A reform of car parking organisation as an instrument for creating sustainable urban regions

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Abstract
Sustainability is one of today's major challenges. Numerous studies provide evidence that cities worldwide are not sustainable. Neither land use nor transport are organised in a sustainable manner. Indicators to measure sustainability include urban sprawl, air pollution and consumption of non-renewable resources of energy. The transport and land use planning strategies of the last decades have not created sustainable cities and urban regions. Research results indicate that the instruments used, for example public transport investments, parking charges, road pricing, company transport plans or public awareness campaigns were not powerful enough. Empirical evidence shows that their ability to reverse unsustainable trends was limited. E.g. car use and hence fossil fuel consumption is still increasing worldwide. Recent research, making use of a dynamic integrated land use and transport model, shows that the approach "more of the same", i.e. more public transport, higher parking charges and road pricing etc., is hardly sufficient to achieve the objective of sustainability. Even if prices would be increased far beyond politically acceptable levels. As a conclusion the use of new, innovative instruments has to be taken into account. A detailed analysis of generalised costs of different modes of transport is used to detect the key elements which are determining transport user behaviour. These were found to be access and egress to public transport stops and parking places. Based on these findings a reform of car parking organisation is suggested as an alternative instrument to achieve sustainable cities and urban regions. The capability of this instrument is demonstrated using a simulation case study of the city Vienna. In this case study the performance of the proposed car parking organisation is compared with three more conventional strategies: "continue as before" and two different types of urban road charges.

Introduction
Sustainability is one of the major challenges which today's decisions makers and planners face. One of the possible definitions of sustainability is equity between today's and future generations (May et al. 2003). That means that the activities of today's generation should not limit or hinder the opportunities of future generations. To make this definition operational the use of a set of seven sub-objectives is suggested (May et al. 2003). Two of these sub-objectives are careful treatment of non-renewable resources and protection of the environment (May et al. 2003). The following section "Indicators of sustainability" defines indicators which are suitable to measure these two sub-objectives. An important aspect in the selection of the sub-objectives and indicators is that the integrated land use and transport model MARS, employed later in the case study, has to be able to calculate them in a reasonable way. E.g. the sub-objective "Contribution to economic growth" cannot be taken into account because modelling macro-economic development is not within the scope of MARS. Another example is that due to the strategic character of MARS it is not possible to calculate car noise emissions and imissions. To do so the MARS

results would have to be fed into models on a more detailed level of dis-aggregation.

During the last decades cities worldwide realised that they do not operate in a sustainable way. Decision makers responded with the implementation of different transport related instruments. Among them are public transport improvements, road capacity increases, parking fees, cordon charges and different combinations of them. Contrary to the expectations empirical observations presented in section "Indicators of sustainability" indicate that the set targets were not met. To analyse why this has happened and to highlight ways to overcome the identified problems is the aim of the section "What determines travel behaviour?". Results of research into travel behaviour are presented and the pivotal point for influencing travel behaviour is identified.

The section "Transport policy instruments" gives a brief overview about which instruments are available to change travel behaviour. Considering them all in the case study would be far beyond the scope of this paper. Therefore a selection of four scenarios to be tested and compared in the simulation case study was made. A brief description of the instruments forming these scenarios is given. To tackle the issue of sustainability adequately it was seen as essential not to focus solely on the transport system. Therefore the dynamic Land Use Transport Interaction (LUTI) model MARS was employed in the case study. The section "The integrated, dynamic land use and transport model MARS" gives an overview about the basic characteristics of this simulation tool.

The section "Case study Vienna" presents the results of the model calculations. The development of modal shares and annual CO_2-emissions are presented in graphical form over the modelling period of 30 years. The development of workplace location relative to a scenario "do minimum" is presented as geographical maps. These developments are compared with the overall objective of sustainability and the official objectives and targets of the city of Vienna. Some key indicators of the four scenarios are compared in a table. The final section "Conclusions" summarises the results and draws conclusions.

Figure 1. *An Austrian example for urban sprawl and consumption of land: the city of Linz (Stift 2002).*

Indicators of sustainability

(Minken et al. 2003) summarises a wide range of suggestions for indicators to measure sustainability and its sub-objectives. Consumption of land, consumption of fossil fuels and atmospheric emissions are amongst them. Land and fossil fuel are non renewable resources. Their consumption is therefore suitable as an indicator to measure sustainability. Atmospheric emissions are directly linked to the consumption of fossil fuels and their production endangers the environment. The model MARS is able to calculate these indicators.

The observation of the statistical data for the indicators consumption of land, consumption of fossil fuels and atmospheric emissions shows that today's cities are not sustainable. The instruments which have been applied in the past were not effective enough to achieve the goal of sustainability. The following sections illustrate these observations.

CONSUMPTION OF LAND

In Vienna the amount of built up land has increased by about 10.4 square kilometres or 8.4% between 1995 and 1999 (Petz 2001). This was a yearly rate of increase of about 2% p.a. During the period 1991 to 1998 the amount of land consumed for the purpose "transport" has increased by about 4 square kilometres or 8.3 % (Petz 2001). The yearly rate of increase was about 1.1% p.a. The number of residents on the other hand had only yearly rates of increase of about 0.1% p.a. (ÖSTAT 1995; Statistisches Amt der Stadt Wien 2003). The consumption of land expands over proportionally. An over proportional growth of built up land is by no means sustainable. Figure 1 illustrates the high consumption of land of new developments in the outskirts of an urban region.

FOSSIL FUEL CONSUMPTION AND GREENHOUSE GAS EMISSIONS

The average fuel consumption of the Austrian car fleet is decreasing. The average car consumed about 8.4 litres per 100 kilometres in 1992. Until 1996/97 the average consumption decreased slightly to 8.1 litres per 100 kilometres (Herry et al. 2002). But the improvements in fuel efficiency were offset by an increased car use. For example the car and motorcycle share for commuting in Vienna increased from 39.5% in 1981 over 42.9% in 1991 to 43.9% in 2001 (ÖSTAT 1995; ÖSTZ 1985; Statistik Austria 2004). This trend could also be seen in the development of greenhouse gas emissions. The CO_2-emissions of the Austrian transport sector increased by about 50% between 1980 and 1999 (Figure 2). This exponential growth in transport related carbon dioxide emissions is by no means sustainable. Other atmospheric emissions show a stable or decreasing tendency (Herry et al. 2002).

