change in trips relative to baseline scenario: fuel price scenario, off-peak period, year 30

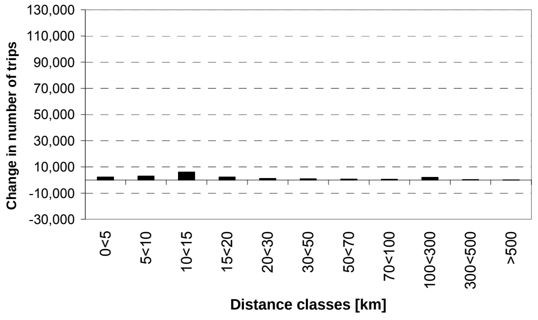
Car



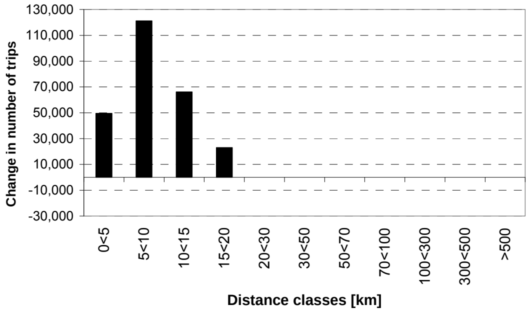
Bus



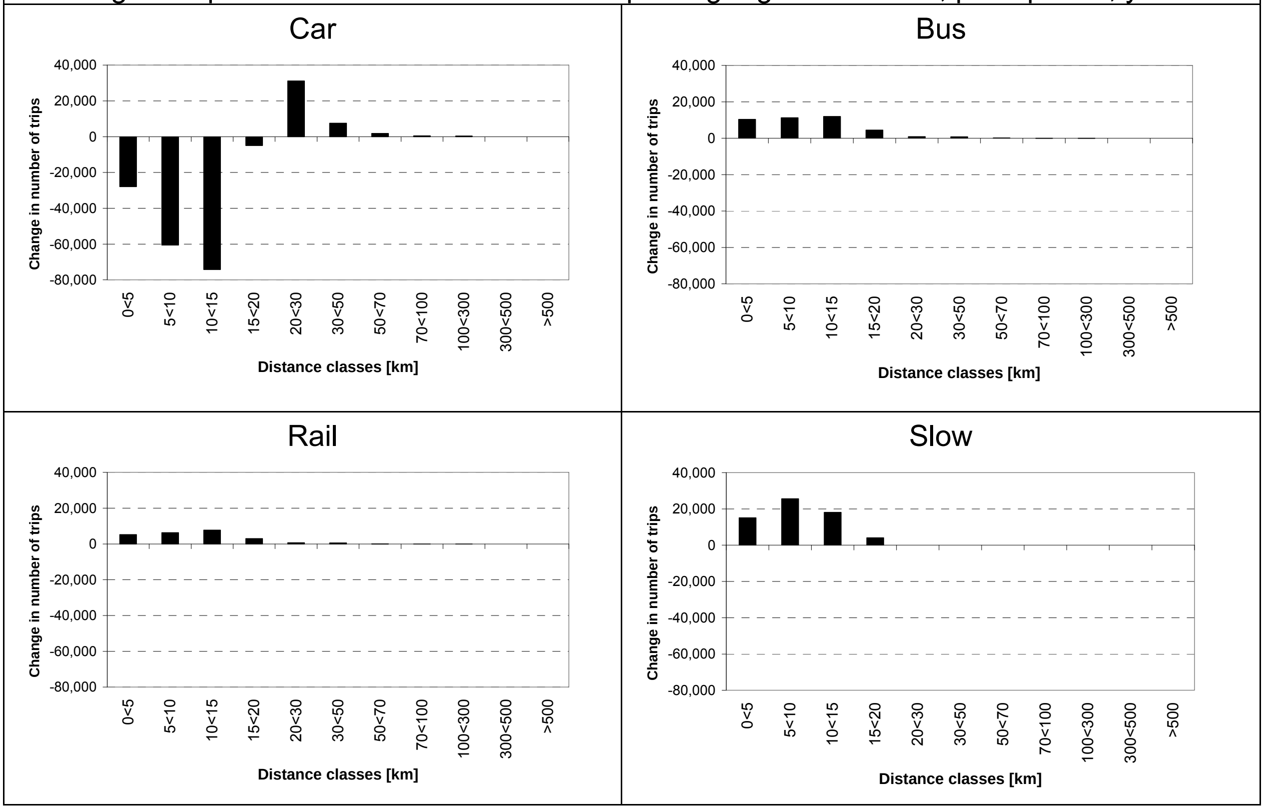
Rail



