DISSERTATION

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über das Thema

Reducing CO_2 emissions in the passenger transport sector in Austria - a modelling approach with MARS Austria (MARS-Metropolitan Activity Relocation Simulator)

Erstbegutachter:
Ao.Univ.-Prof. Mag. Dr.
Günter Emberger

Zweitbegutachter:
Univ.-Prof. Mag. Dr.
Michael Getzner

von
Mag. Anna Mayerthaler
Marinelligasse 13-15
1020 Wien

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Abstract

Concerns over transport problems have been a constant issue over the past decades and recently deepened in the context of climate change because of the ever-increasing transport related CO_2 emissions. The transport sector is the sector not only experiencing the strongest growth over the last years but the sector with the biggest share in national GHG emissions compared to all other sectors (Anderl, Freudenschuß et al. 2011).

Not only the CO_2 emissions are in a steep rise but according to the federal ministry of transport innovation and technology, the majority of the trips in Austria are car trips and the share of private motorized transport of the total passenger kilometres travelled is increasing since 1990 (Bundesministerium für Verkehr Innovation und Technologie 2012).

To date there is just one modelling approach in Austria to forecast the developments in the passenger transport sector, which is the Austrian transport prognosis 2025+. The necessity in CO2 reduction and changing the transport behaviour towards eco friendly modes and the existence of a single prognosis so far clearly make the case for further research in this area.

In this thesis a modelling approach for the whole territory of Austria is used to improve the understanding of development paths for the passenger transport sector. The work is guided by to research hypothesis:

(1) There is interaction between transport, the spatial structure of settlements and the economy forming a dynamic self-organising system.

(2) Non-motorized modes are an essential element of the transport system and are strongly influenced by settlement patterns. Due to spatial linkages, they have to be considered even at higher spatial levels where their influence is not intuitively apparent.

From a methodological point of view land-use/transport interaction (LUTI) modelling is chosen. The strategic land-use/transport interaction model MARS is such a LUTI model (Pfaffenbichler 2003), applied on a series of urban case studies. In this thesis it has been developed further to use it for the whole territory of Austria and to model the impacts of transport and land-use policies on a national scale in a forecasting approach. MARS is a system dynamics model with

the main feature to model different system speeds, which occur in the interrelations between the transport and the land-use system.

The main research questions raised are:

(1) What are the overall effects of different transport and land-use policy scenarios and different development paths of electric mobility on transport behaviour and CO_2 emissions on a national scale?

(2) Which policy combinations enable to reach the set targets in the "Kyoto protocol" and European targets like in the "White Paper 2011" and the "Roadmap 2050"?

Starting from a "business as usual" scenario, which depicts the development over time without any substantial changes, different policy scenarios are developed. In addition, to single out the separate policies, two scenarios are developed where no technological progress (concerning the fleet development) is taking place.

The set of transport policies cover pricing measures as well as physical measures and differ in magnitude and selection of policy. The land-use policies implemented differ in magnitude but consist of the following components:

- Share of new developments taking place within or outside the settlement entity
- Amount of land consumption
- Liveliness of town centres (shrinking and growing municipalities)

For the fleet development also different scenarios are developed, differing whether and how electric vehicles gain acceptance.

It becomes apparent that the fleet development (whether there is a strong shift towards electric cars) and the energy mix (high shares of renewables or not) for the production of electricity supplying the E-cars, is a crucial factor in influencing CO_2 emissions.

Taking the transport behaviour into consideration, stand-alone transport policies seem to be more influential than stand-alone land-use policies.

The thesis shows that a pure shift in technology with the assumption of a fast change of energy supply towards renewable energy would significantly decrease CO_2 emissions, but would not influence the transport behaviour towards less energy consuming modes. From a societal perspective this might not be the desired outcome taking into consideration that the urban agglomerations in Austria are growing. Keeping the quality of living at a high level while reducing the availability of public space per person (because also E-cars consume public space) is difficult. Therefore changes in physical infrastructure and more public space for the environmentally friendly modes will be necessary to fulfil the task of increasing the quality of living in cities.

Electric cars might be a good alterative in rural regions where the conditions for public transport are less favourable for enabling people to fulfil their daily needs.

The thesis provides added value in the field of national transport/land-use modelling. The developed model is capable of modelling different transport and land-use policies as well as different development paths for electric vehicles. The research carried out gives insights into the effects of divers transport and land-use policies on the development of CO_2 emissions and the transport behaviour in Austria.

Kurzfassung

In den letzten Jahrzehnten waren Verkehrsprobleme ein anhaltendes Thema, dessen Bedeutung sich im Kontext des Klimawandels durch die ständig steigenden CO2-Emissionen im Sektor Verkehr noch verstärkt hat.

Der Sektor Verkehr ist nicht nur der Sektor mit den größten Steigerungsraten der letzten Jahre, sondern auch dem größten Anteil, an nationalen Treibhausgas Emissionen (Anderl, Freudenschuß et al. 2011).

Nicht nur die Treibhausgas Emissionen steigen, sondern auch das Verkehrsverhalten entwickelt sich zunehmend in eine problematische Richtung. Laut dem Bundesministerium für Verkehr, Innovation und Technologie wird die Mehrheit der Fahrten in Österreich mit dem Auto zurückgelegt und der Anteil des motorisierten Individualverkehrs an den zurückgelegten Personenkilometern steigt seit 1990 (Bundesministerium für Verkehr Innovation und Technologie 2012).

Bis heute gibt es nur einen Modellierungsansatz in Österreich, um die Entwicklungen im Sektor Personenverkehr zu prognostizieren; die Verkehrsprognose 2025+.

Die Notwendigkeit, in diesem Sektor CO_2-Emissionen zu reduzieren und das Verkehrsverhalten in Richtung Umweltverbund (zu Fuß, Fahrrad, öffentlicher Verkehr) zu ändern sowie die Tatsache, dass bis heute nur eine einzige österreichische Verkehrsprognose dazu existiert, stellen die Argumente für eine weitergehende Forschung in diesem Bereich dar.

In dieser Dissertation wird ein Modellierungsansatz für ganz Österreich entwickelt. Ziel ist, das Verständnis für Entwicklungspfade im Sektor Personenverkehr zu verbessern. Die Arbeit ist von folgenden Forschungshypothesen geleitet:

(1) Es besteht Interaktion zwischen dem Transportsystem, den räumlichen Strukturen von Siedlungen und der Wirtschaft. Diese bilden ein dynamisches selbst-organisierendes System.

(2) Nicht-motorisierte Verkehrsmittel sind ein essentieller Teil des Gesamtverkehrssystems und werden stark durch Siedlungsstrukturen

beeinflusst. Sie müssen auch auf räumlichen Aggregationsebenen berücksichtigt werden, wo ihr Einfluss nicht offensichtlich ist.

Methodisch wird der Ansatz von integrierten Modellen zur Darstellung von Siedlungsentwicklung und Verkehr (LUTI) gewählt. Das strategische Transport- und Landnutzungsmodell MARS (Pfaffenbichler 2003), welches in mehreren urbanen Fallstudien erprobt wurde, ist ein solches LUTI Modell.

In dieser Arbeit wurde es weiterentwickelt und angepasst, um Gesamtösterreich abbilden zu können und die Auswirkungen von Transport- und Landnutzungs-Politikmaßnahmen für die Prognosebildung zu modellieren. MARS ist ein systemdynamisches Modell. Der große Vorteil dieser Modelle liegt in der Möglichkeit, unterschiedliche Systemgeschwindigkeiten, die bei Interaktionen zwischen dem Verkehrs- und dem Landnutzungssystem vorliegen, zu modellieren.

Die primären Forschungsfragen dieser Dissertation lauten:

(1) Welche Gesamteffekte auf das Verkehrsverhalten und die Entwicklung der CO_2 Emissionen ergeben sich durch unterschiedliche Transport- und Landnutzungsszenarien sowie verschiedener Entwicklungspfade der Elektromobilität?

(2) Welche Politikmaßnahmenkombinationen ermöglichen es, die Klimaziele des „Kyoto Protokolls“ und europäischer Ziele wie dem „Weißbuch Verkehr 2011“ oder der „Roadmap 2050“ zu erreichen?

Ausgegangen wird von einem „Business as Usual“ Szenario, welches die Entwicklung über die Zeit ohne nennenswerte Eingriffe beschreibt. Anschließend werden verschiedene Politikszenarien entworfen. Zusätzlich, um die einzelnen Politikmaßnahmen hervorzuheben, werden zwei Szenarien entwickelt, die keinen technologischen Fortschritt (keine Veränderung der Flotte hinsichtlich Elektromobilität) enthalten.

Das Bündel an Maßnahmen der Verkehrspolitik reicht von Preispolitik bis zu Eingriffen in die gebaute Infrastruktur. Diese unterscheiden sich je Szenario nach Stärke und Auswahl der Maßnahme. Die Raumplanungspolitik unterscheidet sich im Ausmaß je Szenario, betrifft aber immer folgende Komponenten:

- Anteil von neuen Entwicklungen innerhalb/außerhalb der Siedlungseinheit

- Ausmaß des Landverbrauchs
- Lebendigkeit von regionalen Zentren (in schrumpfenden und wachsenden Gemeinden)

Die Flottenentwicklung, die sich vor allem durch unterschiedliche Durchdringungsgrade von Elektromobilität unterscheidet, wird ebenfalls in verschiedenen Szenarien abgebildet.

Es zeigt sich, dass die Flottenentwicklung (abhängig von der Durchdringung von Elektrofahrzeugen) und der Energiemix (größerer oder kleinerer Anteil erneuerbarer Energieformen) entscheidende Faktoren für die Entwicklung der CO_2 Emissionen sind.

Bei der Betrachtung des Verkehrsverhaltens zeigt sich, dass alleinstehende Verkehrspolitikmaßnahmen einen größeren Einfluss als Raumplanungspolitikmaßnahmen haben.

Diese Arbeit führt vor Augen, dass eine rein technologische Veränderung der Flotte, mit der Annahme eines schnellen Anwachsens von erneuerbaren Energieträgern, die CO_2 Emissionen signifikant reduzieren kann. Jedoch ergibt sich dadurch kein Einfluss auf das Verkehrsverhalten und damit keine Änderung in der Aufteilung auf die verschiedenen Verkehrsmittel in Richtung weniger energieintensiver Verkehrsmittel. Aus gesellschaftlicher Perspektive kann das nicht das gewünschte Ergebnis sein. Die städtischen Agglomerationen in Österreich wachsen, bei dem gleichzeitigen Ziel die Lebensqualität in den Städten zu erhöhen. Dies scheint schwierig, wenn immer weniger öffentliche Fläche pro Person (auch Elektrofahrzeuge benötigen Platz) zur Verfügung steht. Deshalb sind Umgestaltungen der physischen Infrastruktur und die Zurverfügungstellung von mehr Flächen für umweltfreundliche Verkehrsmittel notwendig, um das Ziel erhöhter Lebensqualität in Städten zu erreichen.

Elektrofahrzeuge stellen allerdings eine gute Alternative zur Erfüllung der täglichen Bedürfnisse in ländlichen Gebieten mit schlechten Bedingungen für den öffentlichen Verkehr dar.

Die vorliegende Arbeit liefert einen Beitrag im Bereich der nationalen Verkehrs- und Landnutzungsmodellierung. Das entwickelte Modell ist fähig, verschiedene verkehrspolitische Maßnahmen, Raumplanungsmaßnahmen und verschiedene

Entwicklungspfade der Elektromobilität im Sektor Personenverkehr zu modellieren. Die Forschungsarbeit liefert neue Erkenntnisse über die Effekte der verschiedenen Politikmaßnahmen auf die Entwicklung der CO_2 Emissionen und des Verkehrsverhaltens.

Gewidmet der Erinnerung an meinen Vater

O. Univ. Prof. Dr. Willi Mayerthaler

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PREFACE

This thesis is the result of an almost four year long process of working and studying at the Research Centre of Transport Planning and Traffic Engineering at the Vienna University of Technology and beyond that time.

Over the years, and with help from my supervisor, Ao.Univ.Prof. Günter Emberger, I gained knowledge in the field of land-use transport interaction modelling resulting in this thesis and a lot of other accomplished case studies and published papers. I want to thank Günter Emberger for involving me in LUTI modelling and MARS, thus enabling me to examine environmental research questions by modelling, and supporting me with my thesis. I would also like to thank Univ.-Prof. Michael Getzner for being my second supervisor and giving me hope when I was doubting whether I could finish the thesis.

Furthermore, I want to thank Dr. Paul Pfaffenbichler, the father of the urban MARS model, giving me help and advice concerning all sorts of MARS related questions.

Without DI Reinhard Haller, my former colleague at the research centre, the development of MARS Austria would not have been possible in this way. We collaborated on the development of MARS Austria in a research project funded by FWF, working closely together. Thank you, Reinhard.

Concerning the policy scenario design and the ideas modelled I want to thank DI Tadej Brezina, another colleague at the research centre. We thoroughly discussed the transport policies that could be implemented.

I am grateful to Maximilian Kloess, a further colleague from the University of Technology - Energy Economics Group (EEG), for granting me to use the fleet development for the scenarios modelled and Christian Redl, also from EEG, who provided me with possible future energy supply development paths for Austria.

I want to thank DI Ursula Mollay from the Austrian Institute for Regional Studies and Spatial Planning for the population data shaping the land-use policies.

Last but not least I want to thank my family, first of all my mum, who supported me throughout the years and motivated me to finish the thesis. Harald Frey, my companion always offered me support and advice when I struggled.

LIST OF ABBREVIATIONS

AVV	=	Ministry of Transport, Public Works and Water Management – Netherlands
BAU	=	Business as usual (scenario)
bmvit	=	Austrian Ministry for Transportation, Innovation and Technology
CBA	=	Cost-benefit analysis
CEO	=	Chief Executive Officer
CGE	=	Computable general equilibrium models
CLD	=	Causal Loop Diagram
E-car	=	Electric cars and plug-in hybrids
Eco modes	=	Transport modes: pedestrian, bicycle, public transport bus and public transport rail
EE	=	Energy Economics Group
HO	=	Home - Other
HOH	=	Home - Other - Home
HW	=	Home - Work
HWH	=	Home - Work - Home
IPCC	=	Intergovernmental Panel on Climate Change
LMS	=	Netherlands National Model
LT	=	Long term
LUTI	=	Land-use/transport Interaction
MCA	=	Multi-criteria analysis
NEG	=	New Economic Geography
NMS	=	National Transport Model of the Netherlands
OH	=	Other - Home
ÖIR	=	Austrian Institute for Regional Studies and Spatial Planning
PMT	=	Private Motorized Transport
SD	=	System dynamics
ST	=	Short term
TPO	=	Transport policy only (scenario)
LPO	=	Land-use policy only (scenario)
TIGRIS	=	Transport Infrastructure – Land Use Interaction Simulation

WH	=	Work – Home
550ppm	=	not very ambitious policy scenario
500ppm	=	ambitious policy scenario
450ppm	=	very ambitious scenario

1 INTRODUCTION

1.1 CO_2 emissions in the transport sector

Over the past decades, concern over transport problems has been a constant issue. This concern has recently deepened in the context of climate change because of the significant and ever increasing transport related CO_2 emissions.

The transport sector and the part of the industry which is not participating in emission trading are the only sectors in Austria where GHGs[1] did not decrease but increase from 1990 to 2009 (Anderl, Bednar et al. 2011).

In Austria the transport sector is the sector that has experienced the strongest increase in emissions in the last few years. Looking only at the emissions in the passenger transport sector the same pattern becomes apparent.

> "In 2009 the most important source of GHGs was transport, with a share of 27% in national total GHG emissions. 15.3% of national GHG emissions were released by passenger cars, 2.2% by light duty vehicles, 8.5% by heavy-duty vehicles and 0.2% by mopeds and motorcycles." (Anderl, Freudenschuß et al. 2011, p. 75)

The share of 27% of transport represents the biggest share compared to all other sectors (Bundesministerium für Land- und Forstwirtschaft Umwelt und Wasserwirtschaft 2009).

In Austria, CO_2 emissions from road traffic increased by a steep 61.8% over the period from 1990 to 2008 (Anderl, Freudenschuß et al. 2010). The transport sector is the sector experiencing the strongest growth in emissions over the last few years. The CO_2 emissions of the road transport and freight transport in Austria (domestic) in 2009 (passenger- and freight transport) add up to 14,880,000 tonnes

[1] Abbreviation for greenhouse gas

of CO_2 (Anderl, Freudenschuß et al. 2011). The following modes of transport (vehicles) are included:

- Cars,
- light duty vehicles,
- heavy-duty vehicles
- rail and
- shipping.

Air transport, small mopeds, motorcycles and off-road transport are not included.

CO_2 emissions in the passenger transport accounted for 10,191,000 tonnes in the year 2009, which amounts to 68.5% of the total CO_2 emissions of road transport. This is reasonable since passenger cars have the highest share of passenger kilometres compared to the other modes (see Figure 1).

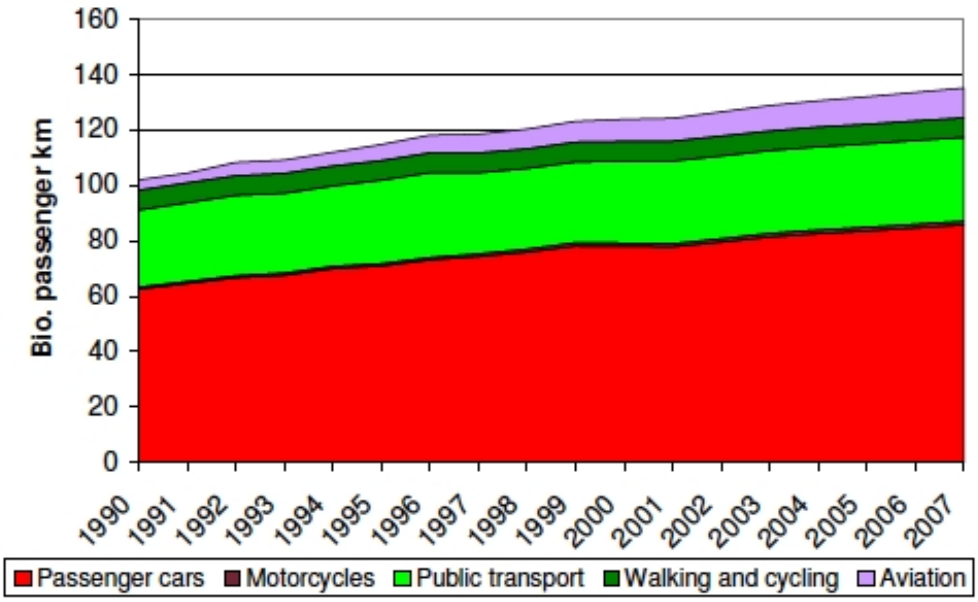

Figure 1 Shares of different modes of transport in passenger kilometres (domestic transport). Source: (Bundesministerium für Land- und Forstwirtschaft Umwelt und Wasserwirtschaft 2009)

The total CO_2 emissions of the transport sector in 2009 (domestic and Austrian fuel consumed abroad) amount to 22,990,000 tonnes of CO_2. Taking CH_4 and NO_2 into account this leads to 23,403,000 tonnes of CO_2 equivalent.

1.1.1 National and EU CO_2 reduction targets

1.1.1.1 National target - Kyoto protocol

In 2002, the Federal Ministry of Agriculture, Forestry, Environment and Water Management defined CO_2 emission targets for the whole transport sector in order to reach the Kyoto protocol target[2]. The set target for 2010 was 16.3 million tonnes of CO_2 equivalent for the year 2010. In 2002, when the report was compiled, the prognosis for 2010 stated emissions of 20 million tonnes of CO_2 equivalent.

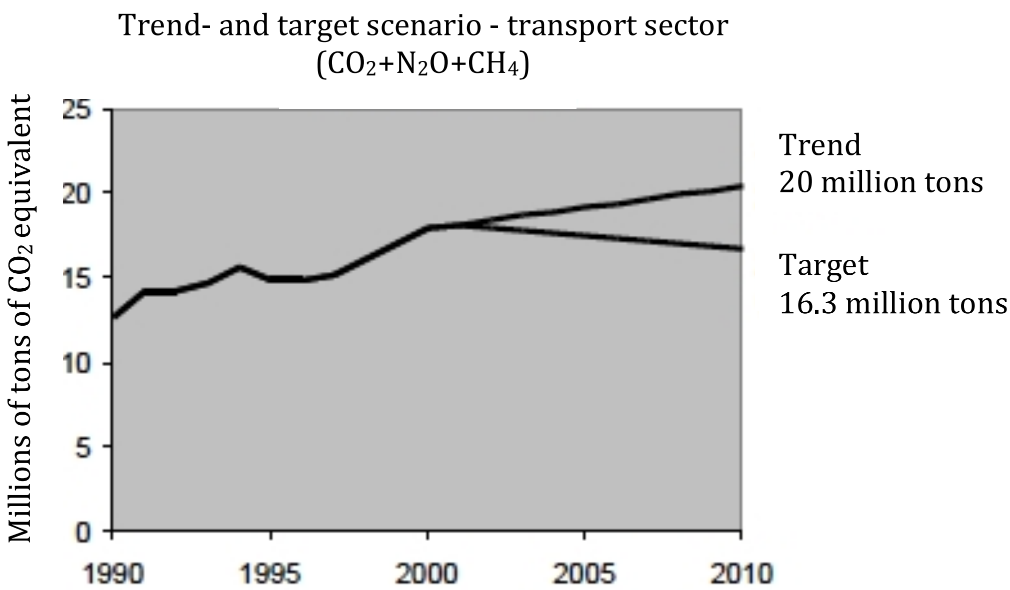

Figure 2 GHG emissions sector transport 1990 and reduction target 2010. Source: (Bundesministerium für Land- und Forstwirtschaft Umwelt und Wasserwirtschaft 2002,p.43)

Since the amount in 2009 was already much higher than the prognosis of 2002 for 2010, it is quite clear that the target of reaching 16.3 millions of tonnes CO_2

[2] A reduction of GHG emissions of -13% for all sectors to the base year 1990 until 2010. Source: Bundesministerium für Land- und Forstwirtschaft Umwelt und Wasserwirtschaft (2009). Fifth National Communication of the Austrian Federal Government under the Framework Convention on Climate Change. Unit V/4. Vienna, Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft.

equivalent is clearly missed. The reduction potential in 2002 was stated to be 3.7 millions of tonnes.

The calculation of 1990 concerning the reduction potential allocated to the passenger transport road sector only foresees a reduction to 6,287,982 tonnes of CO_2 in 2010.

1.1.1.2 European targets

In the European “White Paper 2011” (Europäische Kommission 2011), a reduction of 60% of carbon emissions in the transport sector in Europe is set for the year 2050 as compared to the base year 1990.

The “Roadmap 2050” of the „European Climate Foundation (ECF)“[3] outlines three targets of a decarbonized low carbon economy in 2050. There are three pathways, a decarbonisation of 40%, 60% and 80%. An 80% decarbonisation overall would mean a nearly full decarbonisation in power, road transport and buildings. The 80% emission reduction implies a reduction of 95% in the transport sector by 2050 compared to the base year 2010. 20% of this reduction should be achieved by abatement within the sector, while 75% are the result of a fuel shift towards biofuels, electric vehicles and fuel cells (European Climate Foundation 2011).

These targets are European-wide targets for the transport sector. The effective share for Austria can be different from these targets.

For Austria, a reduction of 95% in CO_2 emissions would imply reducing the emissions in the transport sector by the year 2050 to 1,188,000 tonnes of CO_2 (calculated from 23,753,000 tonnes of CO_2 in 2010). The share of passenger road transport emissions is 67%, which would imply a reduction in the passenger transport sector to 795,000 tonnes CO_2 in 2050.

[3] http://www.europeanclimate.org/

1.2 General developments in the passenger transport sector

The latest nation-wide mobility survey in Austria was accomplished in 1995. In 2013 the new nation-wide mobility survey will be accomplished, results are to be expected in autumn 2014 respectively spring 2015[4]. Therefore no current in depth data about transport behaviour is available for Austria.

Concerning the modal split there are several regional survey results (Amt der Öberösterreichischen Landesregierung 2001; IMAD - Institut für Marktforschung und Datenanalyse 2002; Amt der Niederösterreichischen Landesregierung and Niederösterreichische Landsakademie 2008; Herry 2009) as well as the transport prognosis 2025+ (see chapter 3) results which was cited in the "overall traffic plan 2012 (Gesamtverkehrsplan)" (Bundesministerium für Verkehr Innovation und Technologie 2012). Table 1 presents the 1995 mobility survey results as well as the 2012 prognosis results. The majority of the trips in Austria are car trips with 58% in 2012.

Modal split - [% of trips]	Total 1995	Total 2012
walking and cycling	32%	24%
public transport	17%	18%
car	50%	58%

Table 1 Modal split for Austria in 1995 and 2012. Source: (Herry, Sedlacek et al. 2007, p. 100), (Bundesministerium für Verkehr Innovation und Technologie 2012, p. 22)

Per weekday 27 billion trips are travelled in Austria (Bundesministerium für Verkehr Innovation und Technologie 2012). 53% of these trips are short distance trips within the municipality- or city borders (Bundesministerium für Verkehr Innovation und Technologie 2012).

[4] Information about the date for the expected results was given by word of mouth from Markus Schuster, an employee at Herr Consult GmbH, the company commissioned with the analysis of the survey data.

The choice of transport mode differs regionally. While Lower- and Upper Austria have relatively high shares of car trips, the city of Vienna has a share of 27%. In Vienna and Innsbruck the pedestrian shares are higher than in the federals states (Upper- Lower Austria and Vorarlberg). Table 2 presents the modal split for Upper- and Lower Austria, Innsbruck with its hinterland, Vorarlberg and Vienna.

Modal split - [% of trips]	Upper Austria 2001	Lower Austria 2001	Innsbruck with its hinterland 2003	Vorarlberg 2008	Vienna 2012
pedestrian	17%	16%	27%	15%	28%
bicycle	7%	7%	13%	18%	6%
public transport	12%	13%	16%	13%	39%
car	62%	64%	42%	53%	27%
motorbike			1%	1%	
Mixed PMT - PT	2%		1%		

Table 2 Modal split from regional surveys. Source: (Amt der Överösterreichischen Landesregierung 2001; IMAD - Institut für Marktforschung und Datenanalyse 2002; Amt der Niederösterreichischen Landesregierung and Niederösterreichische Landsakademie 2008; Herry 2009; Wiener Stadtwerke Holding AG 2013)

Table 3 presents the passenger kilometres for Austria in 2010. In total 101,570 million passenger kilometres are travelled. 71% of the passenger kilometres travelled are travelled by car.

Passenger km per mode [million (m.) passenger km]	Data 2010
Car	72,334[5]
pt bus	9,735
pt rail	14,772
Slow	3,131
Total	101,570

Table 3 Passenger km per mode data from 2010. Source: (Österreichische Luftschadstoffinventur (OLI) 2010)

[5] Mopeds and motorcycles are not represented but account for 1,599 m. passenger kilometres, leading in total to 73,912 m. kilometres for car, E-car, moped and motorcycle.

Figure 3 presents the development of the passenger kilometres from 1990 till 2010. It can be seen that especially the share of private motorized transport increased from 1990 till 2010.