What determines travel behaviour?

Travel behaviour, i.e. the decisions whether, when and how to travel, is determined by two factors: the costs for a journey and the time consumed by a journey. German research from the 1990ies shows that different parts of a journey are perceived differently (Walther et al. 1997). Probably everyone will confirm from own experience that access and egress times as well as waiting and changing times are perceived as being more unpleasant than in-vehicle times. In the decision process these times are subjectively weighted higher than their measured physical time. Figures 3 and 4 show the results concerning this subjective evaluation of the different parts of a motorised trip (Walther et al. 1997). Within the same research also "value of time" factors to convert the different cost components of a journey to time units were determined. The subjectively perceived time plus the costs transferred to time units measure the disutility of realising a journey at a given time with a given mode of transport. The probability of choosing one alternative is the ratio of the reciprocal disutility of the alternative to the sum over all alternatives. These principles are utilised in the model MARS (see section "The integrated, dynamic land use and transport model MARS"). It can be directly seen in Figures 3 and 4 that a one unit change in access/egress time has a much higher behavioural effect than a one unit change in in-vehicle time. Therefore this part of a journey can be seen as the pivotal point to behavioural changes.

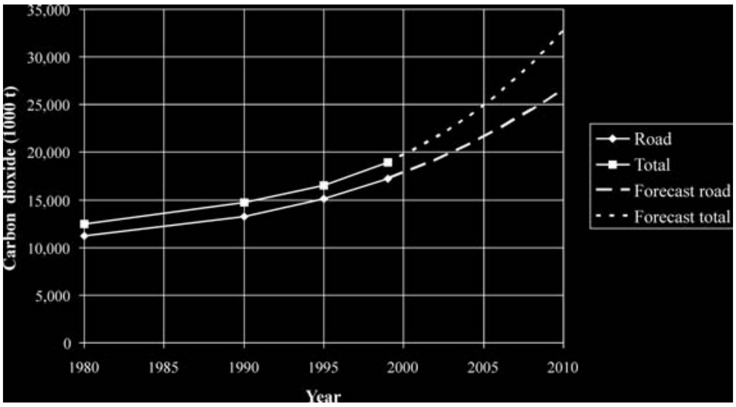

Figure 2. Development carbon dioxide emissions of the Austrian transport sector between 1980 and 1999 (Herry et al. 2002).

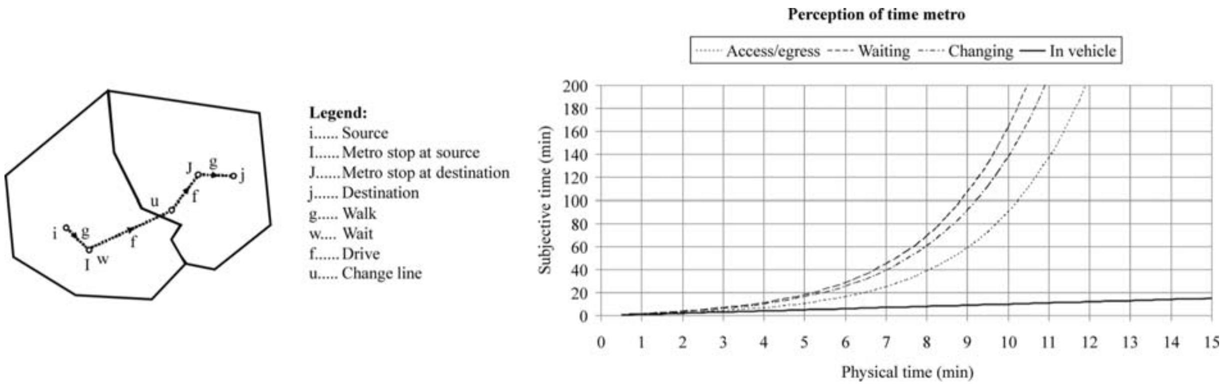

Figure 3. Subjective evaluation of the different parts of a metro trip (Walther et al. 1997).

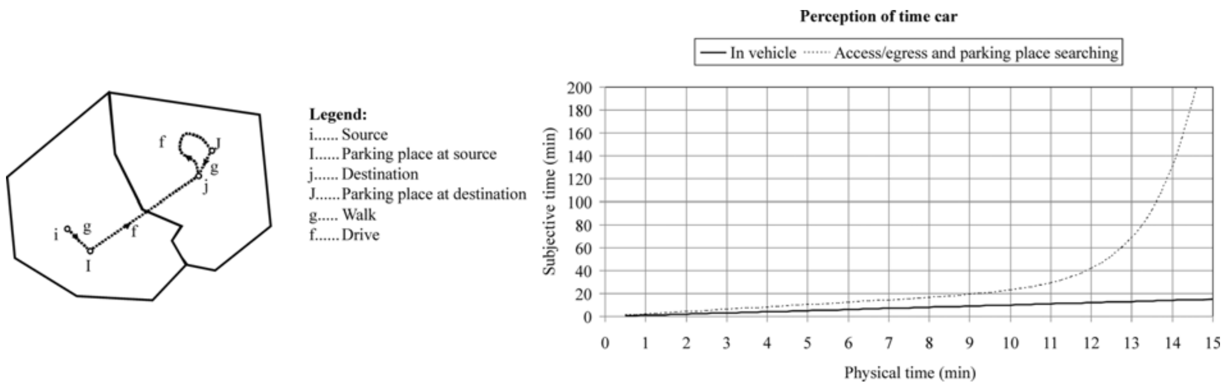

Figure 4. Subjective evaluation of the different parts of a car trip (Walther et al. 1997).

Transport policy instruments

What are policy instruments? *Policy instruments are the tools which can be used to overcome problems and achieve objectives* (May et al. 2003 p. 18). The objective of transport planning with respect to sustainability is to change travel behaviour. As shown in the previous section there are two principle possibilities to affect travel behaviour: by changing the costs or by changing the times connected with a journey. (May et al. 2003) provides a comprehensive overview about the policy instruments available in today's planning practice. (Minken et al. 2003) provides an extensive list of potential policy instruments. Detailed descriptions of a wide range of policy instruments can be found in the KonSULT Knowledgebase (www.elseviersocialsciences.com/transport/konsult/index.html).