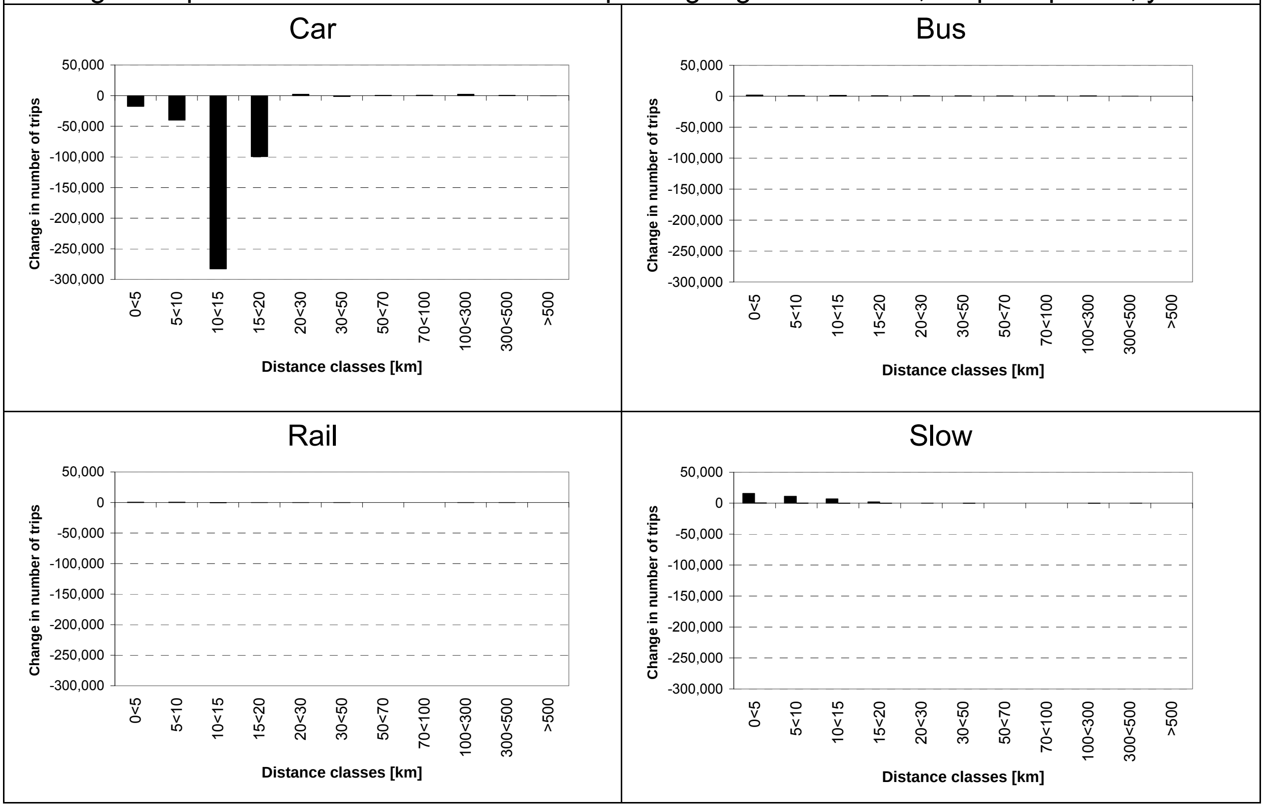
Slow



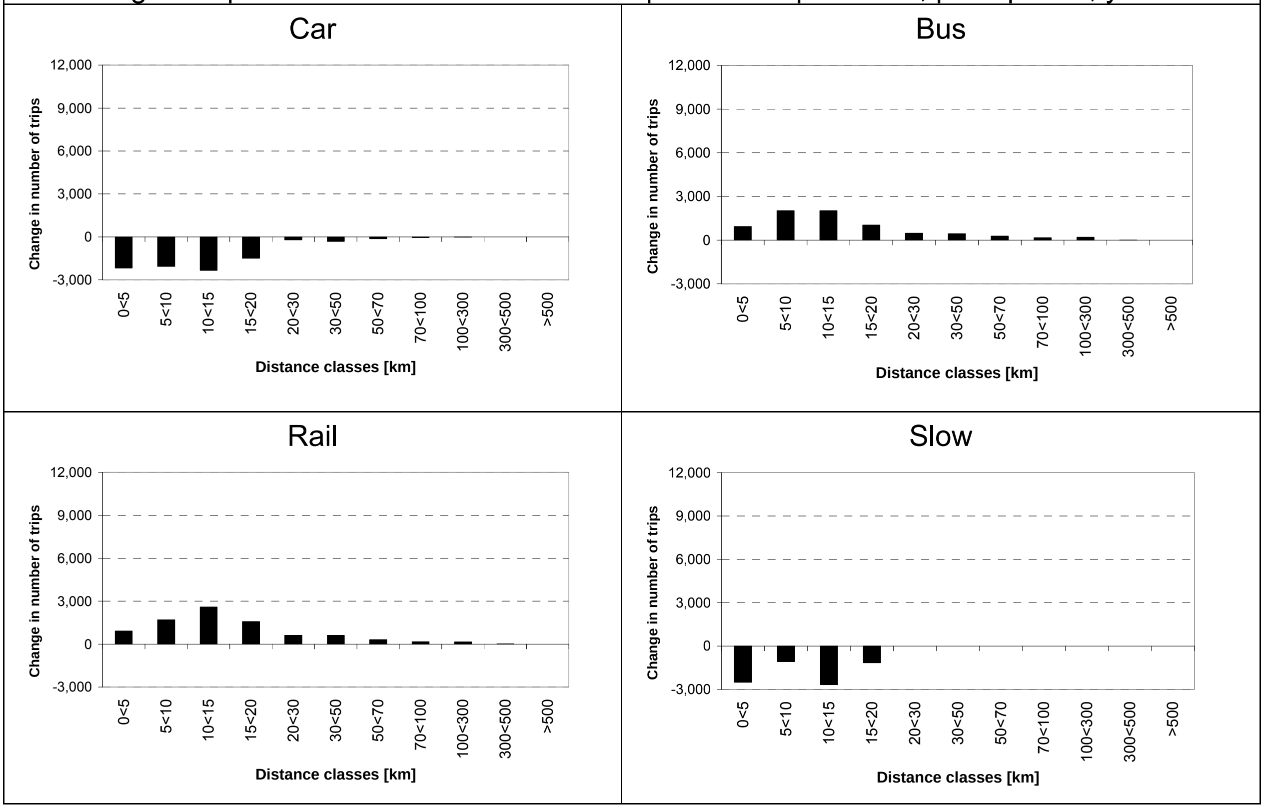
Change in trips relative to baseline scenario: parking regime scenario, peak period, year 30



Change in trips relative to baseline scenario: parking regime scenario, off-peak period, year 30



Change in trips relative to baseline scenario: public transport fares, peak period, year 30



Change in trips relative to baseline scenario: public transport fares, off-peak period, year 30