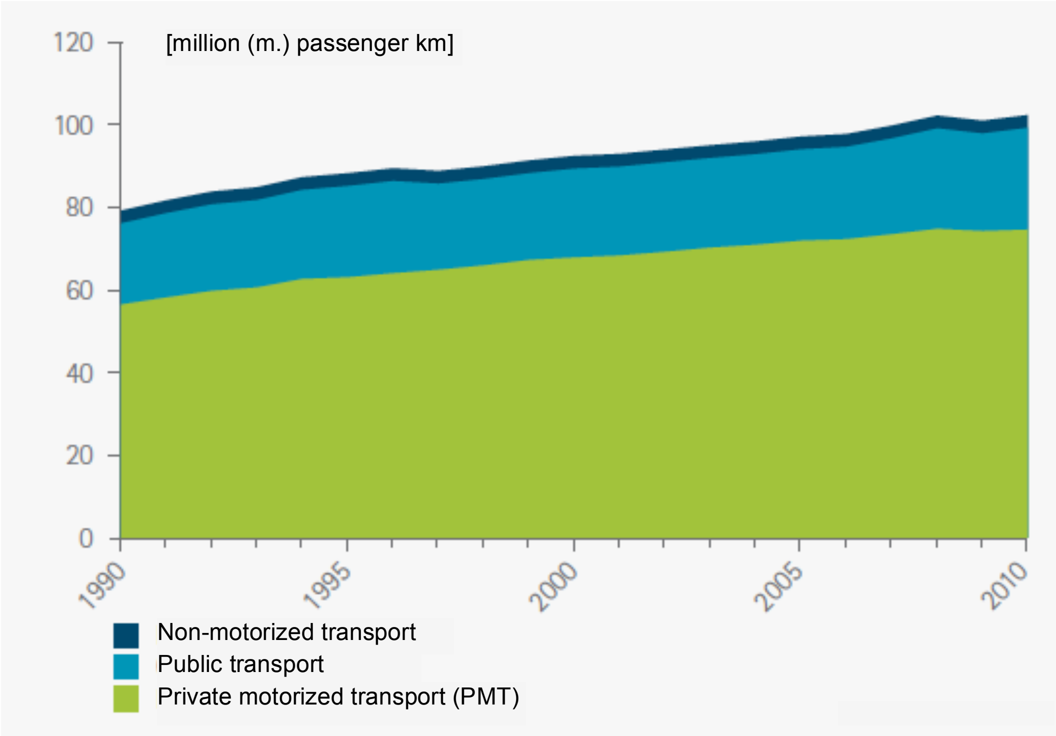

Figure 3 Development of the passenger kilometres in Austria from 1990 till 2010. Source: (Bundesministerium für Verkehr Innovation und Technologie 2012, p. 23)

Figure 4 presents the level of motorization for the Austrian provincial capitals for the years 2004 and 2012. In the biggest cities the car is losing its importance. In Vienna and Graz the level of motorization declined from 2004 to 2012. This is also an international trend: in Zurich and Berlin the level of motorization also declined between 2004 and 2012 (Statistik Austria 2013).

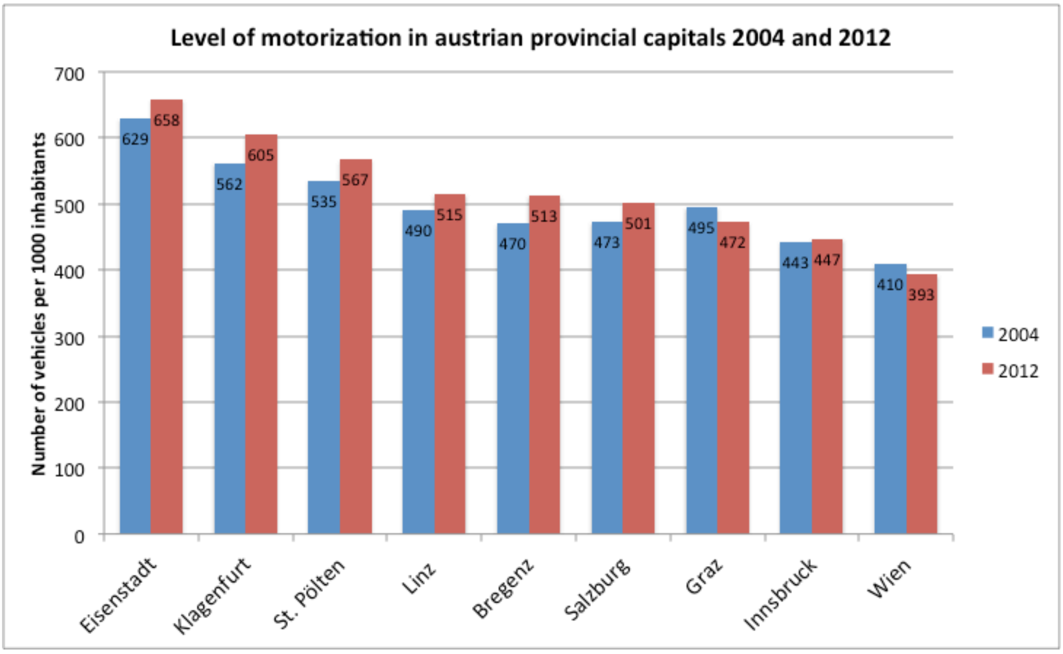

Figure 4 Level of motorization in Austrian provincial capitals 2004 and 2012. Source: (Statistik Austria 2013)

The usage of new technologies in the transport sector has changed in the recent years. High penetration rates of internet-use and smart phones enable new applications and services helping for example car sharing to a breakthrough. Especially young people do not use their own car exclusively any more. Looking at the modal split from young people in Germany who own their own car, all other modes of transport could increase their shares in 2008 compared to the end of the 90ies and the year 2000 (Institut für Mobilitätsforschung 2011). The trend is multimodality, the combination of different modes of transport. In Austria 42% of the customers of CarSharing.at (an Austrian car sharing provider) use public transport or the bike more often, 16% abandon their own car (CarSharing.at/Zipcar 2013). It is expected that trough smartphones the possibilities of multimodal and mobile information supply will play a major role in the future. A survey from Austria showed that a majority of interviewed experts believe that additional information services and services such as ticketing, real time information, etc. would decrease barriers for using public transport (Cervinka, Ehmayer et al. 2010). Further they believe that by showing different routes and modes of travel, eco modes could be promoted (Cervinka, Ehmayer et al. 2010).

1.3 Research questions and aims of the thesis

Section 1.1 outlined the challenges the passenger transport sector is facing concerning CO_2 emissions and section 1.2 presented the developments in transport behaviour. To date there is just one modelling approach to forecast the developments in the passenger transport sector (and goods transport) for the whole territory of Austria, which is the Austrian transport prognosis 2025+ (see chapter 3). The need for CO_2 reduction in the sector (see section 1.1) and the existence of one single prognosis so far clearly make the case for further research in this area. To improve the understanding of possible development paths for the passenger transport sector under the condition of CO_2 emission reduction and combining transport/land-use policies with different development paths of electric mobility two main research questions are raised:

1. *"What are the overall effects of different transport and land-use policy scenarios and different development paths of electric mobility on the transport behaviour and on CO_2 emissions on a national scale?"*
2. *"Which policy combinations enable to reach the set targets described in section 1.1.1?"*

In other words the potential of a set of policy scenarios to reduce CO_2 emissions and achieve a change in transport behaviour towards more environmental friendly modes of travel (walking, cycling, and public transport) are tested. This is accomplished by using MARS Austria (see chapter 5), a land-use/transport model (LUTI) for the whole territory of Austria.

The following questions shall be answered:

1. How can transport and land-use policies be modelled within the MARS model?
2. Which policy combinations are most effective in reducing CO_2 emissions on a national scale, and are therefore recommendable for the purpose of reaching national and international targets?

3. What is the impact of different diffusion scenarios of E-cars[6] on CO_2 emissions?
4. Are technological measures alone sufficient for reaching long-term climate targets?
5. Which policy combinations are most influential in changing transport behaviour?
6. Are stand-alone land-use policies or stand-alone transport policies more effective? Where do combinations of the two lead us?

1.4 Research area and methodology

The work in this thesis is guided by two research hypothesis given below.

(1) There is interaction between transport, the spatial structure of settlements and the economy forming a dynamic self-organising system.

This is today generally accepted in scientific discourse (Miller, Kriger et al. 1998; Preston 2001) and, increasingly, in official transport policy documents (Bundesamt für Verkehr and Bundesamt für Raumentwicklung 2002; Bundesministerium für Verkehr; Bau- und Wohnungswesen 2003; Scottish Executive 2003).

In the regional planning and transport literature the concept is generally termed "land-use/transport interaction" (David Simmonds Consultancy 1999). Scientific contributions originate from a broad spectrum of disciplines. The theory of self-organizing systems applies system principles derived from natural sciences to describe social systems (Nicolis and Prigogine 1977). Allen (1997) demonstrates the effectiveness of such models to reproduce observed urban developments. In economics, a whole new field termed "new economic geography" explains processes of agglomeration and urbanization as the result of the dynamic interaction of factors such as economies of scale and transport costs (Fujita, Krugman et al. 1999).

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[6] Electric cars and plug-in hybrids

Although there are diverse opinions about the influence of land-use policies on travel behaviour among transport scientists, Banister (1999) for example, states that it is a very fundamental way to influence travel behaviour, while Martens (2000) is very sceptical about this influence, the hypothesis here is that there is influence from land-use policy to transport (travel behaviour) which implies that land use-policies should be based on transport impacts.

(2) Non-motorized modes are an essential element of the transport system and are strongly influenced by settlement patterns. Due to spatial linkages, they have to be considered even at higher spatial levels where their influence is not intuitively apparent.

Transportation research has for a long time focussed on mechanized transport modes, considering slow non-motorized modes as residual at best because of an underestimation of their importance for passenger transport (Knoflacher 1997). In transport analysis, non-motorized modes are currently only taken into consideration in purely urban studies.

This practice provokes a bias towards policies focusing on mechanized modes and making the case for a modal shift to public transport. However, sustainability in transport clearly requires more fundamental, structural changes, as highlighted, for example, by the OECD (2000) in its vision of environmentally sustainable transport.

The question whether technological development is sufficient for reaching long-term climate targets or if significant changes in behaviour will be required in addition, is also dealt within this thesis.

The Environment Agency Austria (Umweltbundesamt) states that especially in the long run electric mobility has a high potential in reducing CO_2 emissions, which is hardly comparable with alternative measures (Pötscher, Winter et al. 2010). In addition, Johansson (2009), states that other negative effects of road transport such as noise, particulate emissions, the use of natural resources in infrastructure and the encroachment on natural landscapes, indicate that technical measures alone do not seem the be the most efficient measure. This requires a differentiated discussion of electric mobility. For the scope of the thesis the influence of electric mobility will be analysed in terms of CO_2 reduction potential and transport behaviour (including statements about the other negative effects of road transport as mentioned by Johansson).

In order not to disappoint the reader's expectations, I would like to mention the issues which are not addressed in the present thesis:

- There is no in depth analysis of the necessity and distribution of charging infrastructure of electric vehicles for the assumed penetration rates.
- Further no lifecycle analysis taking into account grey energy for electric vehicles and the use of biofuels is accomplished. The presented CO_2 emissions are emerging from running the vehicles (pump to wheel).

1.4.1 Making the case for formal modelling

From a methodological point of view, the concepts of revealed preference, stated preference and simulation based on formal models can be applied to investigate the land-use/transport interaction (Wegener 2004). There is consensus in the scientific literature that major progress will only be made with formal modelling approaches (SACTRA 1998; Boulanger and Bréchet 2005).

Knoflacher (2007) emphasizes that in order to reach sustainable solutions in transport planning, the interrelationship between structures, behaviour and data has to be known. He states that behaviour is affected by structures, including all elements like physical built infrastructure, regulatory measures, information or social/economic conditions (Knoflacher 2007, p.46). In order to produce different data (measuring the behaviour) changes in structure are necessary (Knoflacher 2007, p.46). Modelling in a way is intervention in structures. With a modelling approach different policy scenarios can be modelled, reproducing this interrelationship between structures and behaviour.

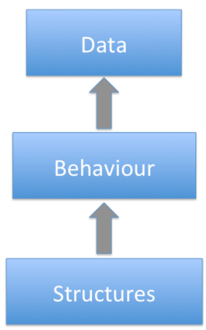

Figure 5 Relationship between structures, behaviour and data. Source: (Knoflacher 2007, p.47)

The notion that land-use and transport are highly interrelated resulted in the development of a series of land-use/transport interaction (LUTI) models (see chapter 2). However, the application of these models has to date been mainly limited to urban regions. While this is understandable as 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 LUTI model (Pfaffenbichler 2003). It has been applied in a series of urban case studies. For this thesis MARS has been developed further to model the whole case study of Austria. This allows modelling the impacts of transport and land-use policies on a nationwide scale. The MARS Austria model is used in a forecasting approach to examine the effects of different policy scenarios on CO_2 emissions and transport behaviour. The time period modelled is from 2010 to 2050. Different development paths for the diffusion of electric cars are modelled as well as different sets of policy combinations (transport and land-use), varying in the choice of policies as well as the magnitude of the policies themselves.

MARS is a system dynamics model (see section 1.4.2). Stated in general terms SD is a useful method for:

> "1. Understanding and explaining the dynamic behaviour of a system in terms of its structure (causal relations and feedback loops) and policies, as well as improving the conceptual models that explain the system;
>
> 2. Designing, formulating and testing different scenarios and policies by posing and answering "what if" questions;
>
> 3. Providing useful information, both to policy and decision-makers, thus giving support to the decision-making progress in the field of strategic planning; and
>
> 4. Improving the management and control of complex systems." (Abbas and Bell 1994, p. 381-382)

One distinctive feature of interrelations between the transport and the land-use system is that changes within these two systems occur at significantly different speed. Transport users respond relatively fast to changes in the transport system, whereas the land-use system is characterized by a considerable degree of inertia, mainly due to the fact that land-use systems are embodied in physical structures such as buildings and infrastructure.

At a closer look, even four different speed levels of changes (Wegener 2004) within the transport/land-use systems can be identified ranging from slow to fast processes:

- Very slow change: networks and land-use.

Transport, communications, and utility networks are the most permanent elements of the physical structure of cities and also rural regions. The land-use distribution is equally stable; it changes only incrementally.

- Slow changes: workplaces and housing.

Buildings have a life-span up to 100 years and take several years from planning to completion. Workplaces exist much longer than the firms or institutions that offer them, just as housing exists longer than the households that live in it.

- Fast change: employment and population.
- Immediate change: goods transport and travel.

The location of human activities in space gives rise to a demand for spatial interaction in the form of goods transport and travel.

The modelling approach in this thesis allows formulating different scenarios and policies by answering “what if” questions. Further system dynamics is capable of modelling different system speeds. To conclude SD was developed for modelling complex interrelated systems. These three capabilities make system dynamics a powerful tool for modelling land-use/transport interactions.

At this point I would like to mention that in this thesis I tried to make all assumptions “as realistically” as possible. If and to which extent the assumed developments are realistic remains to be seen in the future.

Of course science is not free of individual interpretation and subjective evaluation. Each (modelling) result is based on the decision of calculation method and causalities. In this sense each projection into the future underlies the author’s vision of the future. The author of the following thesis is of course not an exception. At this point I would like to mention that in this thesis I tried to make all assumptions “as realistically” as possible. If and to which extent the assumed developments are realistic remains to be seen in the future.

1.4.2 An introduction to system dynamics

System dynamics (SD), originally called industrial dynamics, was developed at the Massachusetts Institute of Technology (Forrester 1961). It can be referred to as a general methodology as well as being a sophisticated dynamic modelling technique (Wolstenholme 1983). It originates from system theory, cybernetics, information science, organisational theory, feedback control theory, military games and tactical decision making.

Based on findings that socio-economic systems often behave counterintuitive, which means that measures that have a positive influence in the short run may have a negative outcome in the long run, Forrester concluded that such systems are composed of several feedback loops. He distinguished two types of feedback loops: positive feedback loops enforcing developments over time, finally even de-stabilizing systems, and negative feedback loops dampening developments over time and stabilizing systems.

System dynamics models consist of three types of structure elements, namely level variables (levels), flow variables (rates) and auxiliary variables (auxiliaries). The description below of these types of structure elements follows Forrester (1961), Abbas and Bell (1994), Sterman (2000) and Bossel (2004).

Levels represent the most important element of a system. They describe the state of the system, and the system behaviour can be derived from their development. The values of levels change during a simulation according to their related rates. A level is basically equal to the value of the same level at the previous point in time plus the net inflow/outflow of rates across the time increment.

Rates can be inflows to a level adding the values of a rate to the values of the level within each time step. But rates can be outflows from a level as well. Rates exemplify streams of actions, decisions or activities that cause the state of the system to change. The distinction between flows of real physical/material quantities and flows of information should be clear. Physical flows are conserved flows that comply with physical rules. Information flows follow their own particular laws. Information need not be conserved, and it may be at more than one place at the same time.

Auxiliaries represent the algebraic or integral calculations that are mainly required to capture information necessary for the computation of rates. Thus, auxiliaries simplify the computation of complex rates by algebraically splitting the computation of rates into several mathematical steps that are convenient to grasp, understand, formulate and present. Three types of auxiliary variables are distinguished: parameters, exogenous factors and intermediate variables. Parameters are constant during the simulation period. Exogenous factors represent variables that have an influence on the system but are not influenced by the system (constants). Intermediate variables are calculated by other variables of the system at the same point in time. Through a special scheme, the different elements are composed of sets of difference equations that describe the interrelationships within the system dynamics model.

In SD modelling, the behaviour of a system is mainly determined by its structure. However, exogenous variables generated independently are also important to show how the endogenous structure of a system reacts to external factors.
Another key factor in SD models is time. Future system states develop out of past and current system states.

In SD, time lags are explicitly taken into account. A time lag is defined as the delay in time between the beginning and the end of this action. There are two types of time delays:

- Information time delays and
- Physical time delays.

Time delays are characteristic of real-world systems. The output of a system dynamics model always consists of dynamic development paths for each variable rather than of a static point-to-point forecast.

1.4.3 Technical implementation

The model will be set up in the dynamic modelling environment VENSIM (http://vensim.com/). VENSIM is a visual modelling tool that conceptualizes,

documents, simulates, analyses and optimizes models of dynamic systems expressed in the 'language' and with the toolset of system dynamics.
The main advantages of VENSIM in regard to this thesis are the ease of use, the suitability for complex models and the existing experience at the Vienna University of Technology, Research Centre of Transport Planning and Traffic Engineering and on my part.

1.5 Structure of the thesis

The thesis starts with a description of land-use interaction modelling (chapter 2). After the identification of the most involved disciplines and concepts the land-use/transport relationship is presented in theory. The chapter contains a short digression on accessibility indicators and an introduction of system dynamics. Further empirical findings of the impacts of land-use on transport are presented. At last national land-use transport models are presented and MARS Austria is compared to these models.

The next chapter (chapter 3) presents the Austrian transport prognosis 2025+, which was carried out with the Austrian transport model. Scope, methodology, the foundations of the prognosis as well as the scenario definitions, model structure and results of the prognosis are presented. A comparison of the MARS Austria model and the prognosis follows in section 9.3.

Chapter 4 describes the development of the MARS model. The modelling purpose and model description with sub-models and additional modules is presented.

Chapter 5 outlines the transition from an urban to the national MARS Austria models. The study area and model zones as well as the data basis are explained. Additionally, two different models (base year 2001 and 2010) are described. This chapter focuses on the structural changes accomplished during the development process. For the thesis the MARS Austria 2010 model is used. Further the calibration and model testing process of MARS Austria. The methodology and data used are described, and the calibration process for the transport model and the workplace location choice model are presented for MARS Austria 2010.

The next chapter (chapter 6) describes how transport and land-use policies are implemented into MARS Austria. The chosen approach for this thesis is explained for the land-use/transport policies as well as for the fleet development.

Chapter 7 describes the scenario modelling. For the in total 8 modelled scenarios the fuel and electricity price developments as well as the fleet development and the emissions per combustion technology are described. Followed by the transport and land-use policies implemented for each scenario separately. The chapter elaborates on the definition of the scenarios in detail. The 8 modelled scenarios are:

- One business as usual scenario (BAU)
- Three policy scenarios (550 ppm, 500 ppm, 450 ppm)
- One scenario without policies but assuming a big technological shift toward electric mobility (tech.)
- Two frozen technology scenario where the shares of the combustion technologies are kept static (to single out the effect of the policies implemented) (TPO and LPO)
- And a BAU scenario without technological changes concerning the fleet development (BAU-frozen)

Chapter 8 presents the results of the policy scenarios modelled beginning with the description of the evaluation framework. It comprises the description of the CO2 emissions as indicator as well as other indicators of transport behaviour. Concerning the results the CO_2 emissions per scenario as well as the modal split, passenger kilometres and vehicle kilometres and the average trip lengths are presented.

Chapter 9 presents the comparison of the results and conclusions. The CO_2 reduction potential is revised and influencing factors for changes in transport behaviour analysed, followed by recommendations for future research. Further the transport prognosis 2025+ is compared to MARS Austria 2010 and a conclusion as well as a summary of the results is provided.

In chapter 10 all the literature is provided.

2 LAND-USE/TRANSPORT INTERACTION MODELLING

Research into the land-use/transport interaction has a long tradition, with early works focusing on the explanation of land rent gradients (von Thünen 1826) and of the hierarchical spatial pattern of 'central places' (Christaller 1933; Lösch 1940). However, due the division of science into disciplines, subsequent research in the field has remained fragmented which prevented a common methodological framework (Allen 1997) and the application in practical policy making (SACTRA 1998).

The most significantly involved disciplines are economics, regional science and transport engineering, all of which brought forward specific modelling approaches.

The following primary concepts (the scientific background is given in parentheses) are identified:

- **"Pure" transport models (transport engineering)**

Operational transport models are today commercially available, have accepted theoretical foundations and deliver disaggregated results. Transport models are widely used to generate input for state of the practise assessment methodologies such as cost-benefit analysis or multi-criteria analysis. However, "pure" transport models are always based on the assumption of fixed spatial structures of settlements and economy. Some examples of commercial transport models are VISUM[7], EMME/2[8] and SATURN[9].

- **"Pure" economic models (economics)**

Macro-economic models

Macro-economic models have been intensively used to forecast national economies and to assess policies in the short and medium term. Macro-economic

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[7] http://vision-traffic.ptvgroup.com/de/produkte/ptv-visum/

[8] http://www.inrosoftware.com/en/products/emme/index.php

[9] http://www.saturnsoftware.co.uk/7.html

models are generally of a neo-Keynesian demand-driven flavour and rely methodologically on the toolset of econometrics. Environmental dimensions, such as energy consumption and production, have been incorporated for the application to transport policy (Boulanger and Bréchet 2005). Nevertheless, the major shortcoming of macroeconomic models in regard to transport and land-use policy assessment-their neglect of any explicit consideration of space-persists.

Computable general equilibrium models

CGE models are operational versions of neo-classical models of the economy, implicating a focus on price and market mechanisms. While CGE analysis has become a standard tool for general economic policy assessment, transport economics is a relatively recent field of application (Bröcker 2004). So far, CGE models account mainly for goods transport and business travel, whereas models which include leisure and shopping travel are not yet operational. Most state of the art CGE models are static. However, only dynamic CGE models explicitly account for migration and spatial investment allocation decisions, i.e. are able to predict the evolution of spatial structure (TNO 2004). Operational CGE models used to assess transport policies are CGEurope (TNO 2004) and E3ME (Barker and Köhler 2000).

- **Integrated models**

Land-use/transport interaction (LUTI) models (regional science, transport engineering)

Operational land-use modelling was pioneered by Lowry in the 1960ies (Lowry 1964). Initial models drew heavily on analogies to physics, e.g. the law of gravity. Most current models have their foundation in random utility theory, which is based on the principle of utility maximization originating from micro-economics. Typically, LUTI models combine at least two separate components: a land-use and a transport sub-model, which generate dynamic behaviour based on time lags between the two systems. State of the art models feature a modular structure, which entails a flexibility to include further aspects such as imperfect markets (David Simmonds Consultancy 1999). There are, however, concerns that LUTI models focus mainly on the redistribution of activities, neglecting aggregate effects, e.g. on employment, as overall economic activity is usually exogenously specified (SACTRA 1998). Some of the most advanced European LUTI models are IRPUD (Wegener 1998), DELTA (Simmonds 2001), MEPLAN (Echenique, Flowerdew et al. 1990) and MARS (Pfaffenbichler 2003).

New economic geography (NEG) models (economics)

The new "genre" New Economic Geography rediscovers spatial aspects in economics inspired by a ground breaking publication by Krugman (1991). NEG uses elements from polarization theory, new trade theory and new growth theory to analyse the questions how agglomerations form and under what conditions they sustain or evolve. In contrast to traditional neoclassical approaches, which generally predict diminishing spatial disparities, NEG stresses the existence of both centrifugal forces-forward and backward linkages, thick markets and knowledge spillovers and centripetal forces-immobile factors, land rent/commuting and congestion. The interaction of these forces may just as well lead to concentration, as to dispersion of economic activities. NEG might have far-reaching policy implications challenging the established belief that free-trade yields benefits for all involved regions under all conditions. It is therefore a very active field of research. Empirical work on NEG, however, is still relatively scarce, amongst others due to technical reasons (Fujita, Krugman et al. 1999).

The modelling approach opted in this thesis is following the tradition of LUTI modelling implemented in system dynamics. The reasoning is the following:

- The use of LUTI modelling is justifiable for the scope of the work. I do not raise the claim of modelling the interrelationship between transport and the economy and the spatial distribution of economic activities in detail. The MARS model takes the overall economic development as given and redistributes working places via changes in accessibility (see section 4.5.2). Further two sectors of working places are assumed in MARS. The unnecessity of modelling the economy in detail explains why the NEG approach is not opted for. The same argument holds true for CGE models, where the focus lies on prices and market mechanisms.

- Pure transport models and macro-economic models typically either work in fixed spatial structures (pure transport models) or still neglect the explicit consideration of space (macro-economic models) and are therefore not the right choice at hand.

- An attractive feature for using LUTI modelling was of course the competence gathered at Vienna University of Technology. Over the last decade the Research Centre for Transport Planning and Traffic Engineering has acquired competence in the field resulting in the development of the urban strategic and dynamic LUTI model MARS (Metropolitan Activity Relocation Simulator). The claim for this thesis was building the nationwide setup of MARS, while changing as little as possible of the generic structure.
- The strength of LUTI models lies in their modular structure, making it possible to include or exclude certain aspects. In the case of the approach used in this thesis one sub-model is replaced by another structure (see section 5.3.3.1). This kind of "switching" certain model parts on and off is a very practical feature of LUTI models.
- The focus of this thesis lies on policy scenario modelling with the scope on the reduction potential of CO_2 emissions. Abbas and Bell (1994) explain that system dynamics is perfectly capable in modelling transport problems because with SD it is possible to answer "what if" questions, the core in policy scenario modelling.
- Another distinctive feature of SD is the possibility of modelling different system speeds and the changes between the transport and the land-use system occur at significantly different speed (see section 1.4.1).
- Last but not least the land-use transport system is a complex interrelated system and one of the strengths of SD modelling lies there.

2.1 The land-use/transport relationship - theory

The notion that land-use and transport are strongly interrelated is accepted common knowledge. This recognition led to the concept of the "land-use/transport feedback cycle", as described by Wegener and Fürst (1999). This interrelation can be summed up following Wegener und Fürst (see Figure 6):

"The distribution of land uses, such as residential, industrial, or commercial, over the spatial area determines the location of human activities such as living, working, shopping, education, or leisure.

The distribution of human activities in space requires spatial interactions or trips in the transport system to overcome the distance between the locations of activities.

The distribution of infrastructure in the transport system creates opportunities for spatial interactions, and can be measured as accessibility.

The distribution of accessibility in space co-determines location decisions and so results in changes of the land-use system." (Wegener and Fürst 1999, p. vi)

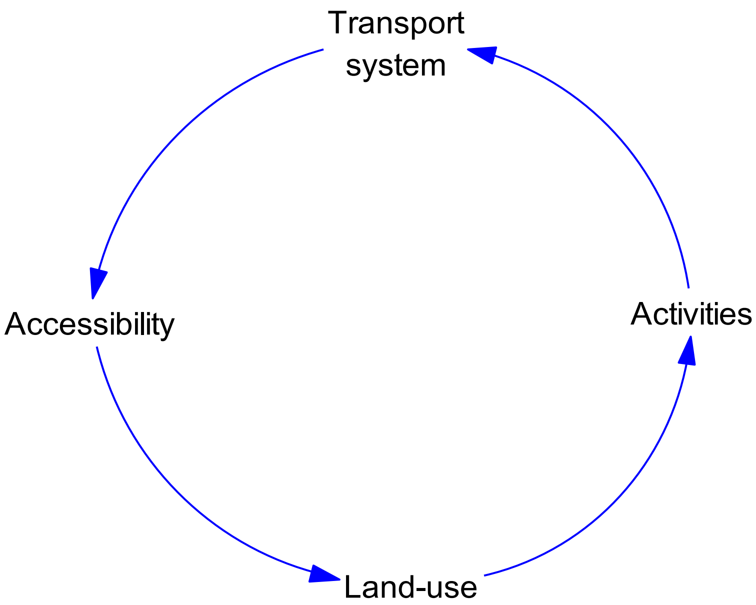

Figure 6 Land-use/transport feedback cycle. Source: (Wegener and Fürst 1999)

Also van Wee (2002) describes this interrelationship, and names it a "conceptual model for passenger transport", where he states that the total volume of passenger transport and the modal split between transport modes depend on the locations of human activities, the needs and desires of people and the transport resistances (generalised transport costs).

The theoretical foundation of the relation between travel behaviour and spatial structure can be found in the theory of utilitarian travel demand (Van Wee 2002). It postulates that demand for travel does not derive its utility from the trip itself, but originates rather from the need to reach the locations where the activities (working, shopping, leisure,…) take place and the needs can be fulfilled.