Table 1 summarises potential pricing instruments. These instruments affect travel costs directly. Via a speed flow rela-

Table 1. Pricing instruments (Minken et al. 2003).

Instruments to influence car use	Instruments to influence public transport use
Parking charges Charges for ownership of private parking space Urban road charging, including area licensing and road pricing Vehicle ownership taxes Fuel taxes	Fare levels Fare structures, such as flat fares, zonal fares and monthly passes Integrated ticketing systems Concessionary fares, which are lower for identified groups of users such as elderly people

Table 2. Infrastructure instruments (Minken et al. 2003).

Instruments to influence car use	Instruments to influence public transport use
New road construction New off-street parking	Upgrades to existing infrastructure New rail stations New rail lines Light rail systems Guided bus systems Park and ride Etc.

Table 3. Management instruments (Minken et al. 2003).

Instruments to influence car use	Instruments to influence public transport use
Conventional traffic management Urban traffic control systems Intelligent transport systems, which use new technology to improve the performance of the road network Traffic calming measures Etc.	New bus services Bus priorities High occupancy vehicle lanes Changes in bus and rail frequency Etc.

tionship in the case of the mode car and overcrowding effects in the case of public transport they can affect travel times indirectly. The traditional planning practice mostly aims to influence travel times by infrastructure provision and management instruments. The common instruments target mainly in-vehicle times. Transport costs can be affected indirectly by the application of infrastructure and management instruments. A selection of infrastructure and management instruments is shown in Table 2 and Table 3.

A combination of the instruments new road construction, upgrades to existing public transport infrastructure and intelligent transport systems is used as the basic scenario in the case study presented later. The pricing instrument urban road charging in form of a cordon charge and a distance based charge will be use in two further scenarios of the case study. Finally a centralised car parking organisation is suggested as an alternative to these three scenarios.

CONTINUE AS BEFORE

In Vienna there are currently three big transport projects on their way, two transport infrastructure projects and one traffic management project. Vienna plans to extend its metro lines U1, U2, and U6 within the next few years (Stadtentwicklung Wien 2002; Stadtentwicklung Wien 2003a; Stadtentwicklung Wien 2003b; Stadtentwicklung Wien 2003c). The works for the extension of the lines U1 and U2 are ongoing. The U1 extension should be opened in 2006, the U2 extension should be read for the European football championships in 2008. The finalisation of the extension of the line U6 is planned for the period 2013 to 2015. A sketch of the existing metro line network and the planned extensions is shown in figure 5 (left hand side). The districts which are mainly affected by the metro extension are the districts north of the river Danube (21 and 22) and the districts 10 and 2. The city of Vienna furthermore plans a ring road highway in the eastern part of the city area (PGO 2003). Figure 5 sketches which districts are affected by this new transport infrastructure. The third ongoing major project is the traffic management project VEMA ("Verkehrsmanagement Wien"). Tasks of this project are the renewal and update of the traffic light control centre and the realisation of several traffic management measures (Hermann 2000). It is estimated that these measures will increase the overall road capacity by about 10%.

CORDON CHARGE

Cordon charging (or toll rings) is a system in which a series of charging points are established at all entries to a given area (often a city centre). The definition of the cordon charge scheme used in the case study is shown in Figure 6. Each car trip entering the inner districts 1 to 9 and 20 is charged. Only inbound trips are charged. Outbound trips remain uncharged. The system can be based on using simple pre-purchased paper licences, automatic number plate recognition or fully electronic systems in which the vehicle has an on board unit, in which a smart card is inserted.

DISTANCE BASED CHARGE

Cordon charging introduces boundary problems. Through traffic will re-route around the cordon, and may increase congestion; drivers may park outside and walk. Those just outside the cordon will pay to travel to the centre; those just

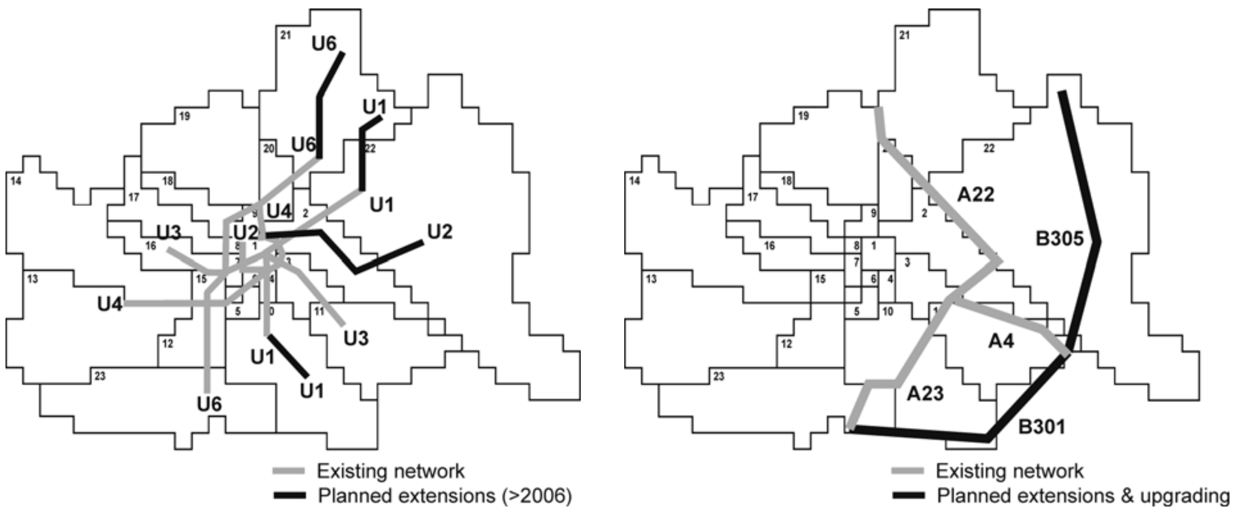

Figure 5. Sketches of the Viennese metro line and highway network.

inside will not. Drivers making long journeys across the cordon pay the same as those making short journeys. These discontinuities can be overcome by continuous charging systems, which charge for all travel within a defined area (such as a city). These can be e.g. based on distance travelled. The simplest form of a (approximately) distance charge would be an increase in fuel tax. A more sophisticated (and exact) form would involve on board units and GPS.