It is important to mention that this relationship is a matter of two-way interaction between transport and the land-use system. Changes in one system influence the other one and vice versa.

Changes to transportation networks, such as the construction of a new highway, influence the investment in land. Development of new settlement structures in turn influences the demand for travel to and from a particular location (Iacono, Levinson et al. 2007).

A certain infrastructure in the transport system creates the opportunities for spatial interaction, which can be measured as accessibility[10].

The distribution of accessibility in space co-determines location decisions for households and firms and thus results in changes of the land-use system (Wegener and Fürst 1999). It is generally assumed that households wish to settle down in areas with higher accessibilities to opportunities such as employment or shopping, while firms are assumed to prefer areas with higher accessibility to labour markets (Iacono, Levinson et al. 2007).

The distribution of land-uses over the area determines the locations of human activities. This distribution of human activities in space requires spatial interactions or trips in the transport system to overcome the distance between the locations of activities (Wegener and Fürst 1999).

2.2 Digression on accessibility indicators

The theories presented in section 2.1 claim that accessibility is the main criterion as to the influence of the transport system on spatial settlement. Geurs and

[10] Accessibility here is defined as the potential for people to reach desired goods, services and activities. (see Litman, T. (2012). Evaluating Accessibility for Transportation Planning, Victoria Transport Policy Institute.)

Ritsema van Eck (2001) categorize accessibility into three groups following different perspectives:

1. Infrastructure based accessibility measures: those are used to analyse the (observed or simulated) performance of transport infrastructure
2. Activity-based accessibility measures: those are used to analyse the range of available opportunities with respect to their distribution in space and the travel impedance between origins and destinations. Activity based measures can be further subdivided into geographical (or potential) time-space measures
3. Utility based accessibility measures: those measures are used to analyse the benefits individuals derive from the land-use/transport system.

As will be presented in section 4.1 MARS Austria works with an activity based definition of accessibility.

2.3 The impact of land-use on transport - empirical findings

The next session will discuss empirical findings of the influence of accessibility on location choice decisions of households and firms.

Wegener and Fürst (1999) give an overview of the empirical studies concerning the land-use/transport feedback cycle. In the TRANSLAND project deliverable 2a (Wegener and Fürst 1999) they gathered empirical studies concerning the relationship of:

- residential density and trip frequency and length,
- residential density and public transport use,
- employment density and travel patterns and
- the neighbourhood design and travel patterns.

Furthermore they investigate the transport impacts on land-use. They highlight two review papers incorporating lots of material from Miller et al. as well as from Stead and Marshall (Miller, Kriger et al. 1998; Stead and Marshall 1998).

The following impacts are based on the TRANSLAND project findings from the deliverable 2a (Wegener and Fürst 1999) complemented by additional sources.

Table 4 shows the influence of land-use policies on transport patterns, while Table 5 shows the influence of transport policies on transport patterns.

Factor	Impact on	Observed impacts
Residential density	**Trip length**	Studies support that higher density combined with mixed land-use leads to shorter trips (cf. (Cervero 1996; Cervero and Kockelman 1997).
	Mode choice	The hypothesis that residential density is positively correlated with public transport use and negatively with car use is widely confirmed (cf. (Kenworthy and Laube 1999; Badoe and Miller 2000; Stead 2001).
Employment density	**Trip length**	Mono-functional employment centres and dormitory suburbs clearly have longer trips[11].
	Mode choice	Higher employment density is likely to induce more public transport use (cf. (Van Wee and Van der Hoorn 2001).
Neighbourhood design	**Trip length**	American and European studies confirm that "traditional" neighbourhoods[12] have shorter trips than car oriented suburbs (cf. (Frank and Pivo 1994; Cervero 1996).
	Mode choice	"Traditional" neighbourhoods have significantly higher shares of public transport, walking and cycling.
Location	**Trip length**	Distance to main employment centres is an important determinant of distance travelled.
	Mode choice	Distance to public transport stops strongly influences public transport use.

[11] Even in the absence of much empirical work, this is a fact accepted by most researchers. (cf. Zondag, B. (2007). Joint modeling of land-use, transport and economy, Technical University Delft.

[12] I define the term „traditional" following Newman, P. W. G. and J. R. Kenworthy (1996). "The land use-transport connection : An overview." Land Use Policy **13**(1): 1-22. and their definition of the traditional walking and the transit city. These two city types are characterized by high densities, mixed land-use and sub-centres at railway stations with walking scale characteristics.

City size	**Trip length**	Mean travel distances are lowest in large urban areas and highest in rural settlements.
	Mode choice	Public transport use is highest in large cities and smallest in rural settlements.

Table 4 Impacts of land-use on transport in empirical studies. Source: (Wegener and Fürst 1999) and additional sources cited in the table, layout adapted by the author

While the number of empirical studies on the impact of land-use on transport is quite high, the number of empirical studies on the impact of transport on land-use is rather marginal in comparison.

This interrelationship was first studied for cities in the 1950s (Wegener 2004). Hansen (1959) showed for Washington DC that locations with good accessibility had a higher chance of being developed (measured as rate of residential development) and that at a higher density than remote locations.

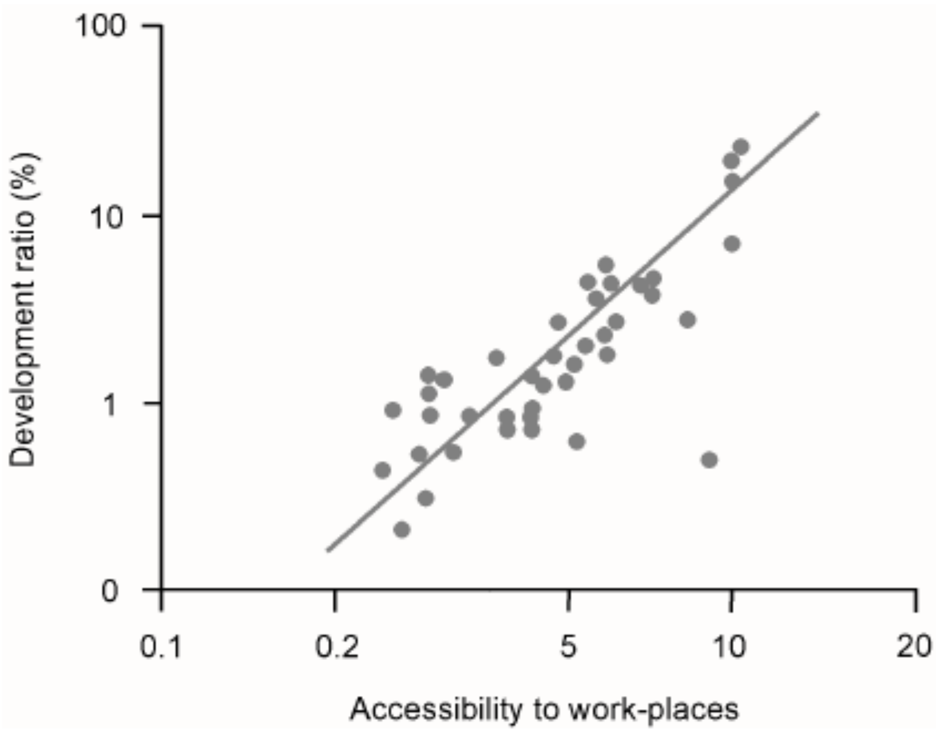

Figure 7 Correlation between accessibility of work-places and residential development in percentage of developable residential land. Source: (Hansen 1959)

However there are also other studies that put the influence of accessibility of location choice into perspective.

Miller, Kriger et al. (1998) reviewed studies of the impacts of commuter rail projects in North America and observed that in the North American context, land-use impacts of rail development tend to be small and concentrate around the train stations. Zondag (2007) states that this finding is likely to be the result of the small share of public transport in North America. In regions with a higher share of public transport in combination with higher energy prices the effects on land-use might be more considerable. For example Kreibich (1978) found increasing residential growth rates along the S-Bahn lines, after the opening of the Munich S-Bahn system in 1972.

Molin and Timmermans (2003) examined six case studies in Belgium and the Netherlands, where they conclude that regardless of the study area and the model specification, accessibility considerations are significantly less important than housing features and characteristics related to the neighbourhood.

This finding leads to the conclusion that accessibility seems to have a modest influence on residential location choice. Among other attributes like demographic developments, neighbourhood design and housing, accessibility is just one of several variables for residential location choice.

Likewise, despite ample common experience, evidence of the importance of accessibility for the location choice of firms, there are only few systematic studies. Wegner and Fürst (1999) and Zondag (2007) gathered empirical research which showed that businesses are, among other factors, especially sensitive to accessibility of freeways. However, Leitham (Leitham, McQuaid et al. 2000) concludes that the importance of road links to location choice varied between different groups of firms. For national and local relocations access to road links is important while for foreign inward investors it is unimportant.

Wegner and Fürst (Wegener and Fürst 1999) state that the impacts of transport on transport patterns tend to be much stronger than those of land-use on transport. Furthermore they state that the causal relationships are relatively undisputed and that empirical studies largely agree on the mechanisms of these impacts. Table 5 lists the most important empirical findings.

Factor	Impact on	Observed impacts
Travel cost	**Trip length**	Price elasticity of trip length was found to be in the range of -0.3.
	Mode choice	Travel cost differences influence modal choice; free public transport will bring more former walkers and cyclists to switch to public transport than car drivers (Macharis, de Witte et al. 2006; van Goeverden, Rietveld et al. 2006).
Travel time	**Trip length**	Travel time savings on the individual level through transport system improvements are spent on longer trips, resulting in no savings within the system (Pfeiderer and Dieterich 2002).
	Trip frequency	Travel time savings through transport system improvements are partly spent on more trips.
	Mode choice	Travel time savings in one mode strongly influence modal choice.

Table 5 Impacts of transport policies on transport patterns in empirical studies. Source: (Wegener and Fürst 1999) and additional sources cited in the table, layout adapted by the author

All these empirical findings support the general idea of the land-use/transport relationship theory which was presented in section 2.1.

2.4 National land-use/transport interaction models

This section gives an overview of some models applied for national case studies. Most of the applications of LUTI models to date are set in urban contexts; for an overview see (Wegener and Fürst 1999; Pfaffenbichler 2003; Wegener 2004; Wegener 2009). At the end of this section a classification of MARS Austria within the other national applied LUTI models is given.

2.4.1 TIGRIS and TIGRIS XL

TIGRIS stands for Transport Infrastructure – Land Use Interaction Simulation, it is a LUTI model for the Netherlands (Schoemaker and Van der Hoorn 2004), owned by the Transport Research Centre of the Ministry of Transport, Public Works and Water Management (AVV). The development of the model started in the 1990s and has so far been applied to four case studies: Randstadrail, the KAN (Kooppunt Arnhem - Nimegen) area, the LHA (Leiden - Haarlem - Amsterdam) area and Randstadt Urbansiation.

The following model description follows Schoemaker and Van der Hoorn (2004). TIGRIS is a long term, incremental, time-based interaction and allocation model covering the following aspects: land-use, congestion and accessibility. In TIGRIS accessibility is known as location factor for land-use that generates mobility[13].
The attractiveness of a zone is subdivided in attractiveness for living purposes and attractiveness for working purposes. The attractiveness is dependent on the accessibility of a zone. The attractiveness for living is determined by the number of dwellings in the zone and a quality of living variable. The attractiveness for working purposes is dependent on the existing jobs and the developed employment capacity in the zone.

Land-use is characterized by the number of dwellings, available employment capacity, population, jobs and amenities per zone. The migration between zones is determined on the basis of their attractiveness and the distance to competing zones.

Mobility is calculated in terms of flows by transport mode (car and public transport) between zone pairs. For every zone an attractiveness measure is derived from various land uses. For every type of land-use there is a weighting factor. Next, the travel volume to other surrounding zones is calculated for every zone, depending on population and car ownership.

The accessibility being assessed as an attraction for the land-use is the variable linking land-use to mobility.

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[13] In TIGRIS the concept of accessibility of a zone is made operational as the amount of activity around a zone, weighted by the distance to that zone: the more there are activities within reach, the more accessible a zone is. Accessibility is distinguished into accessibility for, respectively, amenities, population and jobs (Schoemaker and Van der Hoorn 2004, p. 322).

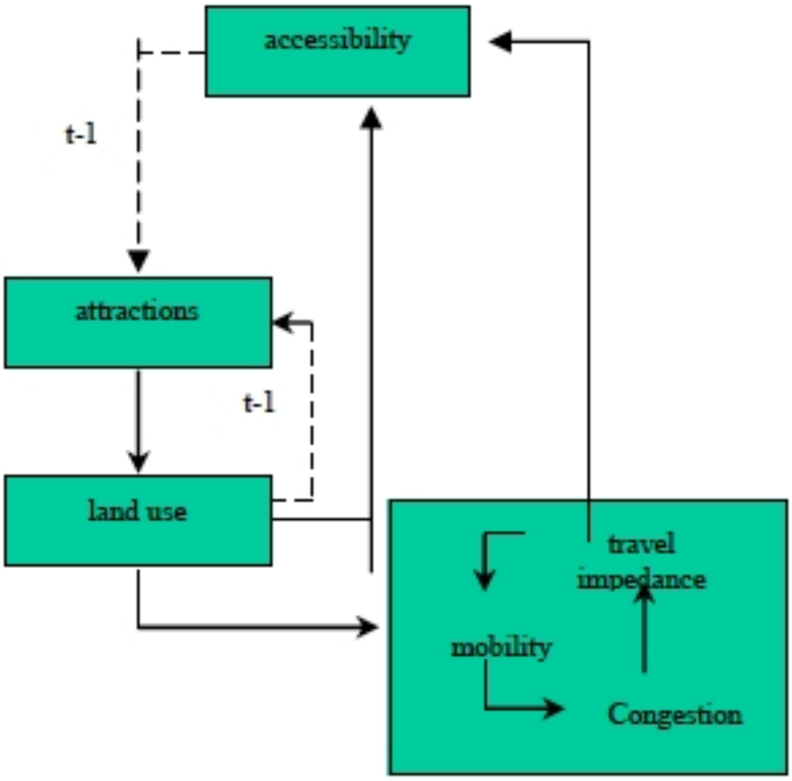

Figure 8 Interaction in TIGRIS. Source: (Schoemaker and Van der Hoorn 2004 p. 320)

TIGRIS requires in general three types of data:

- socio-economic data at national level,
- zone and infrastructure data in the base year (year of calibration),
- scenario-related data which describes the spatial plans (where do we build and how much?) and infrastructure plans between base year and future year of the application.

So far, a new model has been set up for every case study.
TIGRIS is suitable for strategic decisions concerning the national transport policy, and it can calculate global consequences of spatial and/or infrastructure measures. Following an inventory phase of the LUTI requirements of AVVs clients, the new model TIGRIS XL was developed.

The TRIGRSI XL model description is extracted from Zondag and De Jong (2005). RAND Europe and its partners Bureau Louter and Spiekermann & Wegener have developed a new Land-use and Transport Interaction model (TIGRIS XL) for the AVV. The TIGRIS XL model is a system of sub-models that includes dynamic interactions between the sub-models. Its land-use model uses time units of one year, which enables the user to analyse how the system evolves over time. The land-use model is fully integrated in the National Transport Model (NMS) of the Netherlands and the two models, land-use and transport, interact every five years.

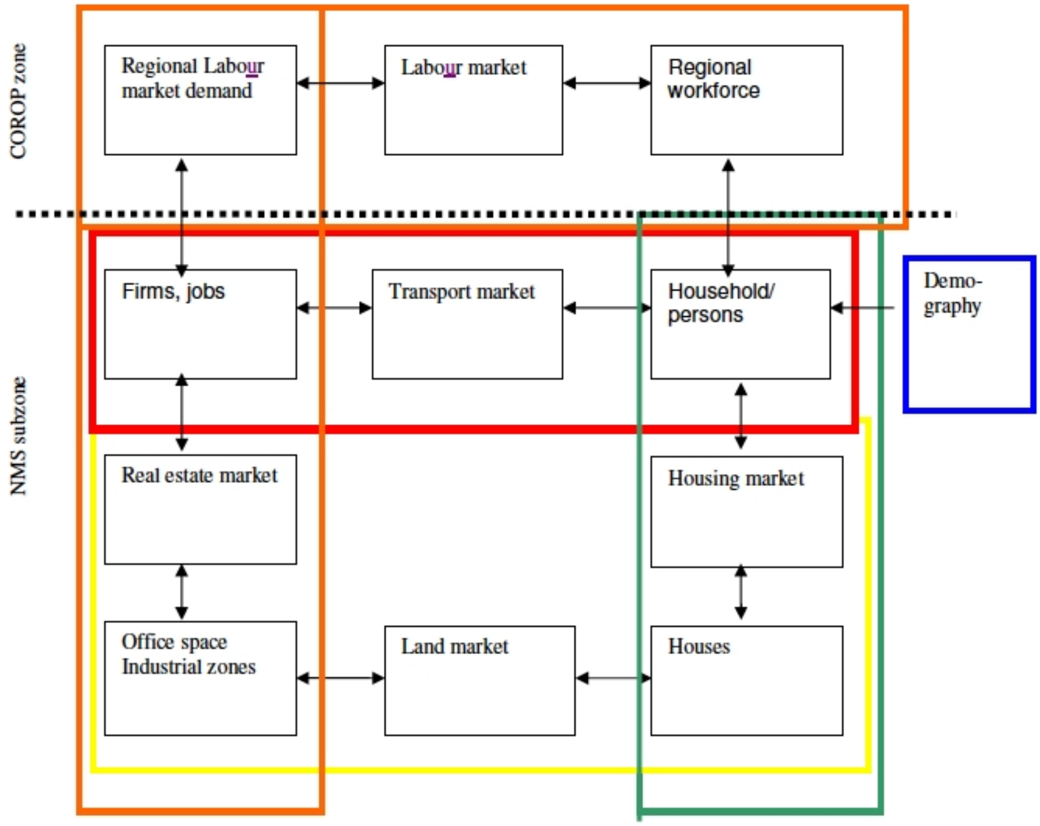

Figure 9 Functional design of TIGRIS XL. Source: (Zondag and De Jong 2005 p. 4)

The TIGRIS XL model operates on two spatial scales: the regional level on the one hand (COROP, 40 regions in the Netherlands) and local transport zones of the National Model System (NMS sub-zones, 1308 sub-zones covering the Netherlands) on the other hand.

The demographic module addresses the transition process of the population and households. It deals with persons by category (gender, age) as well as households by category (size, income, etc.). The demographic module operates at the local zone level and processes both persons and households as well as the transitions (e.g. ageing) and the migration flows calculated in the housing market module.

The land and real estate market module processes the changes in land-use and buildings, office space and houses, and refers to both brown field and green field developments. The land and real estate market interacts with the housing market and labour market module.

The aim of the housing market module is to simulate the annual moves (if any) of households. The module interacts with the demographic, land and real estate, labour and transport market modules to account for, among others, demographic changes and changes in the supply of houses.

The labour market module in TIGRIS XL models the changes in the number of jobs by sector and changes in workforce at a regional and zone level. Specific models have been set up for seven economic sectors to account for the differences in location behaviour between sectors. For each sector, the influence of accessibility on the spatial distribution has been modelled in combination with a set of other explanatory variables. The parameters have been estimated based on a historical data set (1986 - 2000) including employment figures by sector at a local level. The labour market module interacts with the demographic, land and real estate, housing market and transport modules.

The transport module calculates the changes in transport demand and accessibility. The land-use markets for the TIGRIS XL model generate socio–economic input data for the transport module whereas the transport module calculates accessibility indicators based on the changes in socioeconomic data and/or transport policy measures. These accessibility indicators act as input for the residential and firm location choice modules. The transport module interacts with the land-use modules every five years.

For further information about TIGRIS XL and case studies I refer the reader to Zondag (2007).

2.4.2 MEPLAN

At present there is no regional or national application of MEPLAN yet, but Zondag (2007) states that the MEPLAN is a framework capable of operating at an inter-regional level. Moreover MEPLAN was the first of a series of methodologically similar models like TRANUS and PECAS which are described in the next sections (2.4.3 and 2.4.4).

The following information on MEPLAN, if not quoted otherwise, comes from (Abraham and Hunt 1999; Johnston, Rodier et al. 2001; Johnston and McCoy 2006).

The MEPLAN modelling framework is based on the interaction between two parallel markets, the land market and the transportation market (see Figure 10). In the land markets, price and generalized cost (disutility) affect production, consumption, and location decisions by activities. In the transportation markets, money and time costs of travel affect both mode and route selection decisions. The a spatial input-output model at the heart of the system predicts the change in demand for space (Timmermans 2003). This input-output table is expanded to include variable technical coefficients and the use of different categories of space, representing different types of building and/or land. For location choice, LOGIT models are used to allocate volumes of activities in the different sectors of the input-output table to geographic zones.

> "The attractiveness or utility of zones is based on the cost of inputs (which include transportation costs) to the producing activity, location-specific disutilities, and the costs of transporting the resulting production to consumption activities. The resulting patterns of economic interactions among activities in different zones are used to generate origin-destination matrices of different types of trips. These matrices are loaded to a multi-modal network representation that includes nested LOGIT forms for the mode choice models and stochastic user equilibrium for the traffic assignment model (with capacity restraint). The resulting network times and costs affect transportation costs, which then affect the attractiveness of zones and the location of activities, and thus the feedback from transportation to land use is accomplished." (Johnston, Rodier et al. 2001, p. 7)

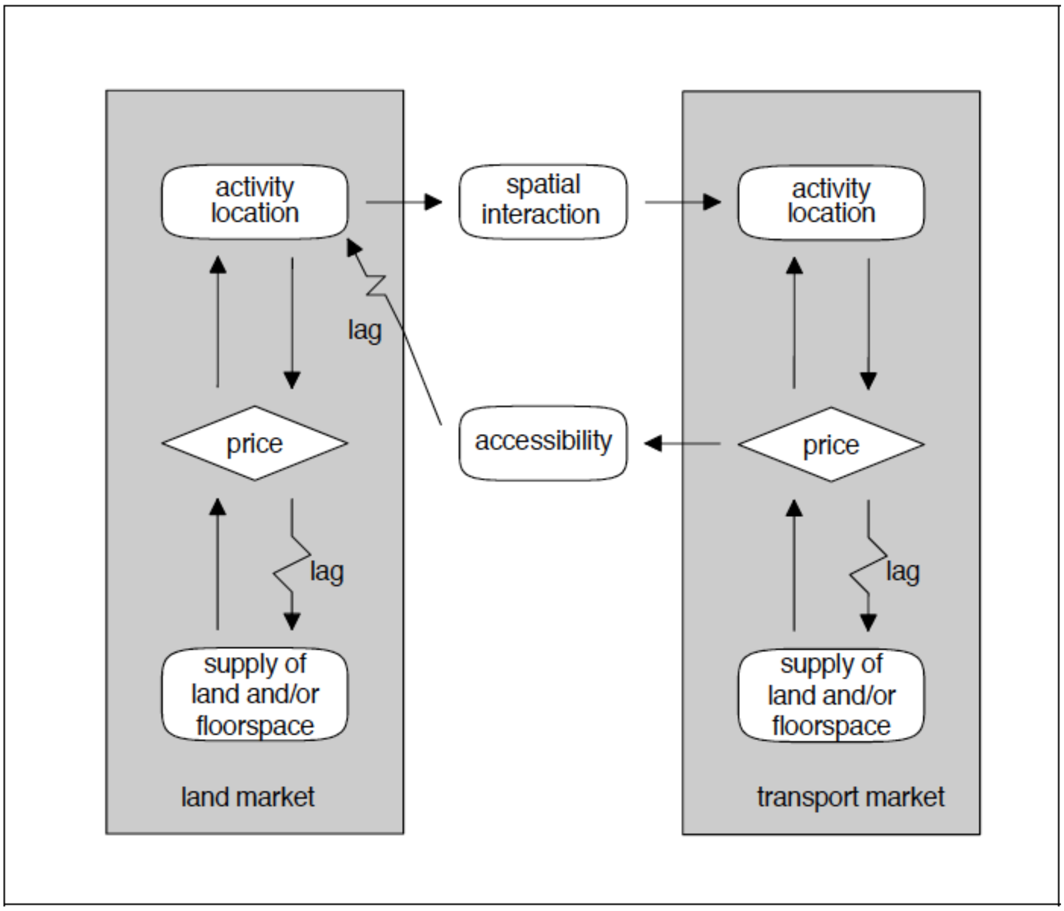

Figure 10 Main structure of the MEPLAN model. Source: (Abraham and Hunt 1999, p. 17)

The framework moves through time in a "quasi-dynamic" way (Abraham and Hunt 1999). First the market model is run, followed by the transportation market model, and then an incremental model simulates changes in the next time period. The transportation costs arising in one period are fed into the land market model in the next time period, thereby introducing lags in the location response to transport conditions. For descriptions of the mathematical forms used in MEPLAN I refer the reader to Hunt (1994). The model has been applied to a series of urban case studies, like Naples, Sacramento London and to the Kano region in Japan (Nishiura and Matsuyuki 2005).

2.4.3 TRANUS

TRANUS simulates the location of activities, land-use, the real estate market and the transportation system (de la Barra 2011). It has been applied to urban but also regional scales. The following description of the model follows (de la Barra 1998; Timmermans 2003; de la Barra 2011).

The TRANUS model consists of two main sub-models: activities and transport. The location and interaction of activities represent the demand side in the activities subsystem. Activities such as industries or households are located in specific areas and interact with other activities to perform their functions. The land and floor space needed to perform these functions are provided by the developer in the real estate market, thus representing the supply side. The interaction between those two systems must lead to a state of equilibrium. This part of the model is basically a spatial input-output model.

In turn, the interactions between activities generate travel requirements. The transport subsystem is based on the need for travel. Demand/supply equilibrium in the transport subsystem is achieved by two means: price and time. If the demand for a particular service outweighs supply, the price of the service may increase, but it is mainly the increase of travel time that achieves equilibrium.

As a result of such an equilibrium, the friction (accessibility, formulated as cost function) imposed by the transport system impedes the interaction between activities. This accessibility feeds back into the activities system, affecting the location and interaction between activities and the prices in the real estate market.

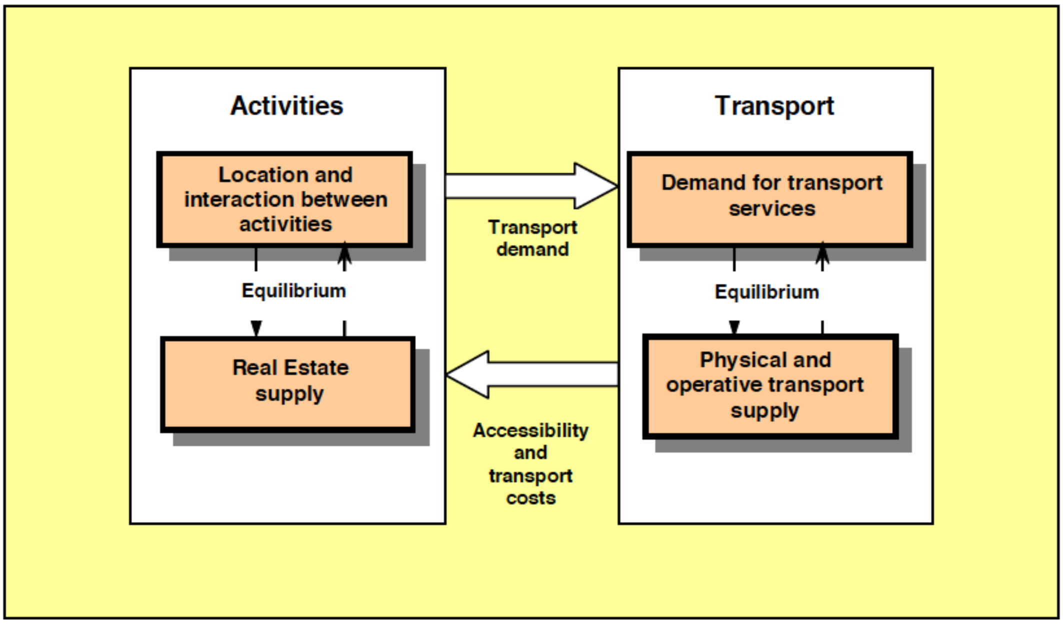

Figure 11 Main sub-models of TRANUS. Source: (de la Barra 2011, p. 6)

The model takes time lags into account, as it steps through time at discrete intervals, starting with the location of final demand, followed by the location and interaction of induced production. Once all activities have been located, the model checks for demand/supply conditions in each location, especially floor space and land. At the end the land-use model evaluates the location of activities, consumption of space and land rent as well as a set of origin-destination matrices with the economic flows by each sector, which are an input to the transport sub-model. The transport related calculations begin with a procedure called multipath search, where several paths or travel options are estimated for each origin-destination pair. The next stage is the estimation of transport costs and disutilities for each intermodal travel path. The number of trips is calculated as a function of the economic flows and an elastic function of transport disutilities. The number of trips may be split by mode, but this is an optional procedure because the multimodal assignment might do this as well. The result of either of the two procedures is the number of person trips or freight performed in each possible combination of physical link and route. The final stage is capacity restriction, in which travel times are adjusted according to the relationships between demand and supply.

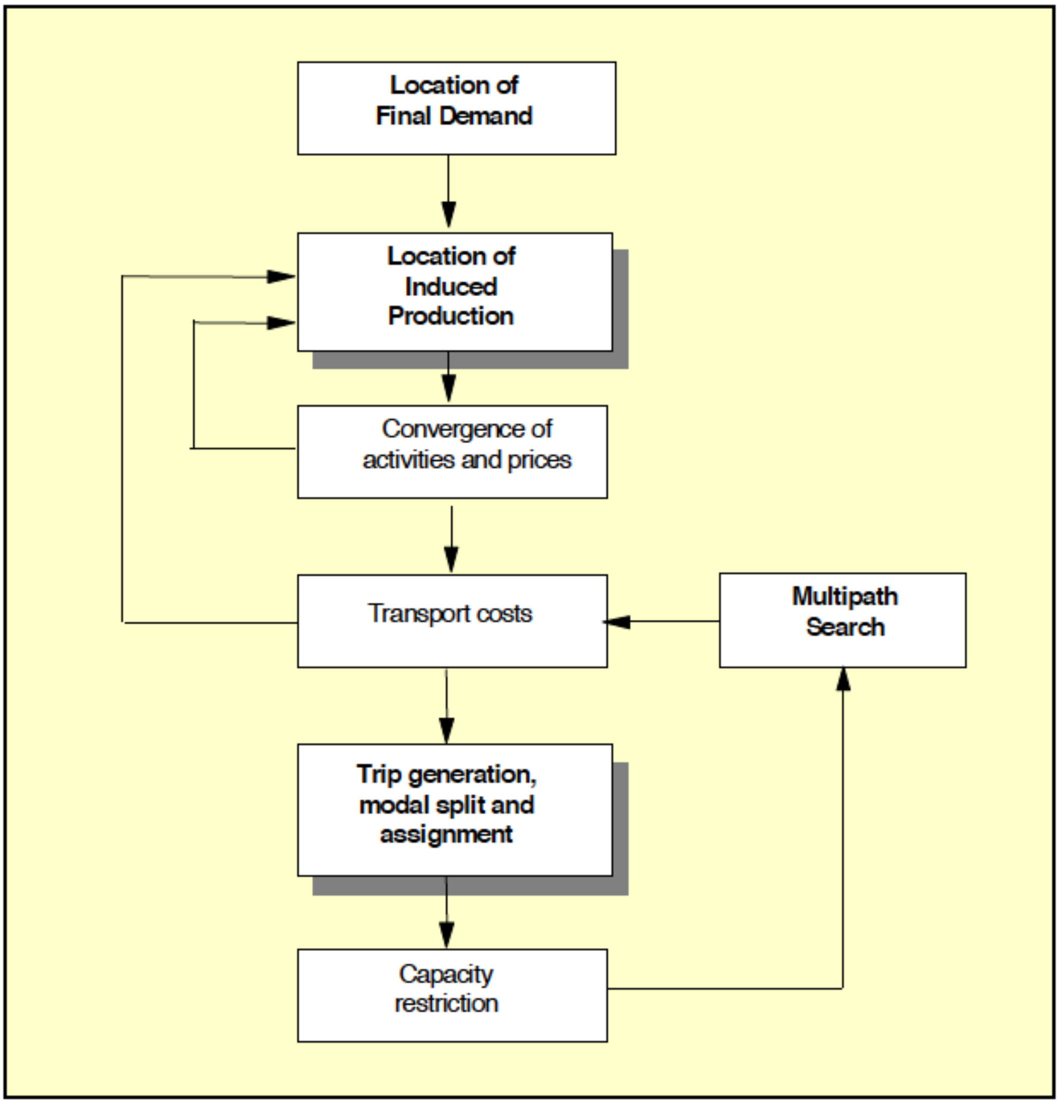

Figure 12 Sequence of calculations in TRANUS. Source: (de la Barra 2011, p. 8)

2.4.4 PECAS

PECAS is a modelling framework for interactive land-use/transport modelling, which is similar to MEPLAN. PECAS stands for Production, Exchange and Consumption Allocation System (Hunt and Abraham 2005). The model description provided follows Hunt and Abraham (2005), Johnston and McCoy (2006) and Zhong, Hunt et al (2007). To date there are three state-wide applications of the PECAS model (Ohio, Oregon and Alberta). Furthermore PECAS is a generalisation of the spatial input-output modelling approach used in MEPLAN and TRANUS described in sections 2.4.2 and 2.4.3.

The PECAS modelling framework consists of three modules, activity allocation (AA), space development (SD) and transport supply (TS) (see Figure 13).

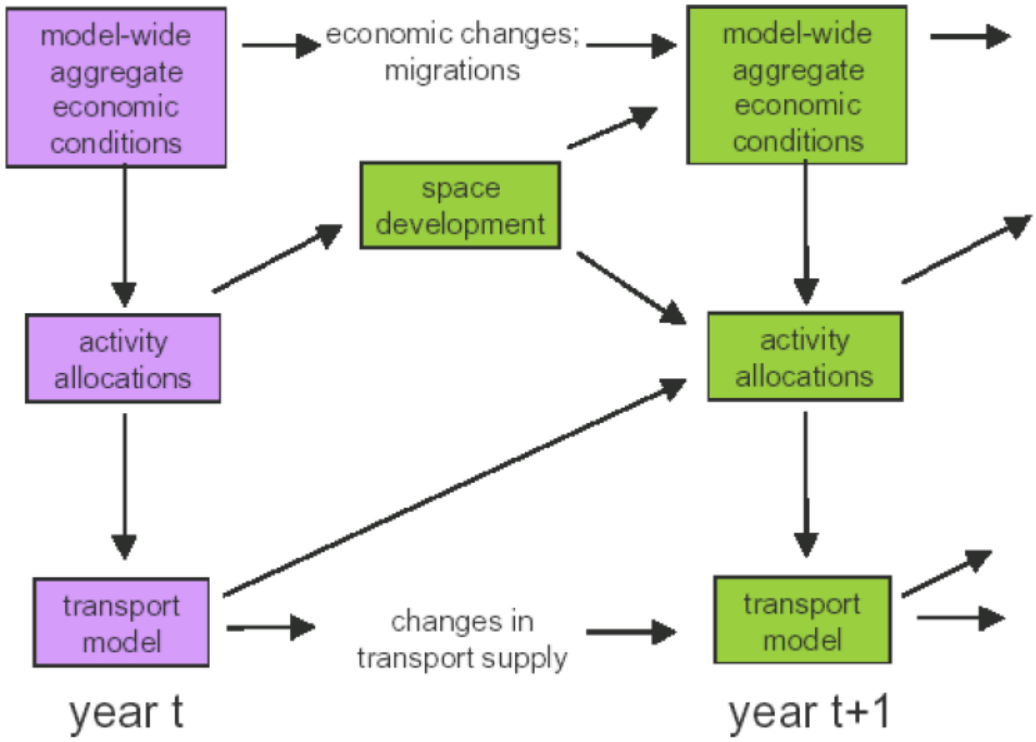

Figure 13 Structure of the PECAS framework. Source: (Johnston and McCoy 2006)

The activity allocation (AA) is an aggregate allocation system for allocating the total activities[14] provided in the spatial regional economic model to zones. It uses a nested LOGIT representation of three types of choice. The first choice, at the highest level of the LOGIT system, is the choice of location for activities. The middle relationship is the choice of how much of which "commodities"[15] to produce (make) and consume (use) per unit of activity. The third relationship is the choice of where to exchange the commodities and the quantities produced and consumed. It implies a choice to travel or to have goods or services shipped, and the utility of these lowest level alternatives includes a calculation of transport cost or disutility using the attributes of travel calculated by the transport supply module. The three levels are connected in both directions from level one to three

[14] Business activities in PECAS are industries based on the North American Industry Classification System. Further several household categories are included.

[15] Commodities in PECAS include categories of goods, services, labour, land and floor space.

and three to one, so production, consumption and location are all influenced by prices and transportation conditions. Prices are established to clear the market for each commodity in each zone. The outputs of the (AA) module are, among other things, a landscape of prices by commodity, flow matrices by commodity and the locations of activities.

The second module, the space development (SD) represents longer-term space development processes. The prices for floor space types coming out of the (AA) module are used, together with an inventory of land characteristics, to calculate expected profits for developers by development type for each unit of land. These expected profits are used as utility functions in a LOGIT model of the choice to be developed.

The third module is the transport supply (TS). It considers the transport disutility of competing modes. It normally includes two sub-modules for modelling household travel and commercial movements. The (TS) module interacts with the (AA) module by changing the disutility of transporting costs. Theses travel conditions by mode form the basis of the influence of the transportation system on the attractiveness of zones as locations for different activities. The trip distribution is finished inside the (AA) module (rather than inside the transport module) and the trip generation is done in the regional economic model by assuming a certain growth rate. The exchanged quantities between activities in zones are assigned to different modes and networks to calculate the transport and travel disutility within the (TS) module.

The model runs in a time step of 1 year. For each time step, the (SD) module runs first to update the inventory of developed space, the (AA) module deals with the short term spatial economic equilibrium of activities and commodity flows, then the (TS) module runs.

2.4.5 Classification of MARS within the described models

At an abstract level there are two basic methods for linking land-use with transport in a combined model (Zondag 2007):

1. "connected": the spatial distribution of population and employment determined in the land-use model are fed as activity totals into the trip

generation step of the transport model; the transport model performs the classical four steps, including trip distribution in particular

2. “integrated”: the spatial distribution of flows of economic interactions between activities determined in the land-use model are fed as origin and destination movements into the transport component and the transport model performs the remaining steps.

One of the models described can be referred to as a “connected” model, this is TIGRIS respectively TIGRIS XL. MARS Austria can also be classified as the “connected” type.

Three of the models described are “integrated” models; these are MEPLAN, TRANUS and PECAS.

MEPLAN, TRANUS and PECAS are spatial input-output models. They are equilibrium models of transport and activity location separately (Wegener 2004). In MEPLAN, PECAS and TRANUS transport and location are simultaneously determined in spatial-interaction location models in which activities are located as destinations of trips. MEPLAN, PECAS and TRANUS incorporate industries and households as consuming and producing “factors” resulting in goods movements or travel (Wegener 2004).

MEPLAN uses a nested LOGIT structure in the transport model. The transport model of TRANUS uses standard LOGIT and PROBIT models. The activity allocation (AA) in PECAS uses a three level nested LOGIT model, the space development (SD) also uses a LOGIT model, and the transport supply (TS) is a discrete choice model, too.

In TIGRIS and TIGRIS XL the location choice is also modelled as nested LOGIT. The National Transport model (NMS), too, is based on a set of discrete choice models in the LOGIT form. TIGRIS XL is not an equilibrium model, but uses a dynamic approach, focusing on the incremental changes (Zondag 2007).

MARS Austria in comparison is a system dynamics model, which makes it related to TIGRIS XL. Furthermore it is based on discrete choice in all of the three main sub-models (residential migration, workplace location and the transport model) that use multinomial LOGIT (see chapter 4).

3 THE AUSTRIAN TRANSPORT PROGNOSIS 2025+

This chapter presents the transport prognosis 2025+ for Austria. This prognosis is based on a network model from the Austrian Ministry of Transport, Innovation and Technology. The chapter will focus on passenger transport. The scope, methodology, basic assumptions, description of the transport model and prognosis results are outlined.

The presented framework for modelling the transport prognosis 2025+ is similar to the PECAS modelling framework (see section 2.4.4). It consists of several models, calculating the activities allocations, which are connected to the transport modules (trip generation, trip distribution, mode choice and assignment).

The transport prognosis 2025+ is the only forecast for the time horizon 2025 – 2050 for Austria performed so far. The modelling approach in this thesis is hence the second approach predicting transport behaviour and emissions for Austria for different policy scenarios. The prognosis output covers behavioural indicators as well as predicted CO_2 emissions. In chapter 9 (section 9.3) the transport prognosis results will be compared to the MARS Austria results.

3.1 Transport Prognosis 2025+

The Austrian Ministry for Transportation, Innovation and Technology (bmvit) commissioned the transport prognosis 2025+ in 2009. The prognosis should cover the time span until the year 2025 in more detail and until 2050 in global figures. Several different institutions worked on compiling the prognosis. The information covered in this section is taken from the final reports (Reports 1, 3, 4 and 7) of the transport prognosis 2025+ (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, Endbericht Teil 1, 3, 4 und 7).

3.1.1 Scope and methodology of the prognosis 2025+

The prognosis covers the whole territory of Austria on a municipal basis and all modes of transport. Before starting the actual modelling work, several working steps had to be completed. The chronology of the generation of the transport prognosis was as follows:

1. Economic analysis and construction of an econometric input-output model for Austria: the actual economic situation and the economic prognosis are the main input for the transport sector. The total transport demand and future development are determined by the economic analysis.
2. Structural data and prognosis (population, workplaces): analysis of the prognosis of population and workplaces for Austria on a municipal basis.
3. Setup of the transport model for passenger transport
4. Setup of the transport model for freight transport
5. Model calculations for the status quo
6. Definition of scenarios (cf. section 3.1.3)
7. Model calculations for the defined time horizons and scenarios

In the transport sector six models in total were used:

1. Trip generation model
2. Trip distribution model
3. Mode choice model
4. Assignment model
5. Network model
6. Transit traffic model

For the economic sector six models were applied as well. All in all, 83 different models were used to generate the transport prognosis 2025+.

3.1.2 Foundations of the prognosis 2025+

The prognosis is based on very detailed data and assumptions about the following:

- population development (per federal state),
- overall economic development,
- structural composition of the economy,
- transport intensities of the different branches,

- foreign trade development,
- development of education in Austria,
- levels of motorization (per federal state and provincial capital cities), and
- overall megatrends.

Key drivers for determining the transport behaviour in MARS are the levels of motorization as well as overall megatrends. For comparability reasons these assumptions are described in more detail in the following.

3.1.2.1 Level of motorization

The prognosis 2025+ worked with its own level of motorization prognosis per district level. The districts of Austria were clustered in 14 groups. The foundation is a growth function (Gompertz-function) with an assumed saturation point. The saturation points were given for three different categories of districts:

1. Vienna: 650 vehicles / 1,000 inhabitants
2. Large cities: 750 vehicles / 1,000 inhabitants
3. All other districts: 850 vehicles / 1,000 inhabitants

The authors point out that the prognosis of the level of motorization is based on a projection of on-going trends. Figure 14 shows the development of the level of motorization over time. The Gompertz-function is defined as a mathematical function having an “S”-shape.

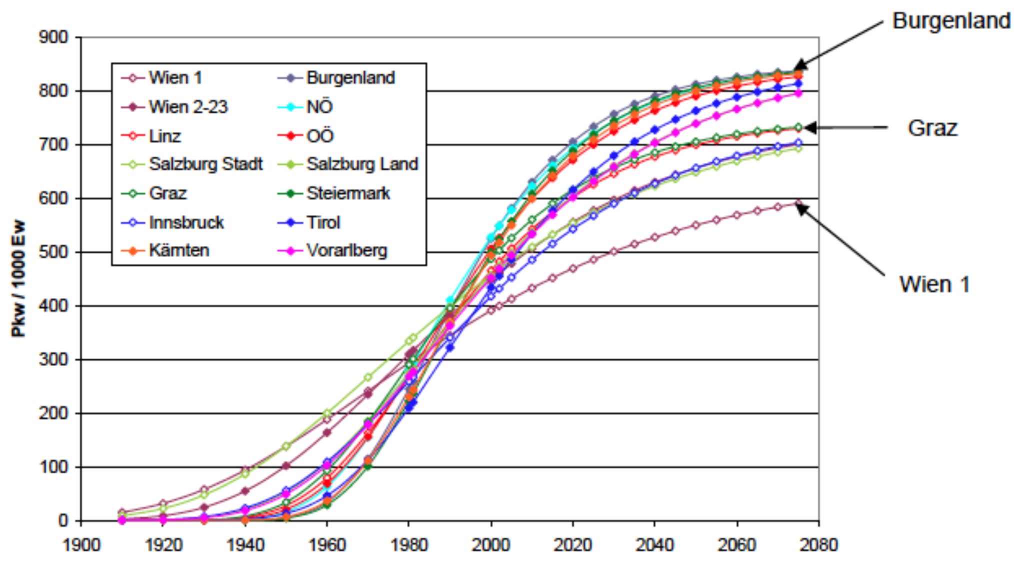

Figure 14 Development of the level of motorization in the transport prognosis Austria 2025. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p. 41)

The level of motorization in Austria in 1965 was 109 vehicles per 1,000 inhabitants and in 2005, it was 507 vehicles per 1,000 inhabitants (Herry, Sedlacek et al. 2007).

Table 6 shows the car stock development over time for the two different scenarios modelled that will be described in section 3.1.3.

Number of cars	2010	2015	2025
Scenario 1	4,700,781	5,077,851	5,551,887
Scenario 2		4,786,044	5,114,435

Table 6 Car stock in the prognosis 2025+, years 2010, 2015 and 2025. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009), own representation.

3.1.2.2 Overall megatrends

The authors state that the crude oil reserves will have declined by 2050. However, possible oil shortages are compensated through efficiency gains in the combustion technology sector and through the usage of alternative fuels. Moreover, they predict rising energy prices, though not a substantial shift towards alternative fuels. A noticeable shortage of oil and rise of the oil price is starting just in the second half of the time frame (after 2025).

They define two scenarios following these assumptions.

In the first one, the shortage of oil leads to a rise in price, but the effect is compensated through efficiency gains in the combustion technologies and the use of alternative fuels, keeping the prices constant.

The second scenario assumes a rise in oil price which increases the costs for car users by 30% until 2025.

3.1.3 The scenario definitions - prognosis 2025+

The prognosis depicts two possible development paths. **Scenario 1,** characterized by an extrapolation of the trends of the recent years, is a “business as usual” scenario.

Scenario 2 assumes rising costs for the car user, infrastructure measures in the public transport sector and more moderate developments of the levels of motorization.

Both scenarios assume an increase of road capacities following the planned infrastructure measures in 2005. Apart from that, the planned rail infrastructure projects and the resulting railway schedules are taken into account.

3.1.3.1 Cost

The cost for private motorized traffic covers:

- running expenses of the car,
- distance dependent road charges and
- the parking cost at the destination.

For public transport, the ticket costs vary depending on different user groups, modes of public transport and distances.

Cost components - car	Unit	Prognosis
Running expenses of the car	Euro/km	0.11
Distance dependent road charges	Euro/km	0
Parking cost at the destination	Euro/h	0.80
Cost components – PT		
Ticket price (adults)	Euro/km	0.083 - 0.092 (average)

Table 7 Cost components considered in the transport prognosis. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009)

Table 7 shows the cost components considered in the transport prognosis Austria 2025+. In scenario one the prices remain constant in real terms, while in scenario two the prices rise by 30% in real terms for the PMT and by 40% for public transport until 2025.

3.1.4 Model structure - transport model Austria

The transport model Austria used for the prognosis consists of three main models:

- Network model
- Passenger transport demand model
- Freight transport demand model

The network model is built on zoning, which refers to the origin or the destination of the trips. The model consists of 2,381 zones, more or less covering the communal districts. The network model contains an integrated net graph covering the transport infrastructure of road, rail and public transport timetables.

The model calculates friction factors for the different modes (see section 4.4.2). The time parts of the friction factor for public transport, for example, are weighted with constant values. For the model, it makes no difference whether the next public transport stop is five or ten minutes away, in the friction factor calculation the time (access/egress) is always weighted with a constant factor of 1.5, for example.

The passenger transport demand model follows the classical four step approach (Ortùzar and Willumsen 1994; Hensher and Button 2000).

In a first step trip generation is calculated from structural data, in the form of population (by cohort group, occupation, car availability and model zones). The model differentiates for “home-bound” trips (differing between 85% - 95% for each group) and non “home-bound” trips.

Secondly trip distribution is calculated. The attraction of a zone is based on structural data like working places, which in turn are determined by the economic development modelled in the spatial input-output model.

In the third step the trips are assigned to the different modes of travel. The transport supply is represented by the state of the transport networks and considers public transport by timetables and cost.

Finally, the forth step is the traffic assignment where the trips are assigned to certain public transport lines or routes for the road transport.

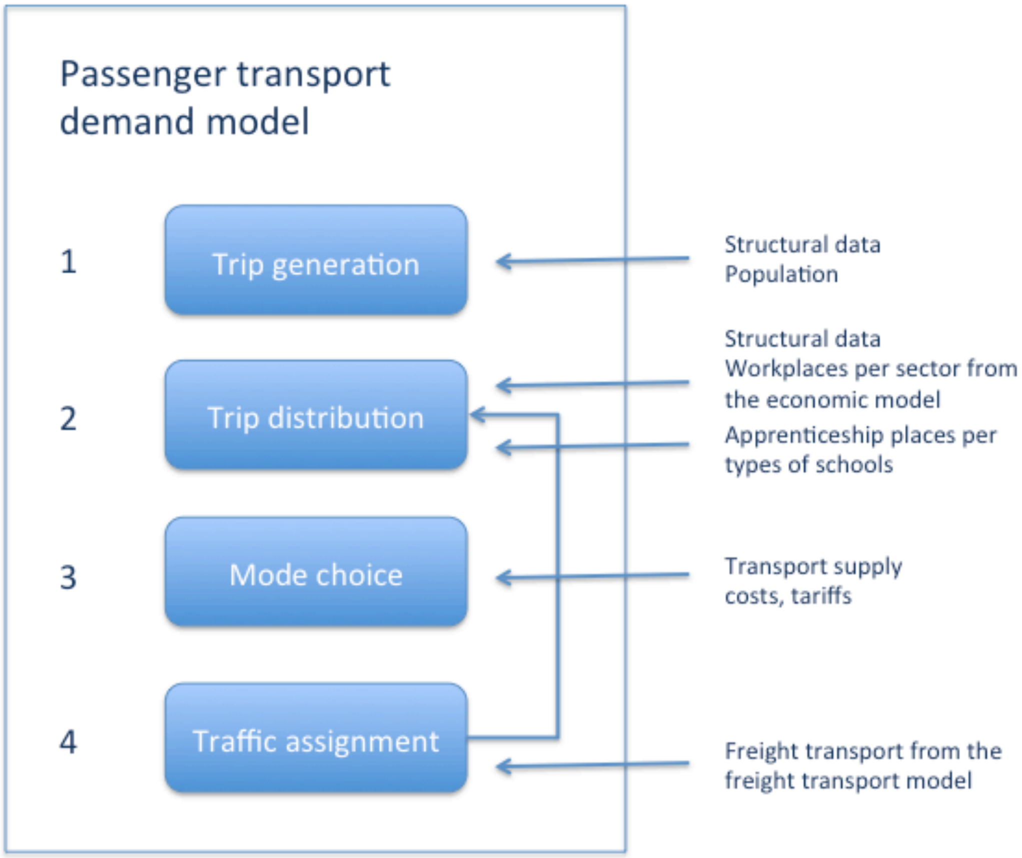

Figure 15 Passenger transport demand model – transport prognosis 2025+. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p. 23), translated into English by the author.

3.1.5 Results of the passenger transport prognosis 2025+

Figure 16 shows the modal split for scenario 1 of the two scenarios described in section 3.1.3.

The modal shares[16] remain relatively constant until 2025. The modal split of cars will increase to 60% between 2010 and 2015, while the share of pedestrians and cyclists will decrease by 1%.

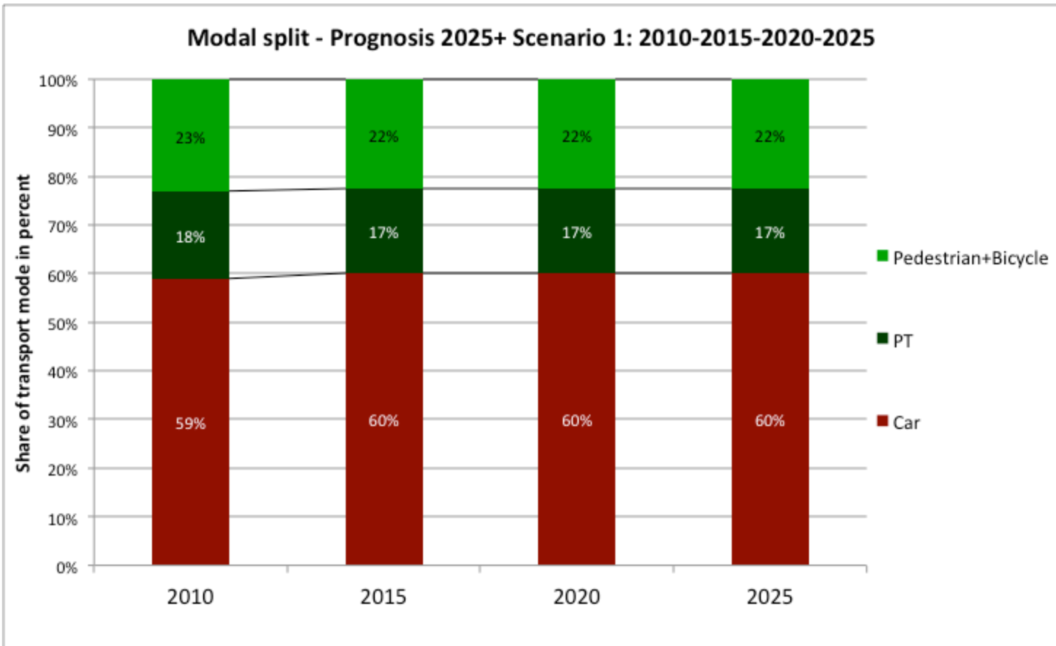

Figure 16 Modal split - Prognosis 2025+ scenario 1, years 2010, 2015, 2020 and 2025. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009), own representation.

Figure 17 presents the modal split for scenario 2. The more moderate development of levels of motorization combined with rising car-user cost (see section 3.1.2.1 and 3.1.3.1) leads to a small reduction of the car share by 1%.

[16] percentage share of trips with these modes of transportation

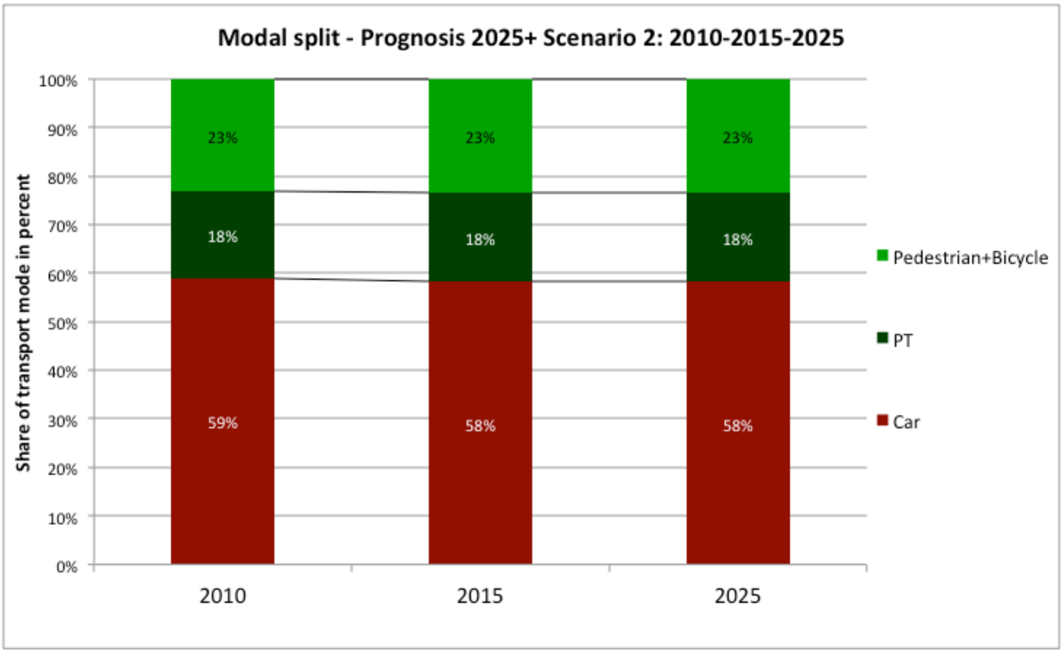

Figure 17 Modal split - Prognosis 2025+ scenario 2, years 2010, 2015, and 2025. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009), own representation.