NEW ORGANISATION OF CAR PARKING

A new organisation of car parking was suggested by (Knoflacher 1980b) as the basic solution for today's transport problems and urban sprawl. The idea behind this suggestion is that the access and egress determines to a very high degree the attractiveness of a transport mode (see section "What determines travel behaviour?"). In traditional transport planning access and egress time is seen as a more or less exogenously given parameter. On contrary (Knoflacher 1980a) sees them as variables which can be influenced by the planner. To establish equal opportunities for the motorised individual traffic and public transport it is essential that the distance to the parked car or motorcycle is at least as far as to the next public transport stop ("Equidistance"). In practice this system could be realised by the construction of centralised garages near to the public transport stops (Figure 7). The space between housing and public transport stops is car free. Only very few exceptions are made for services like refuse collection and mobility impaired. The advantage of such a new parking configuration compared with a simple limitation of parking places in the existing network is that a lot of space is regained for alternative uses: for pedestrians, for cyclists, for playgrounds, leisure areas etc. In the long

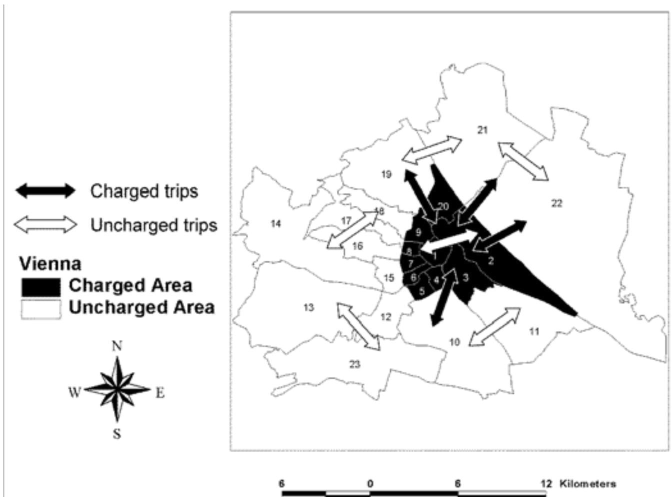

Figure 6. Definition of the Viennese cordon charge.

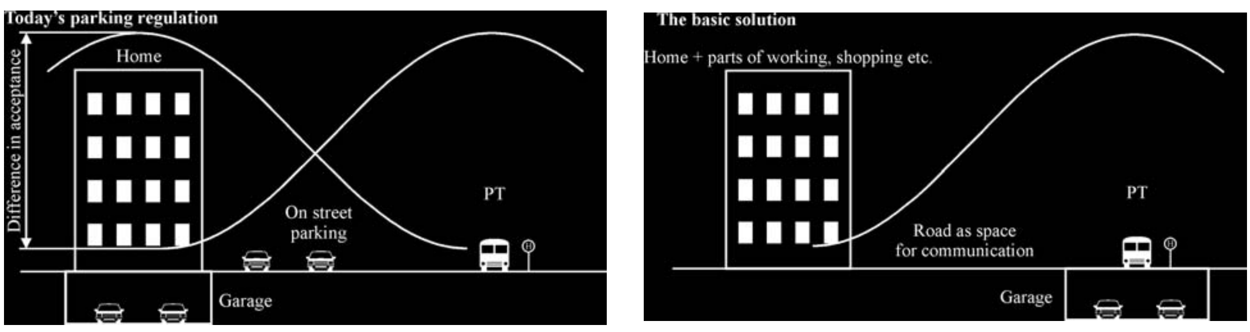

Figure 7. The basic solution – equal distance between home – parking place and home – public transport stop (Knoflacher 1980a).

term service sector businesses will relocate from shopping centres and malls to smaller shops in the car free residential areas. This effect reduces the consumption of land and the necessity for motorised travel and therefore the consumption of external energy. The development of a sustainable transport and land use system can take place.

The described organisation of car parking was not yet implemented to full extent in real life. But there are examples which at least adopt certain elements of the suggested strategy. There is one city which comes very near to the system described here. This city is Venice. Since centuries the core city of Venice is car free. It has central parking places and a central railway station. There are also a lot of initiatives towards car free tourism villages e.g. in Austria, Switzerland and Germany (Buchwald 1999; Kautzky 1996). During the last year car free housing developments have been realised within European cities. (VTPI 2004) presents a summary of such project. Although none of these examples fits the proposed parking systems perfectly, they all indicate that such a solution can be realised.

The integrated, dynamic land use and transport model MARS

MARS is an integrated strategic and dynamic land-use and transport (LUTI) model. The basic underlying hypothesis of MARS is that settlements and the activities within them are self organising systems. Therefore it is sensible to use the principles of synergetics to describe collective behaviour (Haken 1983a; Haken 1983b).

MARS assumes that land-use is not a constant but is rather part of a dynamic system that is influenced by transport infrastructure. Therefore at the highest level of aggregation MARS can be divided into two main sub-models: the land-use model and the transport model. The interaction process is implemented through time-lagged feedback loops between the transport and land-use sub-models over a period of 30 years.

Two person groups, one with and one without access to a private car are considered in the transport model part. The transport model is broken down by commuting and non-commuting trips, including travel by non-motorised 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 utilise 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. Decisions in the land-use sub-model are based on random utility theory. Due to its strategic characteristic a rather high level of spatial aggregation is used in MARS. In most case studies this means that the municipal districts are chosen as travel analysis zones. The outputs of the transport model are accessibility measures by mode for each zone while the land-use model yields workplace and residential location preferences per zone.

MARS is able to estimate the effects of several demand and supply-sided instruments whose results can be measured against targets of sustainability. These instruments range from demand-sided measures, such as with public transport fare (increases or decreases), parking or road pricing charges to supply-sided measures such as increased transit service or capacity changes for road or non-motorised transport. These measures, furthermore, could be applied to various spatial levels and/or to time-of-day periods (peak or off-peak).

To date the model MARS was applied to the following six European case study cities Edinburgh, Helsinki, Leeds, Madrid, Oslo, Stockholm and Vienna. In an ongoing project MARS is adopted and applied to the Asian cities Ubon Ratchasthani, Thailand and Da Nang, Vietnam (Emberger et al. 2005). To test the model MARS an extensive back casting exercise was carried out with data of the city Vienna (Pfaffenbichler 2003). A full description of MARS is given in (Pfaffenbichler 2003). The MARS version used in the case studies presented here was calibrated to fit data from a 2001 household survey (Vienna City Administration 2003).

Case study Vienna

Four different planning scenarios were tested in the Vienna case study presented here: a scenario continuing as before, a cordon charge, a distance based road charge and the new organisation of parking placing.

CONTINUE AS BEFORE

The model MARS was used to predict the effects of a combination of the three projects metro line extension, reing road and traffic management (Pfaffenbichler 2003). For the sake of simplicity it was assumed that all three projects will be in operation by 2006. These results were then compared with the official objectives and targets of the city Vienna. Figures 8 and 9 summarise the results of the MARS model calculations for the indicators modal split, CO_2-emissions and change in the number of workplaces by zone compared to a “Do minimum” scenario.

The diagram “Modal split” on the left side of Figure 8 shows the development of the mode choice over the whole evaluation period of 30 years. The implementation of the projects metro extension, ring road and traffic management increases the share of the mode car in the implementation year 2006. The current trend towards more car use is reinforced. There is only a very small increase in the share of the mode public transport. The additional shares of motorised trips come from a reduction in the non motorised modes pedestrian and bicycle. These effects contradict the official targets of the city of Vienna. In the 90ies of the last century the urban development plan and the transport plan defined a target of reducing the share of car trips to 25% by the year 2010 (Stadtplanung Wien 1994a; Stadtplanung Wien 1994b). This target is shown by the thick black lines. In the meantime it came clear that the target will be missed and it was loosened in the current transport master plan (Vienna City Administration 2003). The target now is to reach a share of car trips of 25% in 2020.

The diagram on the right side in Figure 8 shows the development of the CO_2-emissions over the 30 year evaluation period. The increase in CO_2-emissions of the project combination is even higher than in the “Do minimum” scenario. The targets of the Kyoto protocol are by far missed (UN 1998).

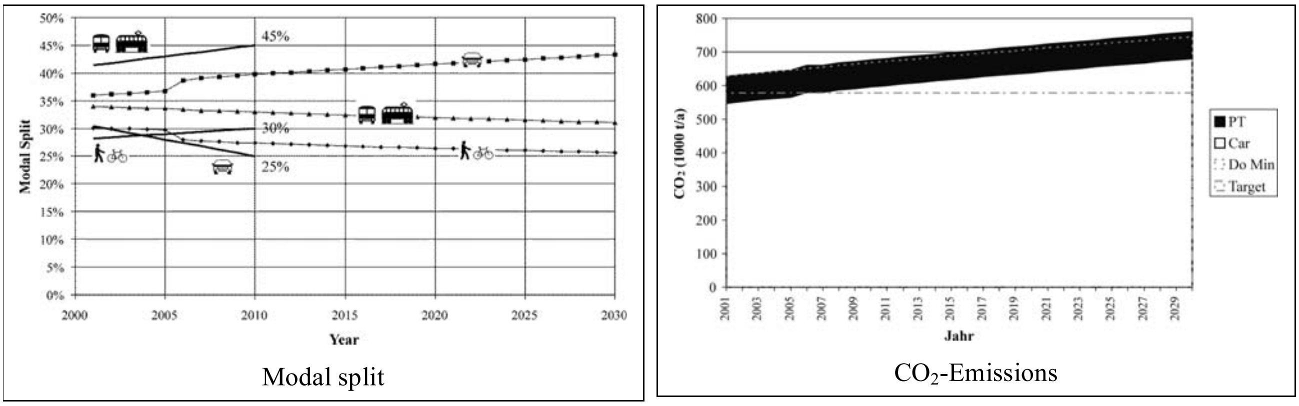

Figure 8. Transport and environmental effects of the planning approach "continue as before" Vienna (Pfaffenbichler 2003).

The map of figure 9 shows the change of the number of workplaces by zone at the end of the evaluation period in relation to the "Do minimum" scenario. Densities are decreasing in the inner districts. More workplaces than in the "Do minimum" scenario move into the outskirts of the city. This causes longer travel distances and higher energy consumption. The changes in the residential settlement pattern due to this scenario are rather small, but follow in principle a similar pattern. The currently planned transport projects do not contribute to the objective of a sustainable urban region.

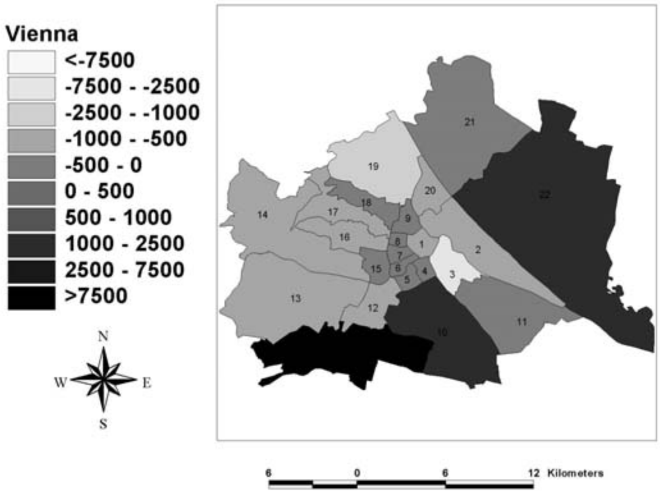

Figure 9. Change in workplaces relative to Do Minimum for the planning approach "continue as before" Vienna (Pfaffenbichler 2003).

URBAN ROAD CHARGES

Two different road charging schemes were tested: a cordon charge and a distance based road charge.

Cordon charge

Figures 10 and 11 summarise the effects of a cordon charge of 5 Euro. The diagram "Modal split" on the left side of Figure 10 shows the development of the mode choice over the whole evaluation period of 30 years. The 1994 targets of the city of Vienna are shown by the thick black lines (Stadtplanung Wien 1994a; Stadtplanung Wien 1994b). The target of the reducing the share of car trips to 25% by the year 2010 is not reached. The changes in overall modal split are only moderate. After the implementation of the road charge car use slightly increases again. The scenario used in the MARS model calculations include a steadily growth in population and economy at a medium rate. The capability of MARS to take a densification of existing building infrastructure into account is limited. Therefore it is not possible to satisfy the total growth in population and workplaces within the core city. To satisfy the demand produced by the underlying socio-demographic scenario it is necessary to develop also in the outer districts. That causes the increase in car use within the period 2006 to 2030 (Figure 10, left side).