Figure 18 and 20 present the development of the passenger kilometres per mode for the scenarios 1 and 2. It can be seen that there is an increase in passenger kilometres for both scenarios, while the increase is smaller in scenario 2.

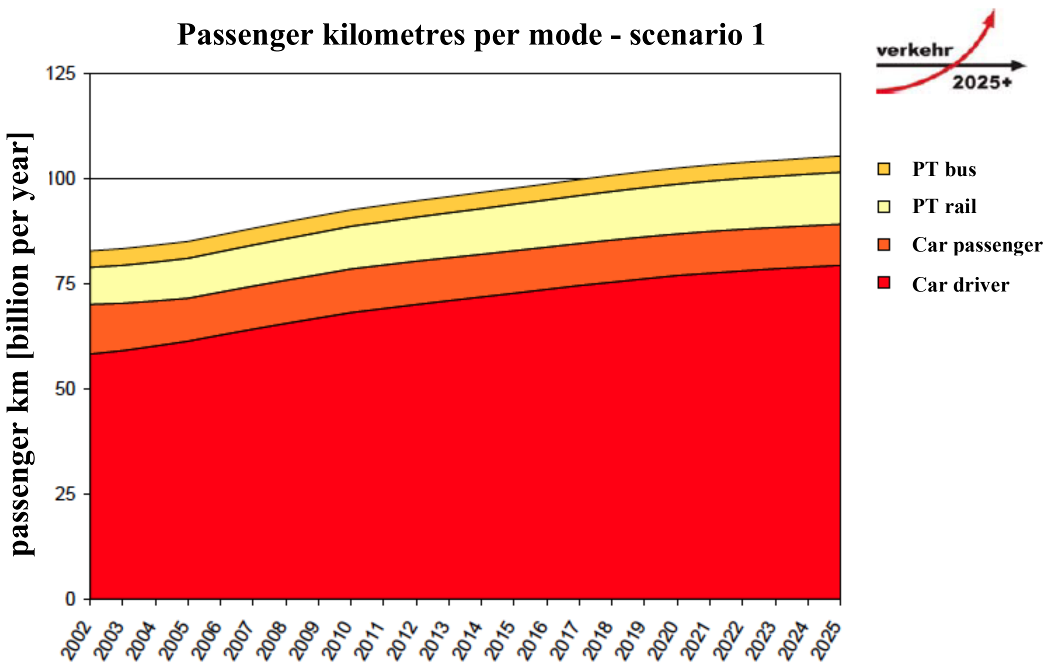

Figure 18 Passenger kilometres - prognosis 2025+ scenario 1. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p.38)

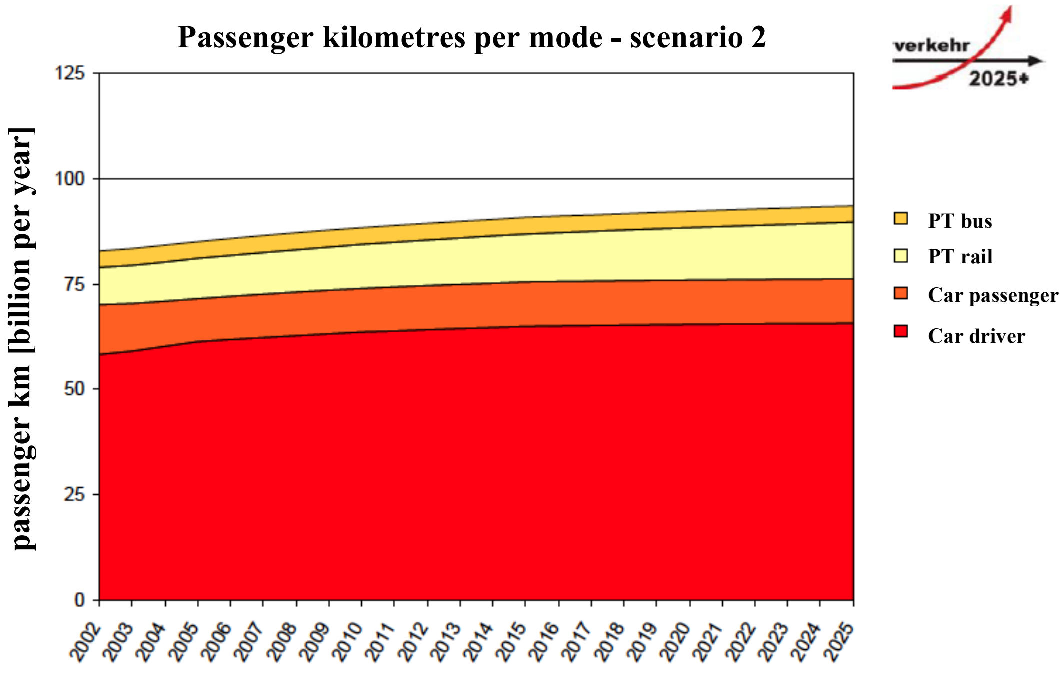

Figure 19 Passenger kilometres - prognosis 2025+ scenario 2. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p.38)

The last result presented here is the development of CO_2 emissions in the passenger transport sector.

CO_2 emissions passenger transport [tonnes per year]	2010	2015	2020	2025
Scenario 1	11,406,000	11,434,000	10,950,000	10,564,352
Scenario 2		9,262,000		7,792,000

Table 8 CO_2 emissions passenger transport prognosis 2025+ in tonnes per year

In scenario 1, the CO_2 emissions in 2010 are 11,406,000 tonnes and they decrease to 10,564,352 tonnes in 2025. This corresponds to a reduction of 7.4%.
In scenario 2 no values are given for 2010 and 2020. Comparing the values for 2015 and 2025, the CO_2 emissions are reduced by 15.9% reaching 7,792,000 tonnes in 2025.

In my opinion the reductions in emissions in scenario 1 is the result of reductions for the specific CO_2 emission factors (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p.24) and the decrease in average trip lengths (TRAFICO - Verkehrsplanung

Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p.39).

In scenario 2 the effect described for scenario one is enhanced by the slight modal shift (decreasing car trips) and an even bigger reduction in average trip length (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p.39). But still the factor influencing the emission reduction the most is the assumed emission factor in scenario 2 (113,35 g/km).

4 THE DEVELOPMENT OF THE MARS MODEL – STRUCTURE AND MAIN SUB-MODELS

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 is either currently set up or has been applied to 13 European cities (Edinburgh, Gateshead, Leeds, Madrid, Trontheim, Oslo, Stockholm, Helsinki, Vienna, Bari, Mulhouse, Strasbourg and Almere), 6 Asian cities (Hanoi, Ubon Ratchathani, Bandah Aceh, Chiang Mai, Bangkok and Ho Chi Minh City), 1 South American city (Porto Alegre) and 1 US American City (Washington D.C).
The model description in this thesis will focus on the overall model structure and some specific modules relevant for the nationwide setup of MARS Austria. As for the detailed description of the changes in model structure for the nationwide case study a separate section (5.3) is provided in chapter 5. For a detailed model presentation of the urban MARS model I refer the reader to Paffenbichler (2003; 2008). Most of the MARS models and MARS Austria are implemented with a simulation software called Vensim (see section 1.4.3). It is a software for modelling dynamic feedback systems widely used among the system dynamics (see chapter 1.4.3) modelling community.

MARS can be divided into six major parts:

1. Data input module
2. Policy input module
3. Transport model
4. Land-use models
5. Emissions/Fleet composition model
6. Output module

Firstly the model purpose is described and secondly each of the 6 major parts is explained in detail.

4.1 Model purpose

The main purpose of the MARS model is to capture the most important feedback loops between the transport and the land-use system. The MARS model consists of sub-models which simulate passenger transport (transport sub-model), housing development, household migration (residential location sub-model) and workplace migration (workplace location sub-model). As described in section 2.1, the transport system is linked to the land-use system via accessibilities.

These accessibilities (formulated as potential to reach workplaces and shopping opportunities) are passed on from the transport sub-model to the residential location- and workplace sub-model, and the spatial distribution of households and employment are an input from the residential location- and workplace sub-model to the transport sub-model. Land price influences both the residential location- and the workplace sub-model and these two sub-models change the availability of land.

Equation 1 presents the accessibility calculation used in MARS Austria.

$$ACC_i^m = \sum_{j,sector} \left(WP_j^{sector} * a + b * f(t_{i,j}^m) + c * f(t_{i,j}^m)^\wedge 2\right)$$

Equation 1 Calculation of the workplace accessibility in MARS

WP_j^{sector}	Workplaces in zone *j* per sector (production service)
$f(t_{i,j}^m)$	Friction factor per mode from *i* to *j*
a	Weighting factor *a*[17]
b	Weighting factor *b*
c	Weighting factor *c*

Accessibility in the year n is used as an input into the location choice models in the year n+1. Workplace and residential location is an output to the land-use

[17] The values of the weighting factors are derived from a study of the Research Centre of Transport Planning and Engineering of University of Technology Vienna on behalf of the Viennese Municipality Department 18. Source: Knoflacher, H. (1997). Untersuchung der verkehrlichen Auswirkungen von Fachmarktagglomerationen. Maria Gugging, Wien, Magistratsabteilung 18.

model. The number of workplaces and residents in each zone in the year n is used as attraction and potential in the transport model in the year n+1. There are also links between the land-use sub-models as they are competing for land, the availability of land influencing its price.

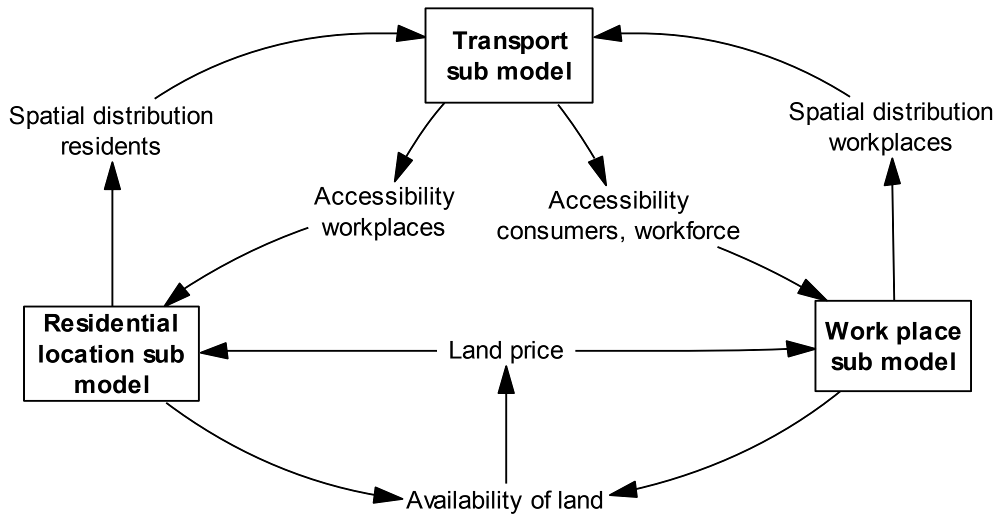

Figure 20 The three main sub-models and their linkages. Source: (Mayerthaler, Haller et al. 2009)

To explain the described feedback mechanism the model offers indicators of the transport behaviour and the spatial distribution of residents and workplaces per model zone for all steps in time. This allows for predictions about the spatial distribution of population and workplaces for the future.

Another main model purpose is the prediction of the influence of certain scenarios (policy simulation) on the transport behaviour as well as migration of residents and workplaces. Via the policy input module (see section 4.3), it is possible to define policy scenarios concerning changes in the transport or the land-use system. These changes are an external input to the model, and allow for policy testing.

MARS iterates in a time lagged manner between the transport and the land-use model over a period of time, normally 30 years.

4.2 Data input module

In the data input module, the trends for the future underlying the case studies can be defined. For example, in most case studies accomplished so far, a certain population growth was implemented. Moreover, the extent of economic growth or decline is defined.

In general, the input module captures the predefined trends, which have to be taken into consideration for the specific case studies. Additionally, infrastructure projects, like ring roads or public transport schemes can be considered in the data input module.

The data input module contains all information necessary to run the model. All external data that are depicted in the model structure take the values/information from the data input module.

4.3 Policy input module

The policy input module is designed as a separate view in the Vensim implementation of the model. Its purpose is to handle the policy profiles of the implemented policy instruments over time. The user can define a certain starting point and end for each policy instrument, as well as the magnitude. At the moment, 19 different policy profiles are implemented in MARS Austria. For example, it is possible to define that in year 5 of the simulation the policy instrument "increase of parking fees in zone i" is set at +20%. In the year 10 of the simulation the increase of the parking fees in a certain zone could go up to +30% and then remain constant at this level until the end of the simulation period. 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.

4.4 The transport sub-model

The transport model in MARS simulates passenger transport and comprises trip generation, trip distribution and mode choice.

In the trip generation, the number of trips originating in or designated for a particular model zone are calculated. The trip distribution allocates the total number of trips to all origin-destination (OD) pairs and the mode choice is the distribution of the trips to the different modes of traffic, normally specified as percentage share. Trip distribution and modal split are calculated simultaneously by a gravity type model.

These elements are the first three steps of the classical four step transport model (Ortùzar and Willumsen 1994).
It considers all relevant regional modes of transport:

- Walking and cycling (slow)
- Public transport rail (PT rail)
- Public transport bus (PT bus)
- Electric cars and plug-in hybrids (E-car)
- Car

The slow mode represents the non-motorized modes of walking and cycling. Depending on the zone size in the MARS model application, this mode is almost exclusively relevant for intrazonal trips (when MARS is applied in a national context). On an urban level walking is also relevant for "external" trips among the zones (where zones have a smaller diameter of about 3 km). MARS is designed as a daily commuting model, and in this sense it distinguishes between different times of day (peak and off-peak) and two trip purposes, which are commuting and others (shopping, leisure,…).

One output of a single simulation step of the transport model are accessibilities, formulated as potential to reach workplaces and shopping opportunities between different zones, which in turn is input for the land-use sub-model.

4.4.1 Trip generation sub-model

Two types of activities are considered in MARS: work and others. A tour in MARS is defined as the succession of a trip to a destination and a return trip from a destination to home. This results in four origin destination groups and two types of tours:

- Home – Work (HW)
- Work – Home (WH)
- Home – Other (HO)
- Other – Home (OH)
- Home – Work – Home (HWH)

- Home – Other – Home (HOH)

The tours HWH cover all commuting trips, whereas the tours HOH comprise all other trip purposes (business, shopping, leisure,…)

According to a survey from 1995 these two tour types considered cover about 77% of the Viennese hinterland and about 71% of Viennese mobility (Herry, Sedlacek et al. 2007). A newer survey from 2004 for the city of Salzburg shows a coverage of 65% for these two tour types (Herry, Sedlacek et al. 2007). It is assumed that about the same high percentage shares are valid in Austria for the other cities with their hinterlands. There are no data about rural regions in Austria, but it is assumed that the shares given above are also valid for rural areas.

The main assumption underlying the transport model is the constancy of travel time budgets. There are numerous surveys and studies that show that travel time budgets are stable in the course of time, among cities, regions and even nations (Zahavi 1974; Zahavi 1978; Schäfer 1998; Schäfer 2000; Schäfer 2006; Metz 2008; Mokhtarian and Cao 2008). Trip rates per capita and day are assumed to be constant for HWH tours because of the law of constant travel time budgets, contrary to other trip purposes this observation seems to be true for HWH tours (Schäfer 2000). For the calculation of the trips with the purpose work, a constant trip rate is multiplied by the number of employed residents in a zone. Approximately 25% of all trips are trips with trip purpose work, and in 1995 about 3.7 trips per day and per mobile person were made in Austria (Herry, Sedlacek et al. 2007). After the distribution and mode choice for the tours HWH, the trip generation for tours HOH can be run. The total travel time spent for tours HWH is calculated, then a remaining travel time budget per person for tours HOH is calculated. This gives a remaining travel time budget per person. Multiplying this by the number of residents per zone, gives the travel time production for tours HOH. For the sum of the tours HWH and HOH travel time per capita and day is constant.

4.4.2 Trip distribution and mode choice

The transport sub-model distributes trips to destinations as well as modes. The trip distribution and mode choice sub-model is further divided into an HWH- and HOH sub-model.

4.4.2.1 Home-Work-Home tours - HWH

The number of trips per origin zone i is taken as input from the trip generation sub-model (see section 4.4.1). The trip distribution and mode choice sub-model calculates the probability that a destination and mode combination are chosen for a commuting trip from a given origin.

The attraction of a zone j as a destination for a commuting trip (purpose: commuting) is assumed to be proportional to the number of workplaces within that zone. Workplace location is given by the land-use sub-model (see section 4.5). The option in mode choice is determined by the access to a car (based on car and driving license ownership), resulting in two groups of people: those with access and those without access to a car. For people without access to a car/E-car the model considers all other modes (PT bus, PT rail, slow) except car/E-car in the mode choice calculation.

The probability that a commuting trip starting from origin *i* is distributed to destination *j* and mode *m* corresponds to the ratio of attraction to friction factor per mode and destination to the sum of all attractions to friction factors from origin *i*. The friction factors are indicators to measure the subjectively perceived effort in terms of time and money, which is necessary to travel from origin *i* to destination *j*. This corresponds to a gravitational, that is, LOGIT approach.

$$T_{ijm}^{g} = \sum_{p} P_{ip}^{g} * \frac{A_{ip} * f(t_{ijmp})^{-1}}{\sum_{mj} A_{ip} * f(t_{ijmp})^{-1}}$$

Equation 2 Trip distribution and mode split calculation

T_{ijm}^{g} Nr. of trips from i to j made by group of persons g using mode m

P_{ip}^{g} Production of trips at source i for purpose p and group of persons g

A_{ip} Attraction of zone j as destination for purpose p

t_{ijmp} Impedance from i to j by mode m for purpose p

$f(t_{ijmp})$ Friction factor from i to j by mode m for purpose p

The calculation of the friction factors is described in the following section. The friction factors are a function of travel time (including the subjectively perceived time for a journey) and perceived travel cost.

The friction factor calculation in MARS, for the subjective valued part of the journey, is based on works of Walther (1973; 1991; 1997), who found out that people do not perceive time in a constant way. In MARS, a definition using generalized costs weighted by exponential functions is used. Walther argues that an exponential function is appropriate for modelling the subjective valuation because it is a common phenomenon that the very same change of an intensity level of one indicator at different base levels may cause diverse subjective perceptions (Walther, Oetting et al. 1997). These friction factors are calculated for each OD pair.

Below, an example of a friction factor calculation for the public transport (bus or rail is given)[18]:

$$f(t_{ijPT}) = t_{W,to,i} * SV_{W,to} + t_{W,i} * SV_W + \sum t_{DR,ij} + \sum t_{Ch,ij} * SV_{Ch} + t_{W,from,j} * SV_{w,from} + R_{C,ij}$$

Equation 3 Calculation of the friction factor for public transport bus or rail. Source: (Pfaffenbichler 2003, p. 76)

$t_{W,to,i}$ Walking time from source i to public transport stop (min)

[18] For the friction factor calculations for the other modes I refer the reader to Pfaffenbichler, P. C. (2003). The strategic, dynamic and integrated urban land use and transport model MARS (Metropolitan Activity Relocation Simulator) PhD Disertation, Vienna University of Technology. pages 75 – 82.

$SV_{W,to}$ Subjective valuation factor walking time from source to public transport stop

$t_{W,i}$ Waiting time at public transport stop *i* (min)

SV_W Subjective valuation factor waiting time at public transport stop

$t_{DR,ij}$ Total driving time from source *i* to destination *j* (min)

$t_{Ch,ij}$ Total changing time from source *i* to destination *j* (min)

SV_{Ch} Subjective valuation factor changing time

$t_{W,from,j}$ Walking time from public transport stop to destination (min)

$SV_{W,from}$ Subjective valuation factor walking time from public transport stop to destination

$R_{C,ij}$ Impedance from costs travelling from *i* to *j* (min)

The different parts of the journey,

- walking from the source to the public transport stop,
- driving from the public transport stop to the destination,
- changing time and
- walking from the public transport stop to the destination,

are perceived and valued differently by the transport users. This is reflected by the different subjective valuation factors. The modeller defines the walking times for access and egress as well as the changing times exogenously, differentiated for each case study setup. The friction factor for public transport cost (impedance caused by travelling from *i* to *j*) is calculated as followed:

$$R_{C,ij} = \frac{c_{ij}}{\alpha * HHI_i}$$

Equation 4 Calculation of the friction factor for public transport cost. Source: (Pfaffenbichler 2003, p. 78)

c_{ij} Costs for a public transport trip from *i* to *j* (€/trip)

α Factor for value of time

HHI_i Household income in zone *i*

The driving time from source *i* to destination *j,* is influenced by the number of commuting trips. The travel time of a private car is influenced by a speed flow relationship and changes in the parking search time. Travel time of public transport is also influenced by the speed flow relationship and the share of PT operated by busses (which are not independent of the traffic flow).

4.4.2.2 Home-Other-Home tours - HOH

In the trip generation sub-model the travel time available for the purpose "other" per origin zone *i* is calculated (see section 4.4.1).

> "The travel time of trips starting in origin *i* is distributed to destinations and modes corresponding to the ration friction factor per mode and destination to the sum of all attractions to friction factors from origin *i*. The number of trips is calculated by dividing the total travel time per mode and OD pair by specific travel time per mode and OD pair." (Pfaffenbichler 2003, p. 54)

Again, the attraction of a zone *j* as a destination is given by the land-use sub-model. For trips with the trip purpose "other" the attraction is the sum of the population living in the destination zone and the workplaces in the service sector.

4.5 The land-use sub-model and its modules

The land-use model part consists of different sub-models, depicted in different views in the Vensim model implementation. Both the migration of residents and workplaces and the development of new housing units within the case study area are modelled. Furthermore the land consumption needed to build the housing units and firms in each zone is calculated.

The final output of the land-use sub-model after a single simulation step is the actual residents and workplace distribution based on the accessibility information from the transport model part and the market forces within the zones, which are derived from several variables like housing rents or land prices.

4.5.1 The residential migration sub-model

For the residential migration sub-model, the overall population size of the case study area and the assumed population growth scenario serve as input. The allocation process starts from a given distribution for the base year.

In the MARS Austria model, migration is modelled in a two-step approach:
Firstly, the number of out-migrants per model zone is estimated. The average out-migration rate of the whole case study is given; this rate is 0.078 following the migration statistics of Austria from 2001 – 2005 (Statistik Austria 2002; Statistik Austria 2005; Statistik Austria 2005; Statistik Austria 2006; Statistik Austria 2007; Statistik Austria 2007). The zone specific out-migration rate is modelled as:

$$OM - rate_i = om - rate * e^{(\alpha_0 + \alpha_1 HC_j + \alpha_2 ACC_j + \alpha_3 POP_j + \alpha_4 LS_j)}$$

Equation 5 Calculation of the out-migration rate in MARS Austria. Source: (Mayerthaler, Haller et al. 2009, p. 11)

$om - rate$	Average out-migration rate throughout Austria
$\alpha_0 \ldots \alpha_4$	Parameters
HC_j	Housing cost in zone j
ACC_j	Access attractiveness in zone j
POP_j	Population (residents) in zone j
LS_j	Living space in zone j

To calculate the out-migrants (O_i), the zone specific out-migration rate is multiplied by the residents per zone for each time step.

Secondly, a migration destination choice model then distributes the out-migrants to the potential destinations based on characteristics of the destinations and the distance between two zones.

The migration destination choice model takes the form of the well-known gravity/spatial interaction model (LOGIT model). The number of migrants between origin *i* and destination j, M_{ij}, is modelled as:

$$M_{ij} = O_i * \frac{\exp\,(\alpha_0 + \alpha_1 HC_j + \alpha_2 ACC_j + \alpha_3 POP_j + \alpha_4 FUA_{ij}) D_{ij}^{\alpha_5}}{\sum_j \exp\,(\alpha_0 + \alpha_1 HC_j + \alpha_2 ACC_j + \alpha_3 POP_j + \alpha_4 FUA_{ij}) D_{ij}^{\alpha_5}}$$

Equation 6 Calculation of migrants between zone *i* and *j*

O_i Out-migrants of zone *i*

$\alpha_0 \dots \alpha_5$ Parameters

HC_j Housing cost in zone *j*

ACC_j Access attractiveness in zone *j*

POP_j Population (residents) in zone *j*

$FUA_{i,j}$ Dummy for functional urban areas origin *i* and destination *j*

D_{ij} Distance between the zones of origin *i* and destination *j*

Migration to a zone is constrained by the availability of housing units (flats). Residents desiring to move to zones with excess demand are transferred to the pool of in-migrants of the subsequent period.

The living costs are approximated by housing cost (HC_j) (in Euro per month); housing cost constitutes a major source for living cost differentials.
Access attractiveness (ACC_j), formulated as the potential to reach workplaces and shopping opportunities, presents the zone's potential for activity participation.
Furthermore, a determinant for the attractiveness of a zone is the number of residents (POP_j) living in the zone since the last time period.

The zone dummy for the same functional urban areas (FUA_{ij}) was applied only for the Austrian case study. It tries to capture core-hinterland relations that result in migration patterns which could not be explained by the variables already considered. Functional urban areas based on patterns of major commuting catchment areas are defined. Inter-district relations within the same FUA are singled out in the estimation using this dummy variable (Mayerthaler, Haller et al. 2009).

Moreover, the distance between the zones (D_{ij}) of origin *i* and destination *j* is applied only to the nationwide case study, MARS Austria.

The choice of variables considered (accessibility by car and public transport, level of housing costs and the distance between the zones) was based on the following lines of argument: Firstly, they repeatedly rank among the most important determinants of migration in empirical migration research (ODPM 2002; Fotheringham, Rees et al. 2004). Secondly, separate empirical studies focusing in particular on Vienna confirmed this importance (Pfaffenbichler 2003).

4.5.2 The workplace location sub-model

The workplaces migration sub module has a structure that is 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 (access attractiveness),
- The existence of building land (land availability),
- The cost for building in a zone (land price),
- The average household income.

Again, access attractiveness, formulated as potential to reach workplaces and shopping opportunities, presents the zone's potential for activity participation. The possibility to build in a zone is only restricted by the limits of land availability in a zone. The cost of building in a zone is determined 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, and identified by means of empirical studies. In a study for the Netherlands, Pellenbarg (2005) lists an average percentage of firm relocations of 7.7% for the year 2002. He also shows that the service sector is the most mobile sector. Pellenbarg also introduces another study by van Steen (van Steen 2005), who observed 2000 firms from 1998 to 2003, where the percentage of firm relocations was between 5.3% and 6.3% for these years.

In Austria this kind of data are missing. For the MARS Austria case study an average time workplaces move of 17.5 years for the service sector and 28.5 years for the production sector is assumed. This corresponds to an average percentage of firm relocations of 5%.

The total number of workplaces in the study area multiplied by the reciprocal of this average time workplaces move gives the total number of out-movers in the study area.

In a next step, the attractiveness to move out of a certain zone is calculated. This is modelled in an exponential function, separately for each sector:

$$Attr_j^{out} = e^{(\alpha_1 * ACC_i + \alpha_2 * land\ price\ attr._{i,sector} + \alpha_3 HHI_i)}$$

Equation 7 Attractiveness to move out for workplaces. Source: (Emberger, Mayerthaler et al. 2010, p. 6)

$\alpha_0 \dots \alpha_3$ Parameters

ACC_i Access attractiveness in zone i

$land\ price\ attr._{i,sector}$ Land price attractiveness per zone i and sector (production/service)

HHI_i Household income in zone i

The in-moving workplaces are defined similarly 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-allocation and newly developed workplaces to the different locations using again a LOGIT model:

$$WP_i^{in} = WP_i^{potential} * \frac{\exp\left(\alpha_0 + \alpha_1 ACC_j + \alpha_2 land\ price\ attr._{j,sector} + \alpha_3 land\ available\ attr._{j,sector} + \alpha_4 HHI_j\right)}{\sum_j \exp\left(\alpha_0 + \alpha_1 ACC_j + \alpha_2 land\ price\ attr._{j,sector} + \alpha_3 land\ available\ attr._{j,sector} + \alpha_4 HHI_j\right)}$$

Equation 8 Workplaces moving in.