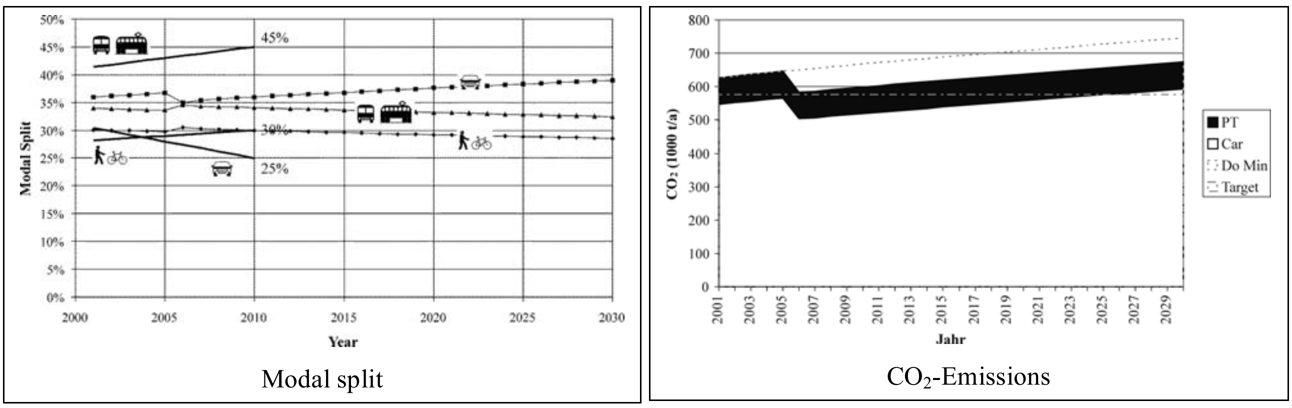

Figure 10. Transport and environmental effects of a 5 Euro cordon charge Vienna.

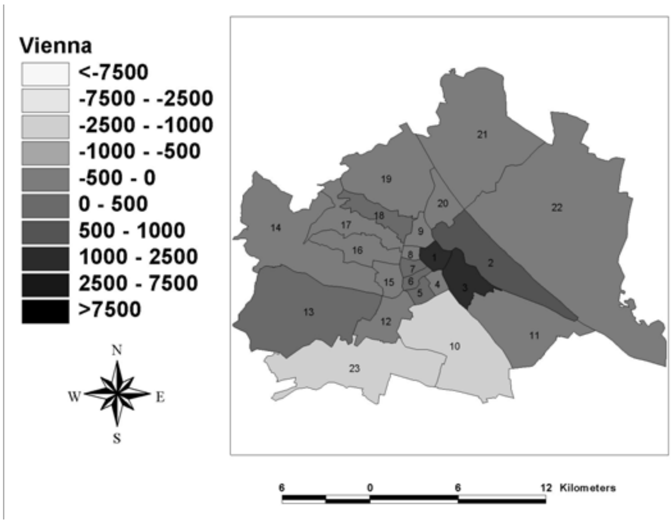

Figure 11. *Change in workplaces relative to Do Minimum of a 5 Euro cordon charge Vienna.*

The annual consumption of fossil fuels is reduced by about 10% compared to the do minimum scenario (Figure 10, right side). Fuel consumption and CO_2-emissions increase afterwards and reach about the same level in 2030 than before the cordon charge in 2005. The targets of the Kyoto protocol are not met (UN 1998).

The map of Figure 11 shows the difference in the number of workplaces by zone at the end of the evaluation period in relation to the "Do minimum" scenario. Densities are increasing in the inner districts. Less workplaces than in the "Do minimum" scenario move into the outskirts of the city. The contribution of a cordon charge works in the right direction but is not sufficient to achieve the objective of sustainability.

Distance based charge

Another possibility for an urban road charge is a distance based charge. Figure 12 and 13 show the effects of a distance based charge of 1 Euro per vehicle kilometre. At the beginning of the 90ies of the last century the average car trip in Vienna was about 7.6 km long (Socialdata 1993). With an average car occupancy rate of 1.3 persons this results in additional costs of about 6 Euro per car trip. Unlike with the cordon charge every car trip is charged.

The diagram "Modal split" on the left side of figure 12 shows the development of the mode choice over the whole evaluation period of 30 years. The 1994 targets of the city of Vienna are shown by the thick black lines (Stadtplanung Wien 1994a; Stadtplanung Wien 1994b). The target of reducing the share of car trips to 25% by the year 2010 is reached. As well the share of public transport as the share of slow modes increases at the expense of car use. After the implementation of the distance based charge car use slightly increases again, but stays more or less below the target of 25% until the end of the simulation period. The reasons for this increase in car use are the same as described in section "Cordon charge".

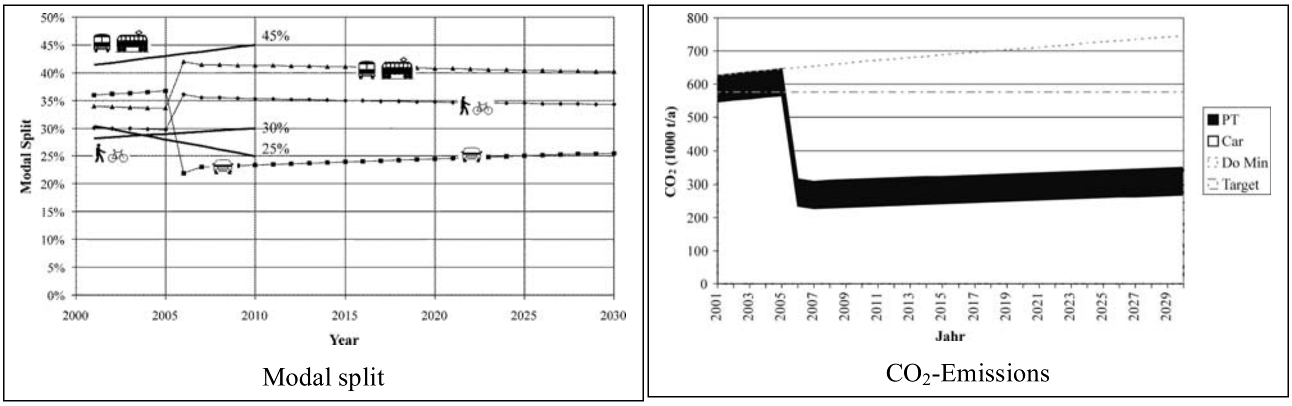

Figure 12. *Transport and environmental effects of a distance based charge of 1 Euro per Veh-km Vienna.*

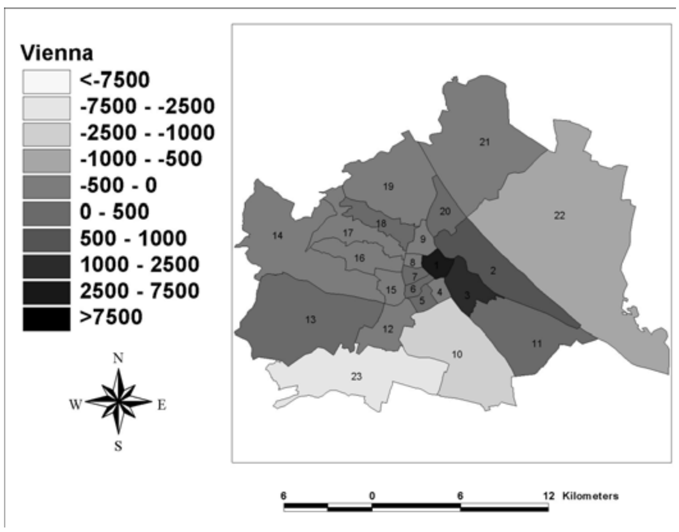

Figure 13. *Change in workplaces relative to Do Minimum of a distance based charge of 1 Euro per Veh-km Vienna.*

The annual consumption of fossil fuels is reduced by about 50% compared to the do minimum scenario. In first year of the distance based charge CO_2-emissions are reduced by about 50% compared to the level of the year 2001 (Figure 12, right side). Although fuel consumption and CO_2-emissions slightly increase afterwards due to population growth they remain about 40% lower at the end of the eval-

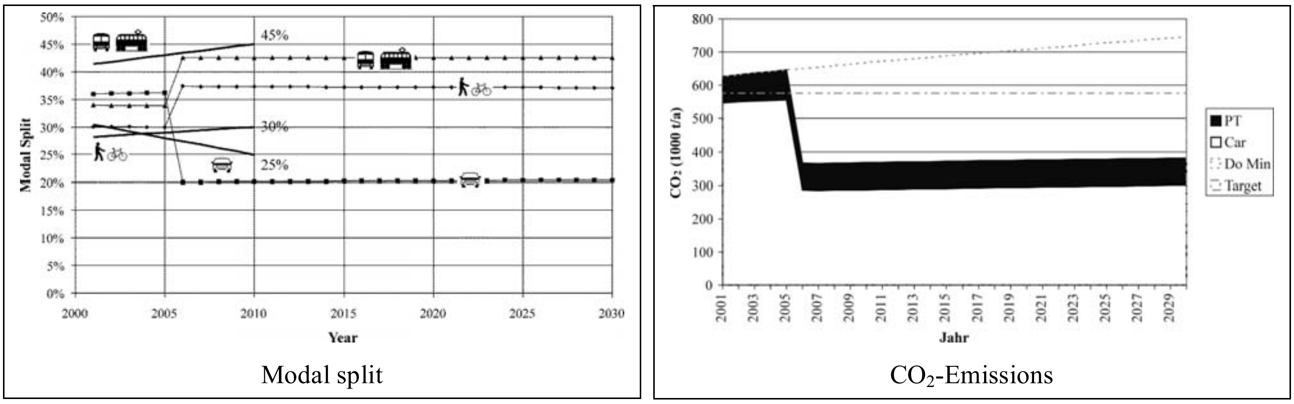

Figure 14. *Transport and environmental effects of the new organization of parking places following the principle of equidistance.*

uation period than at the beginning. The targets of the Kyoto protocol are clearly met (UN 1998).

The map of Figure 13 shows the difference in the number of workplaces by zone at the end of the evaluation period in relation to the "Do minimum" scenario. Densities are increasing in the inner districts. Less workplaces than in the "Do minimum" scenario move into the outskirts of the city.

NEW ORGANISATION OF CAR PARKING

Figures 14 and 15 show the results of the MARS model calculations for the policy instrument new organisation of parking places according to the principles of equidistance. The diagram "Modal split" on the left side of figure 14 shows the development of the mode choice over the whole evaluation period of 30 years. The 1994 targets of the city of Vienna are shown by thick black lines (Stadtplanung Wien 1994a; Stadtplanung Wien 1994b). The target of reducing the share of car trips to 25% by the year 2010 is reached. As well the share of public transport as the share of slow modes increases at the expense of car use. After the implementation of the new car parking organisation car use slightly increases again, but stays below the target of 25% until the end of the simulation period. The reasons for this increase in car use are the same as described in section "Cordon charge".

The annual consumption of fossil fuels is reduced by about 40% compared to the do minimum scenario. In first year of the new car parking organisation CO_2-emissions are reduced by about 35% compared to the level of the year 2001 (Figure 14, right side). Although fuel consumption and CO_2-emissions slightly increase afterwards due to population growth they remain about 30% lower at the end of the evaluation period than at the beginning. The targets of the Kyoto protocol are clearly met (UN 1998).

The map of Figure 15 shows the change of the number of workplaces by zone at the end of the evaluation period in relation to the "Do minimum" scenario. Densities are increasing in the inner districts. Less workplaces than in the "Do minimum" scenario move into the outskirts. A more compact and pedestrian friendly city emerges. A mixture of functions and a decreased pollution are the result of an urban structure based on the principle of equidistance. The urban region can arrive at a dynamic equilibrium and a sustainable city is possible.