$WP_i^{potential}$ Potential workplaces moving in (re-allocating and newly developed)

$\alpha_0 \dots \alpha_3$ Parameters

ACC_j Access attractiveness in zone j

$land\ price\ attr._{j,sector}$ Land price attractiveness per zone j and sector (production/service)

$land\ available\ attr._{j,sector}$ Attractiveness from land availability per zone j and sector (production/service)

HHI_j Household income in zone j

4.5.3 The housing development sub-model

For each time step, MARS estimates a certain number of residents who want to move into a model zone. The land development sub-model checks whether there is enough available building land in the zones to construct new housing units. In the housing development sub-model new housing units are planned and constructed, dependent on the number of people who want to move into a zone, the availability of land and the housing cost. A housing units stock is built up and another stock stores the unsatisfied demand for housing units that may have arisen.

In the MARS model, developers decide whether to build new housing units and if so, how many and where. 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.

Figure 21 shows the causal loop diagram which describes the attractiveness of developing in a certain zone. As already mentioned above, the attractiveness for a developer to develop in a given zone is determined by the rent which can be achieved. The rent is determined by the excess demand for housing, which in turn is related to the planned housing units and, with a time lag, to the housing stock. As new houses are planned and built, the housing stock increases and this reduces the excess demand for housing which then reduces the rent to be achieved, which reduces the attractiveness to develop. This is the balancing loop B1. Loop B2 represents the restriction of land available to build on. The more housing units are planned, the less land available, which reduces the attractiveness to develop. Or vice versa - the more land is available, the more attractive is a certain zone to develop in. Loop B3 extends loop B2 to represent the effect of land availability on land price. The more land is available, the lower is the land price, which increases the attractiveness to develop.

Loop R1 is a reinforcing loop. Newly built houses reduce the excess demand for housing. With a time lag, this in turn reduces the rent in a zone and hence the land price, which makes development more attractive - all other things being equal. At the bottom of Figure 21, the influencing factors of the demand for housing are shown.

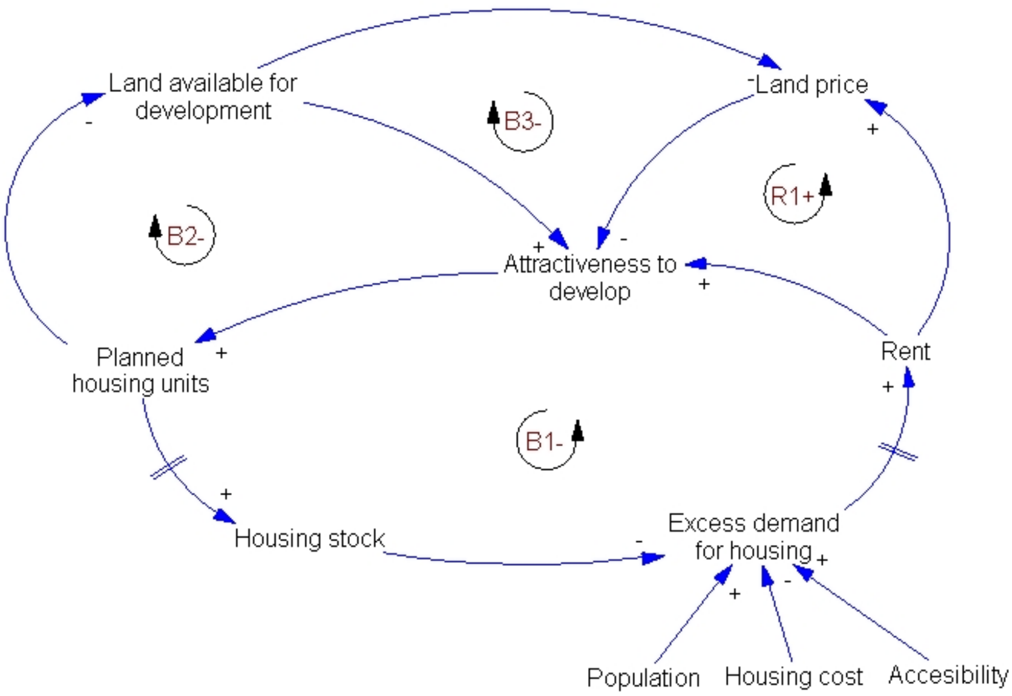

Figure 21 CLD: Attractiveness to develop housing units. Source: (Pfaffenbichler, Emberger et al. 2008)

4.6 Emission/Fleet composition model

The emission/fleet composition model is a combination of an external input data file, defining the development of fuel prices and vehicle fleet, and a model part within MARS calculating the emissions. MARS considers greenhouse gas emissions as well as nitrogen dioxide and particulate matter. The output of this model comprises the emissions per year and/or km for the modes car and public transport.

4.7 Output indicator calculation model

Implemented in the model structure, a series of output indicators are calculated to describe the overall land-use/transport system behaviour. The model calculates modal split shares per means of transport and time of day (peak and off-peak), fuel consumption, average travel times per means of transport, travel time savings, accident costs, and CO_2 emissions, just to mention the most important ones. Output of the land-use model is for example the population- and workplace distribution per zone. Some variable values can also be displayed regarding their development over space and time using the dynamic GIS tool AniMap (see section below). These output indicators can then be used for cost-benefit analysis (CBA) and/or multi-criteria analysis (MCA).

4.7.1 AniMap

AniMap is a computer software which can be used with Mozilla Firefox designated to visualize the MARS output on a map. This way the model output can be presented in an easy understandable way to policy makers and stakeholders.

The key feature is that AniMap, as the name indicates, animates the map over the modelled time period so that changes over time can easily be seen. AniMap also has a function to compare different scenarios on one screen with an animation. With all these features, different scenarios can easily be compared visually.

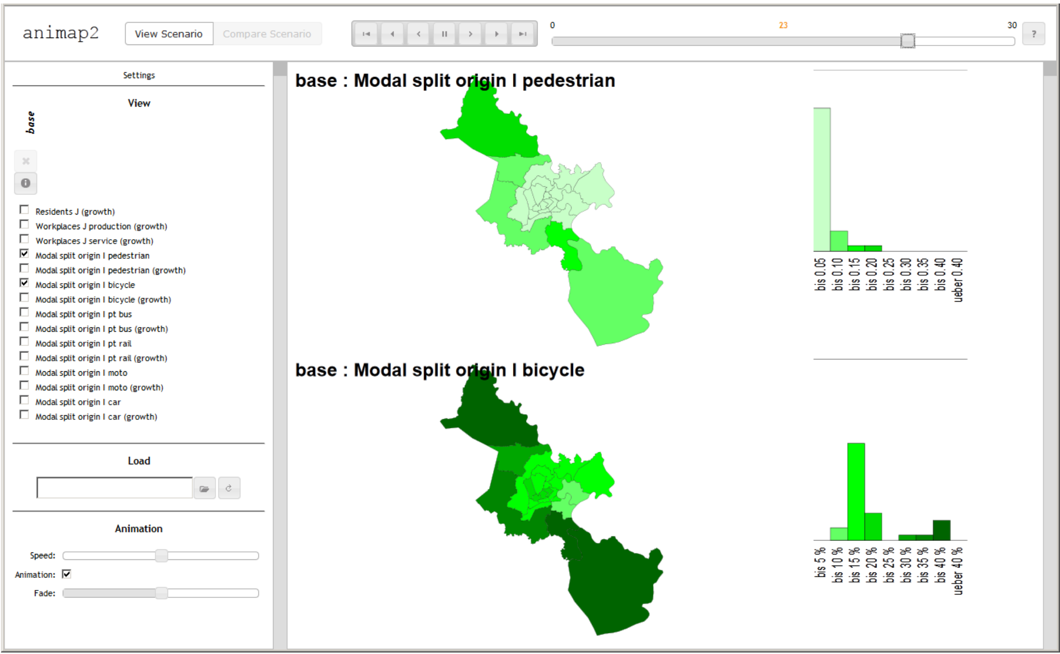

Figure 22 Screenshot of AniMap for the MARS setup of Ho Chi Minh city

5 THE MARS AUSTRIA MODEL

This chapter describes the changes in setting up MARS for the whole territory of Austria. This includes the description of the study area and model zones as well as the main structural changes compared to the urban MARS model.

Two different models, differing concerning the model parts that are active, are described. The second model – MARS Austria 2010 – is then used for the policy scenario modelling in this thesis.

5.1 Study area and model zones

The study area comprises the whole territory of Austria, 120 model zones which are based on the district subdivisions ('politische Bezirke') of Austria plus the 23 municipal districts of Vienna.[19].

There are several reasons why MARS Austria operates on district level. A first attractive feature of the district structure is that it includes the so-called 'independent cities' (Statuarstädte) which are administratively separated from their hinterland districts. Secondly, it is possible to represent core-periphery interactions (such as commuting flows and urban sprawl) for these districts in the model. Thirdly, for many statistics, the district level is the most detailed level for which data are available. Finally, in terms of figures, the number of districts (120) comes in handy from a technical point of view in that it keeps calculation time of

[19] In the administrative division, Austria is divided into 121 districts. For modelling reasons the district "Rust" and district "Eisenstadt-Umgebung" were aggregated to one model zone. The main reason lied in problems in the first model setup. "Rust" is a very small district regarding area and economic indicators like workplaces or income level. In the 121 model zones setting, the model predicted strong population gains for "Rust" and strong losses in workplaces, and this scenario seemed to be very unrealistic. Because "Rust" is very exceptional concerning the zone attributes, the conclusion is that the model setting wasn't capable to handle these huge differences compared to the other model zones

the model within a reasonable time frame (about 40 minutes for one simulation run of 40 time steps – 2010 – 2050).

There are two important features of the case study area worth mentioning. Firstly, the model zones are very heterogeneous amongst each other (see Table 9 and Figure 23).

Indicator (2001 values)	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 (Euros/m²)**	**Housing rent (Euros/m²/month)**
Total	83,859	–	–	–
Minimum	1	7%	14	1.63
Maximum	3,270	98%	577	4.02
Average	693	89%	204	2.60

Table 9 Overview of the case study area attributes – Austria. Source: (Haller, Emberger et al. 2007)

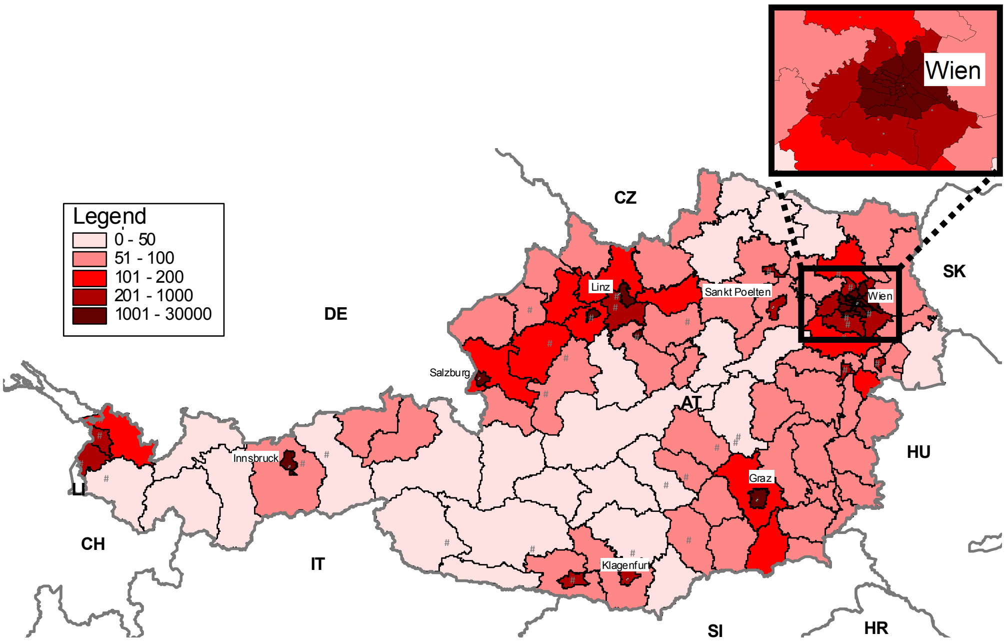

Figure 23 Population density per square meter. Source: (Haller, Emberger et al. 2007)

The case study area comprises highly urbanized, service-sector oriented zones with a highly positive commuting balance, 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.

Apart from that, 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 areas. The polycentric structure can be shown by the representation of the commuting catchment areas in Figure 24. The area in the blue circle shows Vienna, the areas in red circles represent the provincial capitals and the areas in yellow circles are other regional centres with their main commuting catchment areas. The darker the colours the more intense the commuting flows between the centres and the surrounding areas.

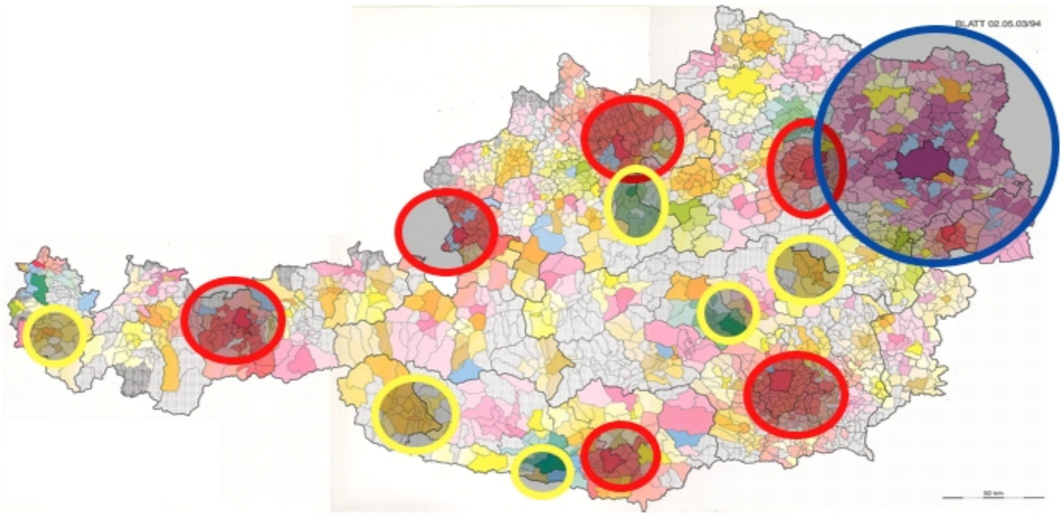

Figure 24 Polycentric structure of Austria depicted by its commuting catchment areas. Source: (ÖRÖK - Atlas zur Räumlichen Entwicklung Österreichs 1994)

5.2 Two models of MARS Austria

5.2.1 MARS Austria 2001

The **first model ("MARS Austria 2001")** uses all model parts of the MARS model. Therefore the two-way interaction between transport and land-use as described in chapter 2 can be modelled endogenously.

MARS Austria 2001 has 2001 as its base year. This means that all data available for 2001 are used, except for the transport behaviour data (modal split) where the data from the year 1995 (Herry 2002) are used. This model was used for a forecasting approach until the year 2031. The results for transport behaviour and CO_2 emissions are published in the conference proceedings of the 12th WCTR[20] 2010 (Emberger, Mayerthaler et al. 2010).

5.2.2 MARS Austria 2010

Due to the context of the main research question (see section 1.3), I started working on a further possibility to implement land-use polices into MARS. In the MARS Austria 2001 model the land-use models are market driven. To have an impact on migration patterns of residents and workplaces either prices or land availability had to be influenced.

In Austria the federal state has no spatial planning competence. There is no federal regional planning act. The Austrian spatial planning conference (ÖROK), which is an institution for coordinating spatial planning in Austria, only makes recommendations. The municipalities are responsible for local spatial planning. The mayor is the building authority of first instance, the local government of second instance.

Therefore, so far, spatial planning has been neither purely market driven, nor under the influence of the federal state, though laws could change the spatial planning competences. The incentive to choose a different approach than implemented in the MARS Austria 2001 structure lied in demonstrating the influence of federal spatial planning policy on transport behaviour and CO_2 emission development.

In the **second model ("MARS Austria 2010")** the land-use policies are implemented as external policies. This means that the residential migration patterns are fed into the model, differing for different scenarios. The advantage of this approach is that the zones can be clustered in different types, allowing for

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[20] 12th World Conference on Transport Research

level of service[21] changes in the transport system, if a zone switches from one type to another, according to the migration patterns of the population. In this way, land-use policies can be explicitly taken into account. In the first model, this is not possible because the level of service is defined exogenously at the beginning of a model run and remains constant over time.

The second model therefore allows to model policy combinations of different land-use and transport policies whereby the land-use policies directly influence the transport system via the change of level of service. In combination with different fleet development scenarios, this is the chosen methodology to answer the main research question (see section 1.3).

Another difference compared to the MARS Austria 2001 model, is that E-cars were not implemented as individual mode of transport yet. Because of the aim of the thesis to model the influence from land-use and transport policies as well as different diffusion scenarios of E-cars (see section 1.3), E-cars were implemented as an individual mode in the MARS Austria 2010 model.

Another reason for the second model is the intention to make long run predictions until 2050. In the second model the base year was changed to 2010, unfortunately with the same problem of lacks in data for the transport behaviour like in the first model (latest nation-wide mobility survey is from 1995). But with advantage that as an outcome of a research project[22] fuel and electricity price developments, energy mix scenarios and fleet developments till the year 2050 could be taken as input for the MARS model (Müller, Redl et al. 2012).

As already mentioned in section above, the main purpose of this setup is, to explicitly test the impact of pre-defined land-use scenarios (in this case different degrees of compacting settlement structures – see section 6.1).

The model was set up with data from 2010 where possible. For some variables data from 2001 (and other years beyond 2001) are taken, as in 2001, the latest

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[21] Level of service here means: timetables, ticket prices, changing times, … for public transport and parking place search times, parking pace prices,… for the transport mode car/E-car.

[22] http://www.klimafonds.gv.at/, Project: EISERN

census which provides a solid database was held in Austria. The following variables do not contain 2010 data:

- Persons per household 2001
- Household income 2007
- Average rent 2009

Due to some lack in data, expert guesses were made, for example concerning data for the transport model, like parking search time, parking fees, etc. For the calibration of the different model parts some exceptions due to data consistency were also necessary. These will be described separately in the chapter where the calibration of the MARS Austria model is discussed in detail (see section 5.4.1).

5.3 Main structural changes from the urban to the national models

Originally MARS was developed as an urban model (see chapter 4). Concerning the set-up of the urban models, these former models where much smaller in size (spatial dimensions) and much more homogeneous regarding the zone attributes like density, population size, number of workplaces per zone, area of the model zone, etc. (see section 5.1). To model a heterogeneous and polycentric study area like Austria made several important changes necessary.

The changes are described separately for the different models of MARS Austria as well as for each sub-model.

5.3.1 MARS Austria 2001 – change in the residential migration model

Section 4.5.1 already presented the two-step approach to model migration methodologically. Here the reason for the change in structure and the necessity to take distance as an influencing factor for migration are described.

Domestic migration in Austria (and elsewhere) is for the most part short-distance. The average distance (crow-fly) between an old and a new domicile is 12.6

kilometres; between the years 2002 and 2006 (see Figure 25) the distance was shorter than 24.3 kilometres for 80% of the migrants.

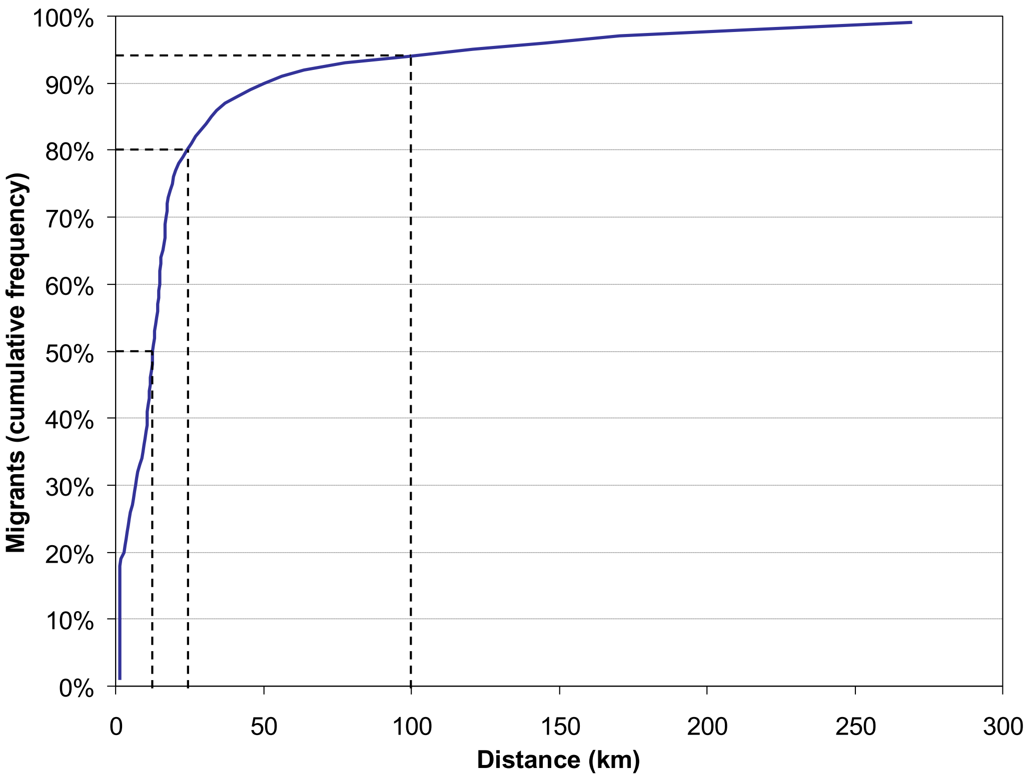

Figure 25 Length distribution of migration trends from 2002-2006

As a result, migration linkages are quantitatively less significant on higher levels of spatial aggregation; as an illustration it may be noted that migration between the districts of Vienna exceeds the migration flows between all other Austrian provinces. This observation was a strong argument for explicitly considering the distance between the zones for migration choices.

In the urban MARS models, the geographical location of origin and destination zones was not taken into consideration. In other words, the model assumed that the destination choice of migrants was not influenced by the location of their current domicile. This fact did not weaken the ability of the migration model to forecast urban migration patterns, because most cities were small concerning the diameter of the case study area. Additionally, the assumption of unconstrained destination choice was perfectly justifiable, because in most cases, the case studies were small enough to make it possible for migrants to maintain large parts of their "everyday life" (including place of work, social networks, spare time activities, etc.) irrespective of their choice of residence. An earlier attempt to implement the model to Austria without structural changes revealed the inappropriateness of this structure for a larger spatial scale (Emberger, Pfaffenbichler et al. 2007).

As the observed length distributions of migration were not reflected in the model design, the model predicted significant population shifts from the West to the East of the country, i.e. over several hundred kilometres.

To improve the model, literature on migration theory (e.g. Muth 1971; Greenwood 1985; Bode and Zwing 1998) and applied migration models (e.g. Flowerdew and Amrhein 1989; ODPM 2002; Roy 2004) were reviewed. Migration theory states that migrants evaluate benefits and costs of migration. Migration related costs include actual costs of migration and the loss of social networks. In most of the applied work on migration, due to the intangible nature of this effect, distance is taken as a substitute for the various types of migration costs. Moreover, distance also reflects an information aspect of migration, as people are usually deterred from moving to more distant places they know less about.

In order to account for the overwhelming importance of distance while changing the model structure as little as possible, a two-stage migration model was implemented as described in section 4.5.1.

5.3.2 MARS Austria 2001+2010 – improving the modelling of intrazonal trips

The main improvement concerning the transport model is the fact that the subscript notation and logic was changed to handle intrazonal trips.

Trip distribution and mode choice in the MARS model are calculated per origin-destination (OD) pair. In the urban MARS models an intrazonal trip is calculated if the origin zone equals the destination zone. The model setup was perfectly suitable for the urban case studies (small diameters of the model zones), but the wider geographical scope made some changes of its structure necessary.

MARS Austria is operating on district level. But the district size varies in total area from 3,270 km to 1 km (see Table 9). Due to the heterogeneity of the case study area (see section 5.1) the model was not capable of modelling intrazonal trips appropriately.

The commuting trip distribution for large model zones appeared to be unrealistic, because the model overestimated the distance and total number of trips. Intrazonal trips taking place in large model zones resulted in high trip lengths.

To estimate the intrazonal trips a “so called” distance class based approach was chosen. For each of the 120 model zones the intrazonal trips are now split up into 5 distance classes, mode split and number of trips being calculated separately for each zone and distance class. Further the attraction of the zone (see sections 4.4.2.1 and 4.4.2.2) is distributed within this 5 distance classes making it possible to give a stronger weight to close distance classes (for example distributing 80% of all workplaces – with serve as attraction for the trip purpose HWH - in large model zones into the distance class 1). This structural change increased the accuracy of the intrazonal trips significantly, leading to average trip lengths per mode comparable to data from 1995 (Herry, Sedlacek et al. 2007).

From an programming point of view the urban MARS models use the subscripts *i* and *j*, representing the origin and destination zones, whereas the subscript *j* is equivalent to *i*.

MARS Austria now uses a subscript *r,* which consists of all model zones *i*:(a101 – a923) [23] and a sub-range of the distance classes *rd*:(rd1-rd5). This new subscript *r* substitutes the subscript *j* in the transport model, for mapping the destination zones.

5.3.3 MARS Austria 2010 changes

5.3.3.1 Implementation of region types and region relationships

For the second model, the residential migration patterns of the population were fed into the model externally. For each zone the development of the number of

[23] The numbers represent the notion for the Austrian district level, the first number indicates the province (1: Burgenland, 2: Kärnten, 3: Niederösterreich, 4: Oberösterreich, 5: Salzburg, 6: Steiermark, 7: Tirol, 8: Vorarlberg, 9: Wien), the following numbers indicate the exact district.

residents over time is an exogenous input to the model. These development paths were provided by Ursula Mollay from the Austrian Institute for Regional Studies and Spatial Planning (ÖIR)[24]. The number of residents per zone (municipalities in this case) was modelled and following this development, the settlement structures for three different scenarios (see chapter 7) were predicted. The outcomes for the municipality level were then aggregated for the district level to make it compatible to MARS Austria 2010.

Though MARS Austria 2010 is operating on district level, the zones can be clustered in different types, allowing to capture the characteristics of the level of service[25], which change when a zone switches from one type to another because of the different migration patterns and different development of settlement structures[26].

An urban region like Vienna has a far better level of service concerning public transport, than for example the district of Hartberg. But over the long time period of 40 years a district can gain in population significantly and develop denser settlement structures, which in turn could change the level of service in this district. To capture these possible changes the Austrian districts were clustered into five region types:

0. Vienna
1. Urban
2. Suburban
3. Rural with favourable conditions for public transport supply
4. Rural with less favourable conditions for public transport supply

Figure 26 shows the districts of Austria clustered in into the five region types for the year 2010 (Vienna and the urban districts are both coloured in black and

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[24] http://www.oir.at/en

[25] Again level of service here means: timetables, ticket prices, changing times, … for public transport and parking place search times, parking pace prices,… for the transport mode car/E-car.

[26] The settlement structures in the municipalities differ in spatial distribution and density of the population.

labelled as region type 1, because the do not differ in the representation in figure 23).