A question which was not addressed in the research presented here is whether residents would move to other cities

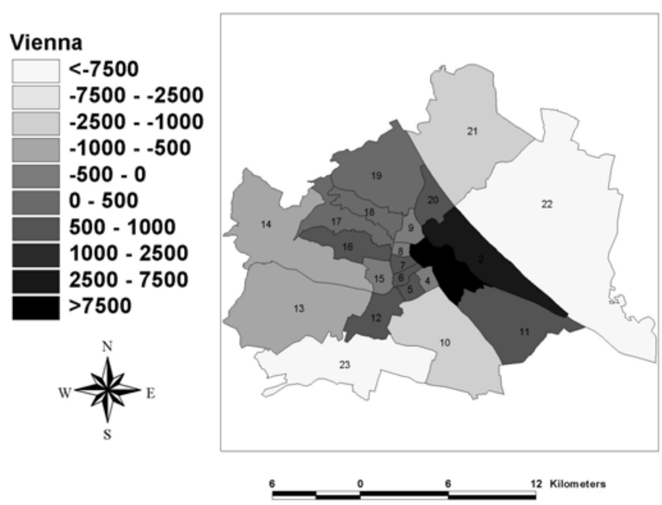

Figure 15. *Change in workplaces relative to Do Minimum of a distance based of the new organization of parking places following the principle of equidistance.*

if the new car parking organisation is implemented in just one city. This question will be tackled in future research by enlarging the case study area and installing the strategy in only part of the case study area.

COMPARISON OF THE TESTED SCENARIOS

Table 4 summarises some indicators for a comparison of the four scenarios tested in the Vienna case study. It can be seen that the strategies "Continue as before" and "5 Euro cordon charge" are neither sufficient to achieve the greenhouse gas emission targets as defined in the Kyoto protocol (UN 1998) nor the official Viennese target of car use reduction (Stadtplanung Wien 1994a; Stadtplanung Wien 1994b). The performance concerning CO_2-emissions of a 1 Euro per vehicle kilometre distance based charge and the new car parking organisation is rather similar. The essential difference is that the distance based charge is very costly for the car users. They would have to pay about 28 Billion Euro over the 30 years evaluation period. The new car parking organisation achieves the same environmental benefits at the expense of time losses for car users worth 3.4 Million Euro in 30 years. The car parking organisation is the only strategy which is able to keep the share of car use in the long term

Table 4. Comparison of different indicators for the tested scenarios.

Indicator	Continue as before	5 Euro cordon charge	1 Euro/Veh-km distance based charge	Equidistance
Modal share car				
2011	39.9%	36.1%	23.5%	20.2%
2021	41.8%	37.7%	24.6%	20.3%
Change CO_2-Emissions				
2001-2011	+8%	-4%	-50%	-41%
2001-2021	+15%	+2%	-47%	-40%
Car user benefits (mio. Euro) 1)				
Costs	+249	-3,511	-27,529	+43
Time	+607	+100	+327	-3,411
Land consumed by businesses relative to do-nothing				
2011	+0.1%	-0.1%	-0.2%	-0.7%
2021	+0.6%	-0.3%	-0.8%	-2.7%
2031	+1.4%	-0.5%	-1.2%	-5.2%

1) Results of a cost benefit analyses. Values are discounted over the 30 year modelling period. The discount rate is assumed with 3.5%.

years at about the same level as directly after implementation. In all other strategies the share of car use rises again in the later years. The equidistant car parking is the strategy which is most efficient concerning the consumption of land. Nevertheless it has to be mentioned that also with this strategy the amount of built up land increases. This is at least partially caused by the current structure of the model MARS. At the moment MARS does not allow a densification of the existing building structure. To overcome this issue is foreseen for the next model generation which is already under development.

Conclusions

A combination of traditional planning instruments (extension of metro lines, highway like ring road, traffic management) increases the attractiveness of public transport but increases as well road capacity. This results in further urban sprawl, more car use and a higher consumption of fossil energy. Applying this strategy it is not possible to achieve the official goals of the city of Vienna which include a significant reduction of car use and stopping urban sprawl. The MARS model calculations have demonstrated that this strategy is even counterproductive. These conventional planning instruments show negative effects concerning the overall objective of a sustainable city.

Furthermore two different scenarios of urban road charging were tested concerning their ability to reduce energy consumption. The first was a cordon pricing scheme. Car trips into the city centre are charged. Despite a charging level of 5 Euro, which is high above levels accepted by the Viennese public, the effects were limited. Neither the objectives of the city of Vienna nor the targets of the Kyoto protocol were met. The second was a distance based road charge. Unlike with cordon pricing every car trip is charged. With a level of 1 Euro per vehicle kilometre, which is about 6 Euro per car trip, it is possible to reach the Viennese targets and reduce the energy consumption of traffic by about 50%. Again this level is far beyond public acceptance. If sustainability is meant to be more than an empty phrase, then it is necessary to apply such painful strategies or to develop new, innovative strategies.

A new organisation of cities car parking systems was suggested as such an innovative strategy (Knoflacher 1980a; Knoflacher 1980b). In the section "What determines travel behaviour?" it was demonstrated that such a strategy tackles the outstanding problems at a point where human behaviour is sensitive. The results from the case study show that this strategy is suitable for reaching the official targets of the city as well as the overall objective of sustainability. The strategy of restricting car parking to central off street garages has the potential to achieve the goal of sustainable cities. The share of slow modes, pedestrians and cyclists, and public transport will be increased at the expense of non efficient car travel. The change will result in a densification of the functionality of the cities. This further supports the reduction of external, fossil energy required to satisfy mobility needs. Urban sprawl can be controlled. The urban regions can reach a state of dynamical equilibrium. A city which is organised based on these principles easily fulfils official targets link the Kyoto protocol. A comparison with the results of the road charging schemes demonstrates that with this strategy environmental objectives can be reached at far lower transport user expenditures and costs.

With today's standards it is hard to imagine such a new organisation of our cities. It is clear that there are a lot of barriers hindering the implementation of such a policy. But examples of car free cities and environments indicate that the suggested policy is applicable in real life. The most important would be a strong political will which has to be kept upright over a rather long time horizon.

Glossary

GPS	Global Positioning System
KonSULT	Knowledgebase on Sustainable Urban Land use and Transport
LUTI	Land Use and Transport Interaction model
MARS	Metropolitan Activity Relocation Simulator
PT	Public Transport
Slow	A summarising term for the non motorised modes pedestrian and bicycle
Veh-km	Vehicle kilometres
VEMA	VErkehrsMAnagement Wien (Traffic Management Project Vienna)

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