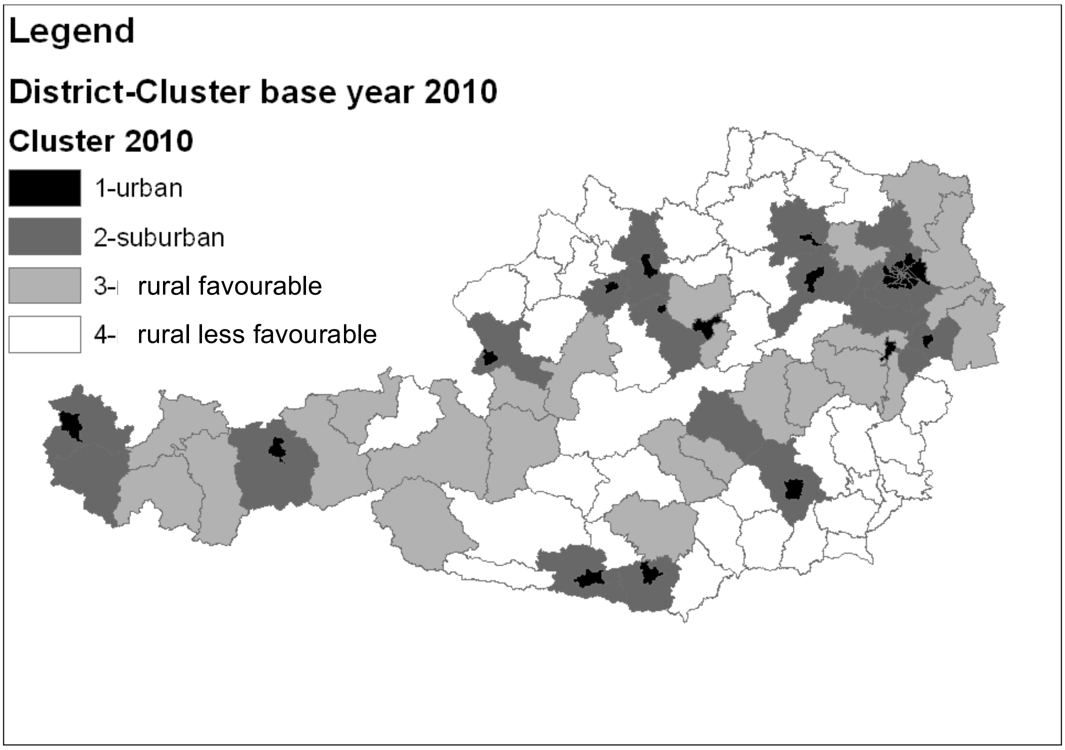

Figure 26 Cluster of the Austrian districts – base year 2010

A district does not only change regarding the total number of its residents but also with regard to its settlement structure. The decision whether a district belongs to region type one, two, three or four is based on the following:

0. Vienna
1. Urban
   City districts and/or districts with a density of at least 2000 inhabitants/km2 (within the settlement entity[27])
2. Suburban
   At least 70% of the population in the district can reach the supra-regional centre/provincial capital within 50 minutes by public transport (ÖROK 2007)

[27] The settlement entity is defined as a connected area of residential houses, industrial-, commercial-, public-, educational- and cultural facilities, office buildings, including recreational areas, where the gap sites between these cannot exceed 200m. Source: Katzlberger, G. (2010). Neuabgrenzung der Siedlungseinheiten 2010. Statistische Nachrichten. **11/2010**.

3. Rural with favourable conditions for public transport supply
    a. Share of population within the settlement entity >73% and population density within the settlement entity >900 inhabitants/km2 or
    b. Population density within the settlement entity >1200 inhabitants/km2.
4. Rural with less favourable conditions for public transport supply
   Remaining districts that do not belong to region type zero to three.

The five region types are influencing the input data for the transport model of MARS Austria 2010, for example via the headway times of public transport, or the access/egress times to the public transport stops or parking places.

In MARS Austria 2010 the input data for the transport model are either provided in vector or matrix format. The vector data are zone specific, while the matrix data are on the basis of origin-destination. Table 10 gives an overview of the input data used the MARS Austria 2010 model.

Influencing variables	**Car**	**E-car**	**Bus**	**Rail**
Vector data				
Walking distance from/to parking place	X	X		
Parking place search times	X	X		
Parking fees	X	X		
Distance to/from public transport stop			X	X
Intrazonal public transport speeds			X	X
Matrix data				
Distances	X	X	X	X
Speed t=0	X	X	X	X
Headway times			X	X
Changing times			X	X
Ticket fees			X	X
Share of public transport unaffected by traffic			X	X

Table 10 Input data in the MARS Austria transport model, classified into vector or matrix data

The five region types allow the distinction of the vector data per region type.

The five region types make 15 interaction patterns between the model zones possible. These 15 possibilities differ for example in headway times or changing times in public transport. It may occur that between two urban zones, the headway times are much shorter than between two poorly connected rural zones. Table 10 sums up the vector and matrix data, which are influenced either by a region type (vector data) or by the region relationships (matrix data) and the changes of both over time.

These interaction possibilities can be displayed as matrix and allow to adapt all the matrix data in the model to the region types. This results in matrix input data, differentiated by region type (see Table 11). The numbers in the "from" and "to" column in Table 11 refer to the region types described above. The number in the "code" column is used in MARS Austria 2010 to read in the appropriate input data per interaction possibility.

Classification	Code	From	To
Vienna interzonal	**0**	0	0
Urban intrazonal	**1**	1	1
Urban <–> Urban (Urban <-> Vienna)	**2**	1	1
Urban <–> Suburban	**3**	1	2
Urban <–> Rural favourable for PT	**4**	1	3
Urban <–> Rural less favourable for PT	**5**	1	4
Suburban intrazonal	**6**	2	2
Suburban <–> Suburban	**7**	2	2
Suburban <–> Rural favourable for PT	**8**	2	3
Suburban <–> Rural less favourable for PT	**9**	2	4
Rural favourable for PT intrazonal	**10**	3	3
Rural favourable for PT <–> Rural favourable for PT	**11**	3	3
Rural favourable for PT <–> Rural less favourable for PT	**12**	3	4
Rural less favourable for PT intrazonal	**13**	4	4
Rural less favourable for PT <–> Rural less favourable for PT	**14**	4	4

Table 11 Interaction possibilities due to the region type classification.

A few paragraphs earlier (page 83 and 84), the characteristics for the five region types were described. As mentioned over time, with population dynamics and different land-use scenarios, it may occur that one district changes in, for example, population density or percentage share within the settlement entity, to such an extent that the district shifts from one region type to another (for example from suburban to urban).

This shift also implies a change in the level of service. The development of the districts over time with their changing region type influences the framework in the transport system and therefore influences destination and mode choice via friction factor changes (see section 4.4.2), because of the change of level of service.

The population per zone serves as input for the calculation of model variables at several points in the model. To name the most important:

- Calculation of the level of motorisation
- Calculation of the vehicle availability
- Calculation of the total time available for trips at off-peak time (see section 4.4.1)
- Calculation of the attraction as destination for an off-peak trip (see section 4.4.2)
- Calculation of potential new housing units

5.3.3.2 E-cars as a separate mode of transport

In order to assess the influence of new technological developments like electric cars on transport behaviour it was necessary to implement E-cars as a separate mode of transport in MARS Austria 2010. In earlier MARS models and case studies E-cars were considered in the CO_2 emission calculation but not modelled as a separate mode. For the emission calculation the technological development of the fleet was considered, changing the specific emission factors for the different technologies.

In the recent MARS Austria 2010 model it is possible to switch different modes of transport on and off. The same holds for the mode E-cars.

To adapt the model structure to model E-cars made it necessary to build up a new friction factor calculation for the mode E-car, to implement it in the trip

distribution and mode choice (see section 4.4.2). The structure of the friction factor calculation is very similar to the mode car. Further the vehicle availability calculation had to be changed as well as all output calculation for the transport model (modal split, passenger kilometres, vehicle kilometres, trip times,…).
This explicit consideration of E-cars makes it possible to simulate policy measures that are designed to influence the travel behaviour of E-car users.

There is an underlying assumption about the charging infrastructure for E-cars, which is available either at the place of origin or destination. The argument is that diffusion up to a certain level is only possible if the charging infrastructure provided is sufficient.

The diffusion of the technology itself, the share of E-cars within the total number of private vehicles, is an exogenous input to the MARS model (see section 6.3).

5.4 Calibration and model testing of MARS Austria

The definition of model calibration and testing is based on Ortùzar and Willumsen:

> "Model calibration consists of finding parameter values that optimize the goodness of fit between model outputs and observed data." (Ortùzar and Willumsen 1994)

Sterman states that model validation in the strict sense of the word, as a matter of principle is not impossible (Sterman 2000, p.846). In line with Sterman the term model testing is used in this thesis.

The methodology, data used, calibration procedure and model fit for each sub-model and the second model (MARS Austria 2010) are presented.

5.4.1 Methodology and data used

The transport sub-model of MARS models transport flows within a time period. Model calibration is thus carried out on a cross-sectional basis to improve the model fit in a base year. In contrast, the land-use sub-models simulate changes from one time step to another, which requires calibration changes in observed land-use.

> "Model calibration is the process of finding estimates for the parameters of a model. A full dataset (explanatory and explained variables) is necessary for parameter estimation. The three main purposes of model estimation are to (i) make quantitative prediction on future development, (ii) to estimate the effects of changes within the system (including changing due to policies) and, finally, (iii) may parameter values themselves deliver some insights on a system under investigation (for example on the sensitivity of migration to distance)."(Haller, Emberger et al. 2008)

Different approaches to derive parameter estimates have been developed based on statistical, econometric and numerical techniques. In the case of gravity models, the most frequently used are ordinary least square (OLS) estimation of multiple regression models and maximum likelihood (ML) estimation of Poisson models.
In this thesis only the OLS estimation is described. For this purpose Vensim has a built-in optimizer functionality which can be used either for model calibration and/or policy optimization. Basically, the optimizer consists of an algorithm which numerically maximizes or minimizes an arbitrary objective function; in Vensim terminology the objective function is called "payoff".

Vensim uses a Powell hill climbing algorithm, which is a mathematical optimization technique, belonging to the family of local search (Selman and Gomes 2002).

Sterman (2000) describes hill climbing like climbing a mountain without any visibility. The following paragraph is rephrased from Sterman (Sterman 2000, p.537):
One would take one step in each direction to see which way the ground rises, and then strike out in the direction that leads most steeply uphill. Every few steps this procedure is repeated, stopping only when every direction that could be pursued leads downhill, which would imply that a/the summit has been reached.

> "Each iteration is a run of the model with a particular set of values of the collection of parameters being searched. The first iteration uses the base case parameter values. After the model has run, the value of the objective function is calculated as a measure of how good or bad the performance was. The trick

> comes in ‘remembering’ which sets of parameter values gave good results and using that information to predict how the set of values should be changed to carry out the guided search for good values, and not wasting effort examining parameter values which lead nowhere.”(Coyle 1996)

Vensim automatically specifies the “payoff” in the calibration mode as the sum of squared deviations between the observed values and the model output for one or more user specific variables. A weight can be attached to each of the variables. Vensim then choses the parameter values in an iterative process to minimize the payoff. The Vensim optimizer draws on the same criterion of goodness-of-fit as (ordinary) least squared estimation (OLS) in regression analysis. However the difference to OLS is that the optimizer can estimate models that are not linear in parameters, like the gravity model. As already mentioned, a weakness of this approach is that there are no analytically known measures of model significance.
This automated calibration procedure was applied to both the transport and the land-use sub-model.

The last national transport survey in Austria was carried out in 1995. Because of the lack of actual transport data the modal split assumptions for the year 2010 (base year – second model) had to be adapted by sources of regional transport surveys (see section 5.4.2.1).

Workplace data are available for the years 1991 and 2001 but not for 2010. There are no data for workplace migration flows. The assumption here is that the development of employment in Austria between the years 1991 and 2001 also continued from the beginning of the year 2010.

5.4.2 MARS Austria 2010 calibration

5.4.2.1 Transport model

Table 12 shows the modal split calculation data for the base year 2010. The 2010 data were calculated with regional survey results (Amt der Oberösterreichischen Landesregierung 2001; IMAD - Institut für Marktforschung und Datenanalyse 2002; Amt der Niederösterreichischen Landesregierung and Niederösterreichische

Landsakademie 2008; Herry 2009) which indicate trends and projections from "Transport Club Austria[28]"(VCÖ 2007). For the trips home – other, the average mode split weighed by the share of additional trip purposes (education, leisure, shopping, official business trips) of other trips was taken.

Modal split - 1995 [% of trips]	Home-Work	Home-Other	Total
car	63.6%	45.9%	50%
pt bus	11.1%	10.3%	10%
pt rail	7.1%	6.9%	7%
slow	18.2%	37.0%	32%
Modal split – 2010 [% of trips]	**Home-Work**	**Home-Other**	**Total**
car	65.8%	52.8%	56%
pt bus	10.7%	9.1%	10%
pt rail	6.9%	6.1%	6%
slow	16.6%	32.1%	28%
Change 2010 – 1995 [percentage points]	**Home-Work**	**Home-Other**	**Total**
car	2.2%	6.8%	5.7%
pt bus	-0.4%	-1.1%	-1%
pt rail	-0.2%	-0.8%	-0.6%
slow	-1.6%	-4.9%	-4.1%

Table 12 Modal split data of the year 1995 Source: (Herry, Sedlacek et al. 2007, p. 100), Assumption for the base year 2010, Source: (Amt der Oberösterreichischen Landesregierung 2001; IMAD - Institut für Marktforschung und Datenanalyse 2002; Amt der Niederösterreichischen Landesregierung and Niederösterreichische Landsakademie 2008; Herry 2009) (VCÖ 2007)

Compared to the data in the year 1995, Table 12 shows that the individual motorized traffic gained in shares while the non-motorized modes and public transport lost. E-cars are not listed because their share in the year 2010 was still very small (<0.0000%).

5.4.2.1.1 Calibration of the transport model parameters

For the transport model the so called k factor (peak/off peak) for the trips HWH (commuting trips) and HOH (all other purposes) need to be estimated.

[28] Verkehrsclub Österreich: http://www.vcoe.at/

$$T_{ij}^{m}=\left[P_i*\frac{A_j*k_{peak/opeak}/f\left(t_{ij}^{m},c_{ij}^{m}\right)}{\sum_{mj}A_j*k_{peak/opeak}/f\left(t_{ij}^{m},c_{ij}^{m}\right)}\right]_{HWH/HOH}$$

Equation 9 Trip distribution and mode split calculation (cf. Equation 2). Source: (Mayerthaler, Haller et al. 2009)

T^{m}_{ij} Number of trips my mode *m* from source *i* to destination *j*

P_i Production of trips at source *i*

A_j Attraction of zone *j* as destination

$k_{peak/opeak}$ k factor per time of day (peak and off-peak)

t^{m}_{ij} Travel time my mode *m* from *i* to *j* (min)

c^{m}_{ij} Travel cost for a trip my mode *m* from *i* to *j* (€)

$f(t^{m}_{ij},c^{m}_{ij})$ Friction factor for a trip my mode *m* from *i* to *j* (min)

HWH Tour home – work – home

HOH Tour home – other activities – home

Table 13 shows the mode and purpose-specific parameters derived from the calibration of MARS Austria 2010. As mentioned in section 5.4.1, the calibration was accomplished within the MARS Austria 2010 model using the Vensim built-in calibration function. For the calibration of the k factor peak 54 iterations were needed, the calibration of the off peak k factor took 20 iterations.

The k factors for the commuting trips are around 1 for the modes pt bus, pt rail and the slow modes. MARS underestimates the mode car, leading to a k factor of 2. For the “other trip” purposes the k factors of the modes car and pt bus are 1.7 respectively 2 indicating an underestimation of MARS, while for pt rail and the slow modes the k factor is smaller.

Trip purpose / k factors	Car	pt bus	pt rail	slow
Home – Work	2	1.2	0.8	0.9
Home – Other	1.7	2	0.8	0.1

Table 13 Mode and trip purpose-specific parameters k peak/off peak of the calibration

5.4.2.1.2 Model testing

There is no commuting data and no origin-destination data for "other trip" purposes available for the year 2010.

Still the main commuting catchment areas are known from 1991 and there is commuting data from 2001 (Statistik Austria 2004). The assumption that the commuting patterns in 2010 would be similar to 2001 but differing in magnitude at least indicates whether the commuting flows are well represented or not. Table 14 shows this comparison for all commuting trips on the left hand side and intrazonal commuting trips in the right hand side.

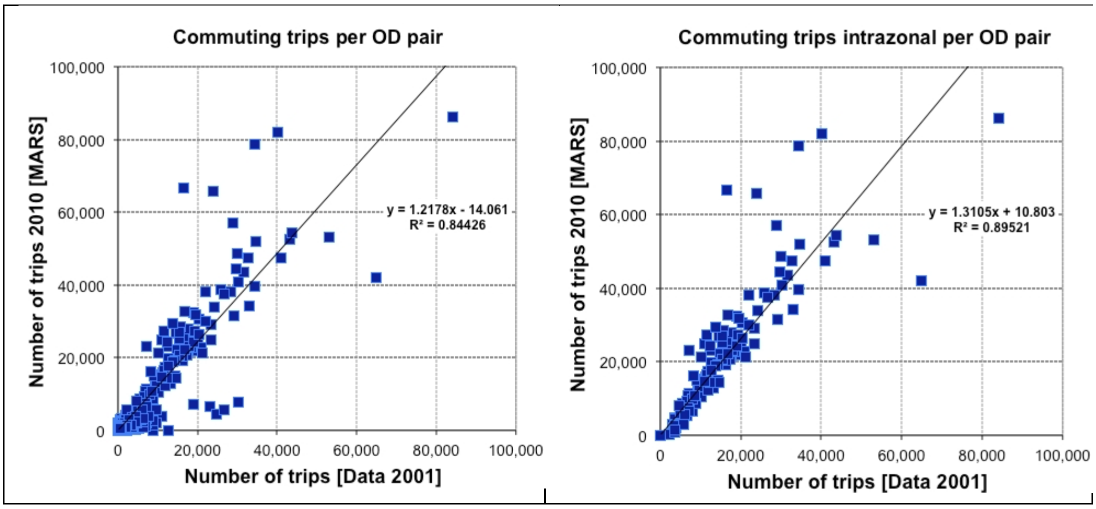

Table 14 Comparison data of commuting trips from 2001 to MARS results with the base year 2010

At the bottom of the left hand figure in Table 14 there are five points, where MARS Austria underestimates commuting connections from surrounding suburban districts to the core cities. These are the following origin destination pairs from left to right:

- Urfahr-Umgebung – Linz
- Linz-Land – Linz
- Salzburg-Umgebung – Salzburg
- Innsbruck-Land – Innsbruck
- Graz-Umgebung – Graz

The intrazonal trip distribution works satisfying, due to the implemented intrazonal distance classes (see section 5.3.2).

In general, the resulting regression coefficients are reasonably high. The R^2 value for the total trips home – work is 0.84, the R^2 value for the intrazonal trips is even higher amounting to 0.89. The equation shows slopes near 1 (1.2 left hand figure and 1.3 right hand figure), indicating that, if the trips in the data set increase by one, the trips predicted by the model will also increase by around 1. The overestimation of 20% respectively 30% originates from 2010 data concerning population and employed. In 2010 the number of employed and the population in Austria was higher than in 2001, resulting in a higher production of trips by zone.

Still this does not prove the conformity of the model, because of the lack of actual data from 2010 concerning commuting data.

The only possibility of testing the conformity was a plausibility test comparing some output variables of MARS produced in the base year with available data. This comparison was accomplished for the following variables:

- Passenger km per mode in 2010
- Vehicle km per car in 2010
- CO_2 emissions in the year 2010
- Average number of trips per day 1995

Table 15 presents the passenger kilometres per mode for the year 2010 and the MARS output (base year 2010). The model output of MARS fits quite well with the data, though showing slightly too many passenger kilometres for the modes car and pt bus, while too few for the slow modes. In total the resulting number fits well with the data.

Passenger km per mode [million (m.) passenger km]	Data 2010	MARS 2010	Difference [%]
Car	72,334[29]	73,862	2,1%
pt bus	9,735	9,982	2,5%
pt rail	14,772	14,775	0%
Slow	3,131	3,089	-1,3%
Total	101,570	101,713	0,1%

Table 15 Passenger km per mode data and MARS output. Source: (Österreichische Luftschadstoffinventur (OLI) 2010)

The vehicle kilometres are presented in Table 16. In MARS the vehicle kms are 2,1% higher than in the data from 2010.

Vehicle km per car [km / year]	Data 2010	MARS	Difference
Car	13,093	13,371	2,1%

Table 16 Vehicle km data and MARS output. Source: (Statistik Austria 2010)

Table 17 shows the CO_2 emissions arising from passenger transport (cars and busses) and the resulting CO_2 emissions from MARS. In total the output from MARS is higher that the CO_2 emissions from the data.

A reason is the differing calculation schemes. The Austrian Federal Environment Agency calculates the emission according to the fuel purchased at the petrol station. Furthermore the amount of petrol sold in Austria is compared to the exported petrol, in order to account for fuel tourism (Umweltbundesamt GmbH 2011, p.27). In MARS the CO_2 emissions are calculated with emission factors per fuel type and technology. The vehicle kilometres per fuel type and technology are multiplied by these specific emission factors resulting in CO_2 emissions. The emission factors take into account the different technologies as well as the composition of the fleet (vehicle categories – compact car, middle class car, large car).

[29] Mopeds and motorcycles are not represented by MARS but account for 1,599 m. passenger kilometres, leading in total to 73,912 m. kilometres for car, E-car, moped and motorcycle.

CO_2 emissions passenger transport [1000 tonnes (t.) / year]	Data 2010	MARS 2010	Difference [%]
car	9,728	11,348	+14,3%
pt bus	301	299	-0,7%
Total	10,029	11,647	+13,9%

Table 17 Total CO_2 emissions passenger transport data and MARS output. Source: (Österreichische Luftschadstoffinventur (OLI) 2011)

Table 18 shows the number of trips per person from 1995 data and from MARS Austria.

Trips per person [trips / day]	Data 1995	MARS 2010
Trips per day	3	2,8

Table 18 Trips per day data and MARS output (all persons). Source: (Herry, Sedlacek et al. 2007)

5.4.2.2 Workplace location choice

Workplace data are available from census data of the years 1991 and 2001. One main difference to the residential migration data is that as far as workplaces are concerned, no data of workplace migration flows is available. For 2010, no new workplace data are available. To estimate values for the two sectors for 2010 the assumption was that growth and shrinking processes per district occurring between 1991 and 2001 continued between 2001 and 2010. Of course this approach cannot take into account external shocks like the financial crisis in 2007 or changes happening due to political or CEO decisions (for example closure of the "Austria Tabak" production site in Linz, where 300 employees lost their jobs[30]).

Moreover, no data on the life cycle of firms are available in Austria. Bodenmann (2006) for example describes that the main migration movements of firms are expected to happen in the foundation or growth phase of a firm. He divides the lifetime of firms into 5 phases:

1. foundation phase

[30] http://news.orf.at/stories/2056673/2056646/. Accessed on 18.12.2012

2. growth phase
3. maturity phase
4. revitalization phase
5. aging phase

Mature and already established firms do not tend to move their locations. Due to the lack of data concerning workplace migration flows, it is not possible to distinguish whether firms that “appear” in certain districts are newly founded or just moved their location from one district to another.

As for the selection of influencing variables on workplace migration, selected variables from already applied urban MARS case studies were taken as well as proposed variables in the literature (Bodenmann 2005; Pellenbarg 2005; Van Wissen and Schutjens 2005; Bürgle 2006).

Both Pellenbarg (2005) and Bürgle list accessibility as an influencing factor for workplace migration. Land availability is quoted by three of the authors (Bodenmann 2005; Pellenbarg 2005; Bürgle 2006) and land prices are named by Bodenmann (2005). The influence of income is stated by Bürgle (2006) and Pellenbarg (2005). Because of the closeness to market and because the workplace migration in this context takes place within Austria and no further influencing variables were selected.

5.4.2.2.1 Calibration procedure

The workplace location sub-model is a gravity model, like the residential migration sub-model. As described in section 5.4.1, the most frequently used methods in the case of gravity models are ordinary least squares (OLS) estimation of multiple regression models, maximum likelihood (ML) estimation of Poisson models and neuronal networks (Bergkvist and Westin 1997).

In this thesis the OLS estimation approach is chosen for the workplace location sub-model. The approach is motivated by the attempt to carry out model estimation and model runs within the same modelling environment. This streamlines the modelling process and prevents the need for additional estimation software. This methodology is a fairly straightforward way to derive estimates of the model parameters. A weakness of the approach is that there are not analytically known measures of model significance (Haller, Emberger et al. 2008).

Though a comparison of ordinary least squares (OLS) estimation of multiple regression models and maximum likelihood (ML) estimation of Poisson models was accomplished for the residential migration sub-model (Haller, Emberger et al. 2008). In this comparison the advantage that the Poisson regression delivers diagnostic statistics was put into perspective, because none of the variables considered proved to be insignificant. And in the comparison the OLS approach yielded to a slightly better model fit than those from Poisson regression (measured in R^2).

For the chosen influencing variables in the workplace location sub-model the significance can only be assumed by literature sources quoted in section 5.4.2.2. It is still a generally used method to calibrate the parameters of most LUTI models (DELTA, TRANUS, MEPLAN, and IRPUD), by informally matching model results with observed data sets or by using expert judgment for the parameters (Zondag 2007). Yet, these procedures do not indicate, such as in formal statistical estimation methods, whether coefficients are significant or not.

The workplace migration parameter calibration was achieved by building a stand-alone calibration model. Again, the built-in calibration tool of Vensim was used.

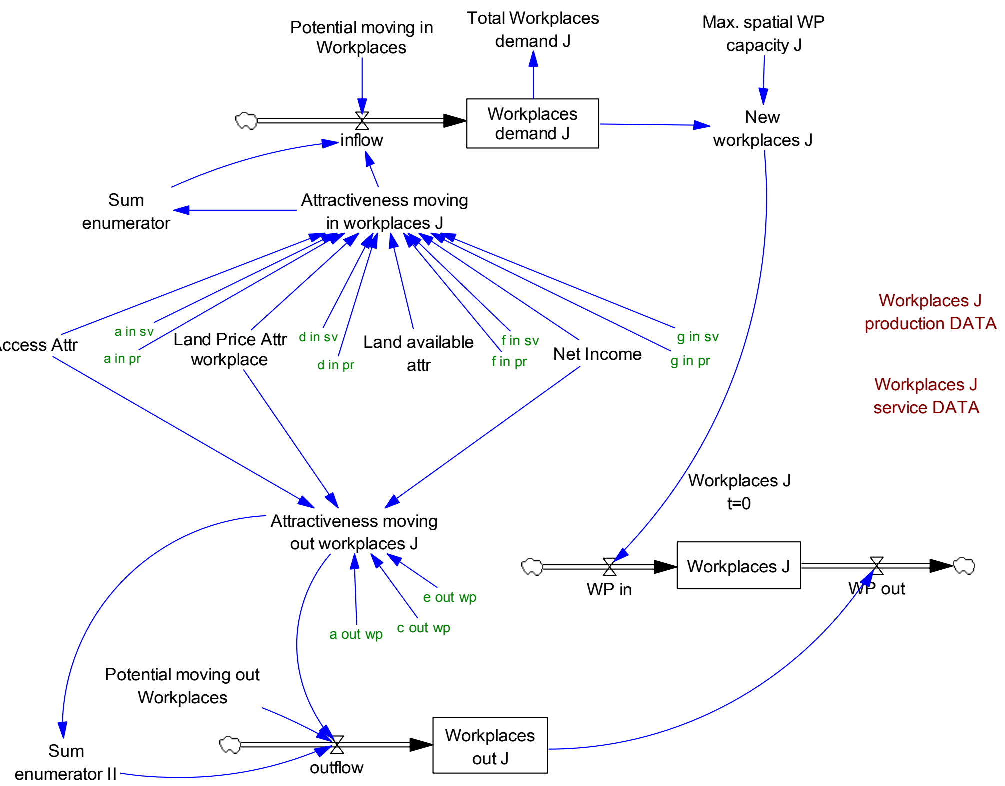

Figure 27 Structure of the workplace migration model

Figure 27 shows the structure of the workplace migration model. The model calculates workplace migration flows, “WP in” and “WP out” of the stock “Workplaces J” over a time period of ten years. For the potential in-movers, the spatial workplace capacity is controlled. This variable is visible in the upper right corner of the figure.

The equations for the calculation of the flows “WP in” and “WP out” are given in section 4.5.2.

Table 19 shows the chosen variables influencing workplace migration in the MARS Austria model. Access attractiveness, land price attractivity and household income influence the workplace in-migration as well as the workplace out-migration. The attractiveness of land availability only influences the workplace in-migration.

Variable	Description	Calculation
WP in/out-migration		
Access attr.	Population accessibility potential with a quadratic decay function based on generalized cost between origin and destination	$ACC_i / \sum_i ACC_i * 120$[31]
Land price attr. [sector]	Land price of possible building land in a zone	$land\ price\ attr._{i,sector} / \sum_i land\ price\ attr._{i,s}$ $* 120$
Household income [HHI]	Household income	
WP in-migration		
Land availability attr. [sector]	Availability of building land in a zone	$land\ available\ attr._{i,s} / \sum_i land\ available\ a$ $* 120$

Table 19 Overview of the explanatory variables for workplace migration

5.4.2.2.2 Model fit

The result of this calibration cannot be tested with data. The scatterplots in Table 20 depict the results of the linear extrapolation in comparison with the output of the calibration of the workplace migration model. The resulting regression coefficients indicate that the workplace migration model is capable of producing the expected behaviour. The R^2 value for the workplaces in the production sector is 0.9, the R^2 value for the workplaces of the service sector is 0.89.

[31] MARS operates with 120 model zones.

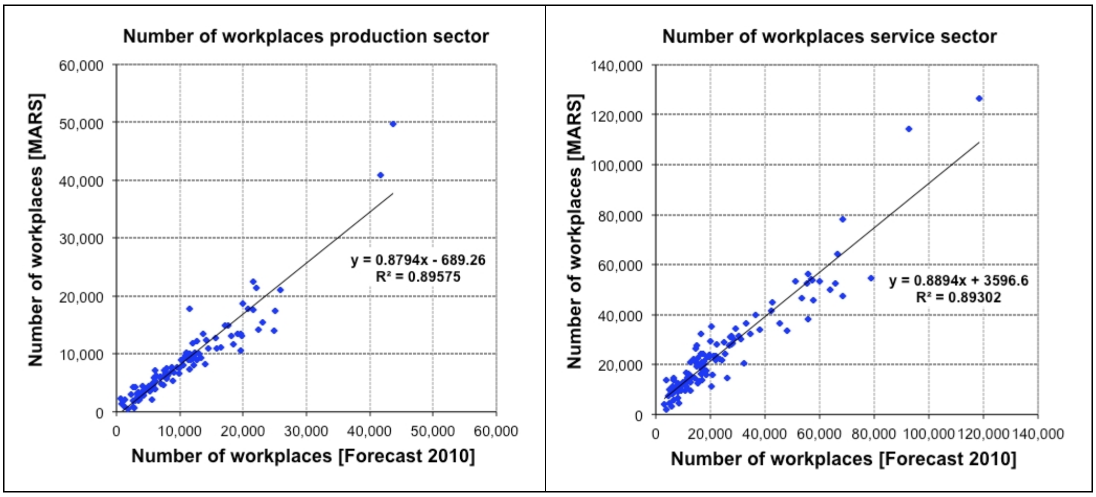

Table 20 Comparison of linear extrapolation and calibration results for the number of workplaces per sector for the year 2010

5.4.2.2.3 Estimated parameters

The parameter estimates for the workplace migration model are shown in Table 21. The "access attractiveness" parameter is negative for the workplace in-migration model for the production sector, but surprisingly it is also negative for the out-migration model. The "access attractiveness" parameter is positive for the in-migration model for the service sector, but also positive for the out-migration model. The signs of the "access attractiveness" parameter for the workplace in-migration model for both sectors is exactly opposite to findings from Bürgle for the wider area of Zurich (Bürgle 2006). The same sign for the in in- and out-migration parameters make the interpretation of the net influence of the access attractiveness variable rather complicated, and additionally corroborates the fact that further information on workplace migration-flows is needed.

The same complexity arises when interpreting the sign of the "land price attr." parameter, which is also positive for the production sector both in the in-migration as well as in the out-migration model and negative for the service sector for in-migration as well as out-migration.

For the parameter of "land available attractiveness", a more intuitive interpretation is possible. It is positive for the in-migration of production and service workplaces, as the availability of building land is an important influencing factor Bürgle (2006), for example, also came to similar conclusions.

The household income parameter is negative for the in-migration of the production sector. A possible explanation could be that higher net incomes in a certain zone imply that the firms have to pay higher wages to their employees, which makes moving into that zone rather unattractive. For the service sector, the opposite is the case - higher net incomes are a signal for higher purchasing power, which in the case of the service sector is a positive incentive to move there. The signs of the parameters are the same but less numerous in the workplace out-migration model.

Parameter	Value
In-migration production:	
a in pr (ACC)	-2.5179
***d in pr* (land price attr.)**	0.782454
***f in pr* (land available attr.)**	0.0690263
g in pr (HHI)	-10.8273
In-migration service:	
a in sv (ACC)	0.0712301
***d in sv* (land price attr.)**	-0.747854
***f in sv* (land available attr.)**	0.0438275
g in sv (HHI)	2.78186
Out-migration production:	
a out pr (ACC)	-2.07355
***c out pr* (land price attr.)**	0.661833
e out pr (HHI)	-10.7314
Out-migration service:	
a out sv (ACC)	0.167764
***c out sv* (land price attr.)**	-1.50355
e out sv (HHI)	1.91275

Table 21 Parameter estimates for the workplace migration sub-model, MARS Austria 2010

To sum up, the calibration of the workplace migration model for the MARS Austria 2010 model was not fully convincing, though the model seems to be able to reproduce the behaviour. The interpretation of the parameter values is difficult and their significance therefore questionable. Still, as the focus of this thesis is to make land term predictions until 2050, a later base year (2010) seemed reasonable.

The calibration procedure was also accomplished for the MARS Austria 2001 model. In this case the resulting parameter values could be interpreted more intuitively. The procedure and results of the parameter estimation of the workplace location choice model were presented at the 49th Congress of the European Regional Science Association (Mayerthaler, Haller et al. 2009).
This supports the suspicion that in the MARS Austria 2010 model, the pure lack in solid data basis is the problem, not the structure of the workplace location choice model itself.

6 IMPLEMENTING TRANSPORT AND LAND-USE POLICIES INTO MARS AUSTRIA

The strength of MARS Austria lies in the capability of modelling transport and land-use policies simultaneously. Further fleet development over time is an exogenous input to the model.

6.1 Implementing land-use policies

For this thesis a different approach to implement the land-use policies into MARS Austria 2010, different than influencing prices of rents or changing the shares of developable land, is chosen. Section 5.3.3.1 introduced the implementation of region types and region relationships. The main reason for modelling the residential development over time exogenously with this approach is to be able to capture changes in settlement structures.

Previously it was possible for example to implement that development of new housing units should take place only in zones along good railway connections (by limiting the space availability in the other zones) in order to enhance public transport use. The change in the level of service for public transport resulting from population concentration was not implemented automatically and stayed constant over time. However the level of service concerning public transport is highly influenced by the settlement structures. Public transport operators generally improve their transport supply in denser settlement structures with a higher share of potential customers. This is especially important because Austria, at its district level, is very heterogeneous (see section 5.1), which was not so explicit in the case of the urban case studies. For the Austrian case study the possibility to distinguish between the five region types (see section 5.3.3.1) allows to map this level of service differences and to change it over time with changing population. Therefore transport data, which in principle (in the urban MARS case studies) would be defined at the beginning of the model run and remain constant over time (without policy implementation), steadily changes over time with this implementation approach (even in the base run, because of the population dynamics).

Figure 28 shows in more detail how the region type and region relationship change influences a certain part of the friction factor, in this case the walking time to and from the next public transport stop (access and egress time). As the implementation structure is generic for the other friction factor parts as listed in Table 10, I shall show just this one example.

The red coloured variables are variables filled with external data from an excel file. The pink ones are processed further in the part of the model where the friction factor by mode and time of day is calculated.

The variable “walking time PT rail iJ ird region type” (egress time) illustrates the walking times from the public transport rail stop to the final destination within the region types per time of day (peak and off-peak). The black shaded variables underneath allocate this information to the region types 0 – 4.

The variable “walking time PT rail ij region type” (egress time) contains the walking times from the public transport rail stop to the final destination from each region type to each region type per time of day. The black variables above allocate this information to the 15 region relationships (see Table 11).

In the variable “walking time PT rail iJ ÖIR”, all this information is brought together. Now if the region type and, as a result, the region relationships from this zone change, this variable changes.

The walking times from the public transport stop are therefore dependent on the region type where the trip originates and the region type of the destination zone.
The walking time to the next public transport stop “walking time PT rail iI ÖIR” (access time) is a vector, as the walking time to the PT stop is dependent on the spatial structure (region type) of the origin zone only.

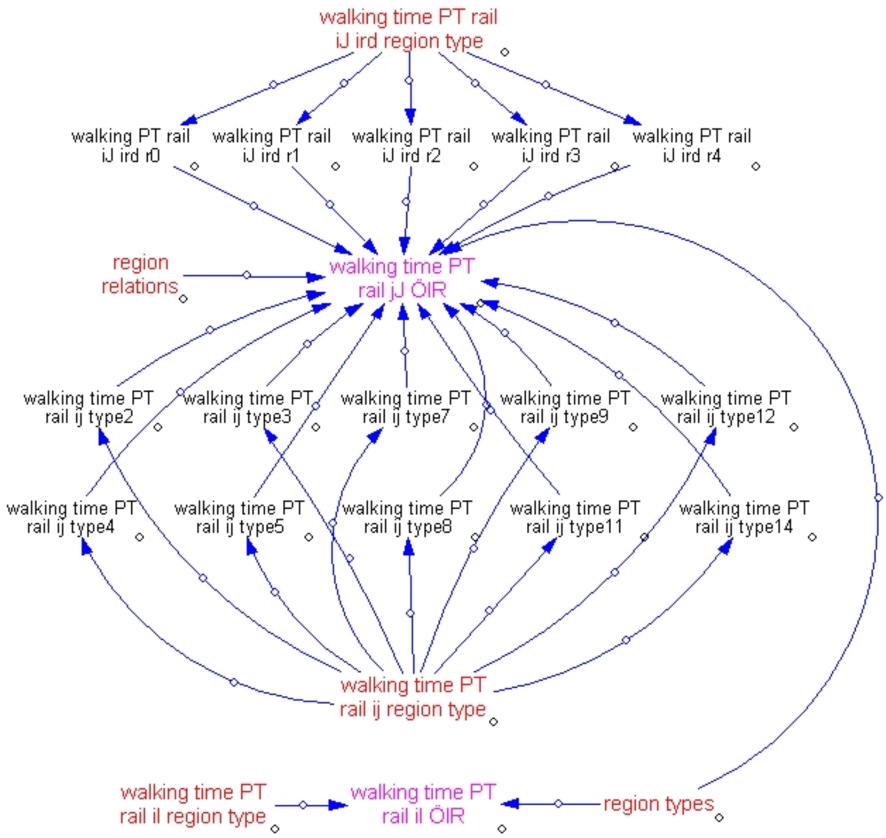

Figure 28 Implementation of the friction factor change through a change in region type and region relationship

The land-use policies which can be implemented with this approach differ in magnitude (see sections 7.1.4 - 7.4.4) but consist of the following components:

1. Whether and in which magnitude building land dedications outside the settlement entity are allowed.
2. Density of new housing units. Change in number and size of new housing units.
3. Construction of new housing units outside the settlement entity or predominantly/exclusively within.
4. Magnitude of reuse of existing housing units within the town centre.

6.2 Implementing transport policies

The policies modelled in this thesis are either pricing policies or infrastructure measures (see sections 7.1.3 - 7.4.3). The policies therefore influence the transport model via the friction factor calculation (see section 4.4.2). Both influence the model via the pink coloured variables depicted in Figure 29.

Concerning the transport policies three different policy scenario combinations are chosen. They are designed from the perspective of political feasibility (or probability) taking into consideration the time frames for changing physical built infrastructure and the focus lies primarily on their potential to reduce CO_2 emissions in the passenger transport system. One scenario, 450ppm (see section 7.4.3), is the most ambitious scenario covering rather extreme transport policies where the feasibility is questionable. Still this scenario is important as it represents a possible paradigm change.

6.3 Fleet development

MARS Austria 2001 and 2010 take the fleet development over time as a given input. This means that other model predictions are needed to feed the model with the necessary data. The focus here lies on whether and how electric vehicles gain acceptance. In this case the model is based on output from a fleet development model of Maximilian Kloess from Energy Economics Group (EEG) of Vienna University of Technology as described in (Kloess 2011) and (Kloess and Müller 2011). Four different scenarios will serve as reference for the diffusion paths of electric mobility and will be further discussed in sections 7.1.2 - 7.4.2.
MARS Austria 2010 considers the following combustion technologies:

- Diesel,
- Petrol,
- Electric,
- CNG and
- Hybrid.

MARS Austria 2010 takes as input the total number of vehicles from the base year until the last time step of the simulation period. The shares of the different technologies are also fed into the model.

For the emission calculation, the number of cars per vehicle class and the specific fuel consumption are also exogenous. These two inputs were calculated by

Maximilian Kloess with his fleet development model for a project at Vienna University of Technology (Müller, Redl et al. 2012) and are used for this thesis. With this setup, the policy design needs to determine both the level of motorization in general, whether it is increasing or decreasing, and the saturation of the technologies.

6.4 Putting transport policies, land-use policies and fleet development together

The linkages from MARS Austria with the fleet development model and land-use scenarios are captured in Figure 29. The pink variables depict exogenous variables based on the population scenarios made by Ursula Mollay from ÖIR, while the orange ones are based on input from Maxilian Kloess from EEG.

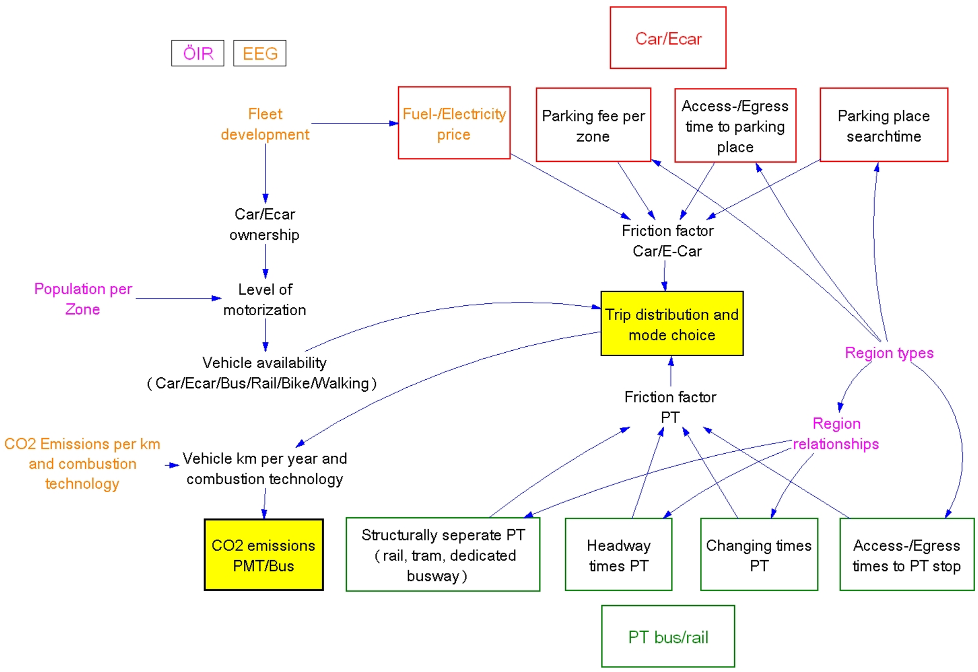

Figure 29 Linkages of MARS with the fleet development of EEG and the population dynamics of OIR

As can be seen, the fleet development influences the car and E-car ownership. The fleet development includes assumptions about the fuel- and electricity price development (see sections 7.1.1 - 7.4.1), which are included in MARS as components of the friction factor calculation of cars and E-cars. EEG also provided specific CO_2 emissions calculated for each combustion technology and the share of cars/E-cars in compact/middle and large vehicle class.

The region types and region relationships influence the fiction factor calculation (see section 6.1), and therefore the trip distribution and mode choice. The variables that change over time through region type or region relationship changes are described in section 6.1.

The description of the approach chosen answers the **first sub-research question** (see section 1.3).

7 SCENARIO MODELLING

All described scenarios are simulated with MARS Austria 2010.

First a so-called business as usual scenario (BAU) is modelled, which depicts the development over time without any substantial changes. In the BAU scenario it is assumed that the population development, as well as the economic development and the migration of workplaces follow the trends of the last few years. This BAU scenario serves as a reference scenario. It represents the transport behaviour and resulting CO_2 emissions in the passenger transport sector without active policy measures but with a change in fleet development.

The BAU scenario is compared with three policy scenarios. Following the goal of CO_2 emission reduction, these scenarios are named after the climate stabilization scenarios from the IPCC (Intergovernmental Panel on Climate Change (IPCC) 2007): 550 ppm[32] (little ambitious), 500 ppm (ambitious), and 450 ppm (very ambitious). Furthermore another scenario where only the fleet development is implemented as very ambitious while there are no policies for transport and land-use is modelled. This scenario is called: tech.

In addition, to single out the separate policies, two frozen technology runs are modelled. In the frozen technology scenario the shares of the combustion technologies are kept static at 2010 levels for the total simulation period. One shows the single impact of the most ambitious transport policies (transport policy only- TPO) the other one the most ambitious land-use policy (land-use policy only - LPO).

In addition as reference a BAU-frozen technology run is modelled, with all assumptions like in the BAU scenario but static shares of combustion technologies over time.

In all scenarios the total population of Austria is increasing according to the prognosis of Statistic Austria (Statistik Austria 2011) to 9,460,113 until 2050.

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[32] ppm stands for parts per million CO_2 in the atmosphere

		BAU	550 ppm	500 ppm	450 ppm	tech.	BAU-frozen	TPO	LPO
Transport policy	BAU	**X**				**X**	**X**		**X**
	little ambitious		**X**						
	ambitious			**X**					
	very ambitious				**X**			**X**	
Fleet development	static technology						**X**	**X**	**X**
	BAU	**X**					**X**		
	little ambitious		**X**						
	ambitious			**X**					
	very ambitious				**X**	**X**			
Land-use policy	BAU	**X**	**X**			**X**	**X**	**X**	
	ambitious			**X**					
	very ambitious				**X**				**X**

Table 22 Overview of the policy combinations (transport policy, fleet development and land-use policy) forming the BAU, 550 ppm, 500 ppm, 450 ppm, tech., TPO and LPO scenario

In order to calculate the emissions for the use of E-cars, scenarios for the development of the energy production sector in Austria are necessary. These scenarios were provided for this thesis from Christian Redl from EEG. The energy production sector was modelled with a simulation model modelling myopic investment decisions in energy producing technologies (Müller, Redl et al. 2012, p.172).

Figure 30 depicts the specific CO_2 emissions for electric vehicles, which are different in the scenarios. It can be seen that the trend in the underlying energy mix is towards more renewable energy sources. For the 450 and 500 ppm scenario the specific CO_2 emissions are zero in 2046, equivalent to an energy production of 100% renewable energy.

For the BAU scenario, the assumption is not so promising. The main reason why a 100% renewable energy production is not achieved is the assumption that the energy demand is still on a steep rise. Till 2050 coal power plants have to be used frequently to offset the energy demand (Müller, Redl et al. 2012, p.178-179). The assumed CO_2 prices are to small to stimulate investments in renewable energy and gas power plants (Müller, Redl et al. 2012, p.178-179).

The steep rise in emission in the 550 ppm scenario between 2035 and 2040 results in a lack of investment in modern gas power stations caused by the gas-coal-CO_2-price relationship in combination with increasing energy consumption (Müller, Redl et al. 2012, p.181). From 2040 old power plants are taken out of service reducing the emissions again (Müller, Redl et al. 2012, p.181).

The tech., TPO and LPO scenarios follow the 450 ppm development. Though in the TPO and LPO scenarios the emissions emerging from electric vehicles are negligible, because the share of e-Cars is kept static at 2010 levels, where the share was <0%.

The BAU-frozen technology scenario follows the BAU scenario development.

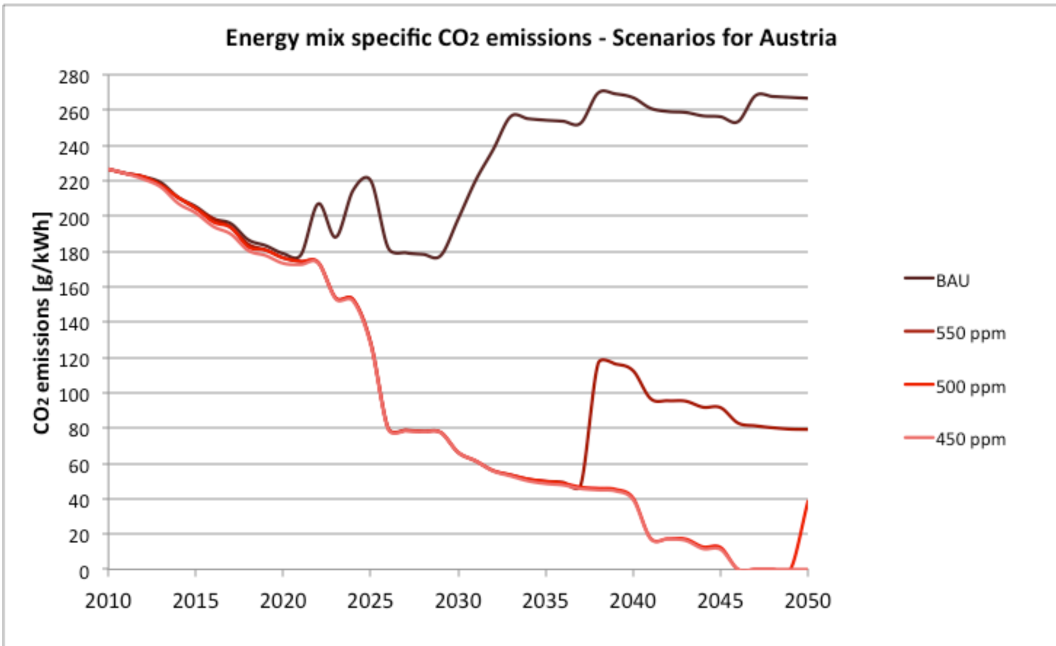

Figure 30 CO_2 emissions in g/kWh underlying the scenarios. Source: Christian Redl, Energy Economics Group, University of Technology Vienna. (Müller, Redl et al. 2012)

Figure 31 shows the energy efficiency development path of the E-cars. It is assumed to be very steady after 2020. This assumption is reasonable, the technological path is the same, irrespective of the level of diffusion of E-cars. The only difference is that in the business as usual scenario this efficiency level is reached a little bit later (2016). These assumptions are based on the energy demand of electric vehicles based on 3 different vehicle classes (compact, middle, large). The development paths were provided by Maximilian Kloess (Kloess and Müller 2011). The assumed energy prices and fuel prices as well as taxes influencing the development of the energy efficiency of e-Cars are the same in the model-based analysis of Kloess and in this thesis.

For the tech., TPO and LPO scenarios the 450ppm development is assumed. In the TPO and LPO scenarios the share of e-Cars is <0%, energy consumption from e-Cars is therefore negligible.

The BAU-frozen technology scenario follows the BAU scenario development.

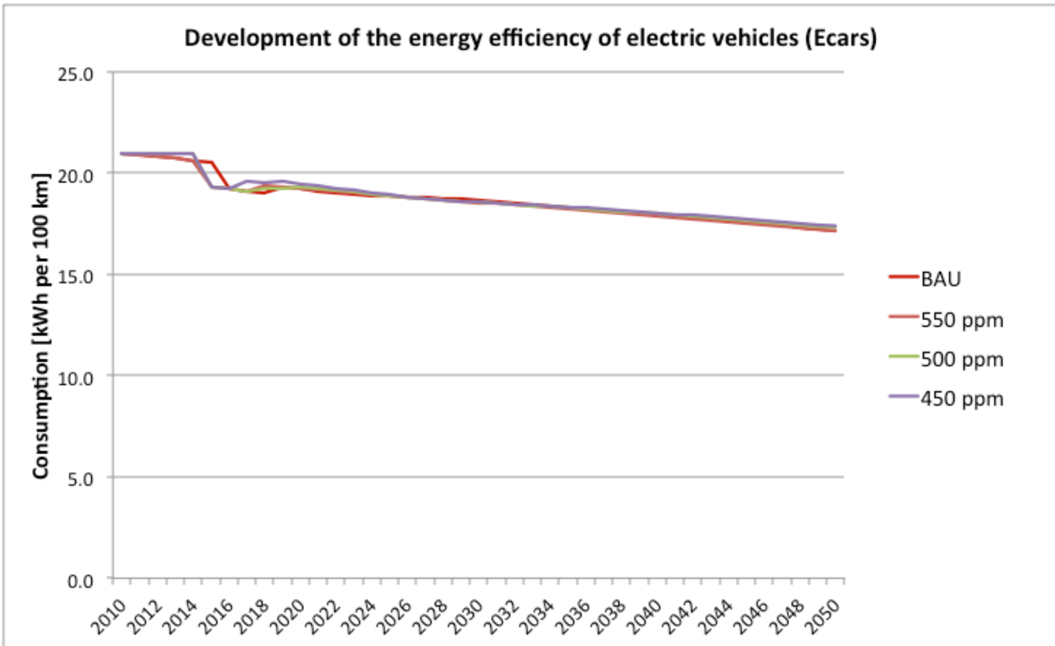

Figure 31 Development of the energy consumption of E-cars for the scenarios BAU, 550 ppm, 500 ppm and 450 ppm

Each scenario is based on assumptions about energy and fuel prices as well as tax.

- Petrol-/diesel-/electricity price
- Tax on petrol/diesel/electricity
- Specific energy consumption of the electric vehicles (E-cars)
- Specific CO_2 emissions of the different combustion technologies

These assumptions are described in the sections where the entire scenarios are described (sections 7.1 - 7.4)

7.1 Base run (business as usual scenario)

7.1.1 Fuel an electricity price developments

Figure 32 shows the development of the fuel prices for cars of different technologies (petrol, diesel, natural gas, hybrid) as well as the development of the electricity price to be expected until 2050 for the business as usual scenario. It can be seen that only a moderate increase over time is assumed. The price of natural gas is assumed to be the same in all scenarios; this might be a point of criticism but can be argued with very small shares of CNG cars in Austria (Kloess and

Müller 2011). The end value of the electricity price is roughly 0.20 EUR/kWh. Today the price is about 0.17 EUR/kWh.

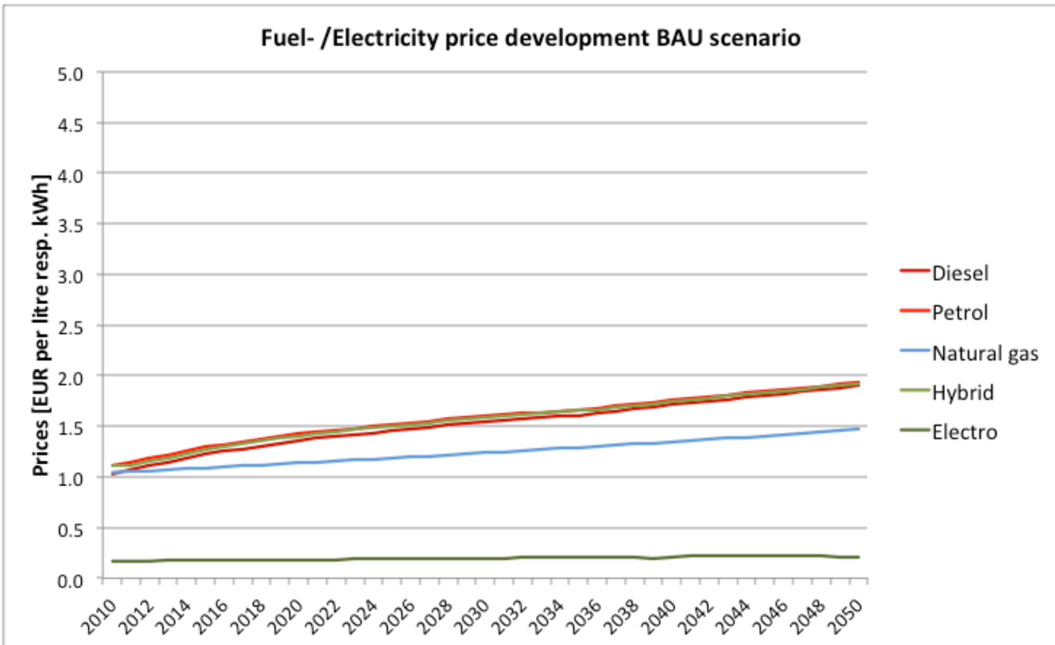

Figure 32 Fuel- and electricity price development including tax BAU scenario

7.1.2 BAU fleet development and emissions per combustion technology

In the BAU scenario, the hybrid share reaches 31%, and E-car share 39% of the total fleet in 2050. In 2030 the share is 28% hybrid and 8% E-cars. As the number of vehicles is increasing faster than the population, the level of motorization is rising, reaching a level of 642 cars/1000 inhabitants. The share of 39% of electric cars in 2050 can be classified as rather high but within range, compared to other available studies. Sammer (2011), for example, presented a share of 16% of electric vehicles for the year 2025 (Leitinger, Litzlbauer et al. 2011). For the year 2050 the Austrian Energy Agency[33] calculated three scenarios within the project "Visionen 2050". In the least progressive scenario the share of electric vehicles reaches 16% in 2050, while in the most progressive one, the share increases to 60% (Renner, Baumann et al. 2010). In the middle scenario the share reaches about 40% in 2050.

[33] Österreichische Energie Agentur. http://www.energyagency.at/

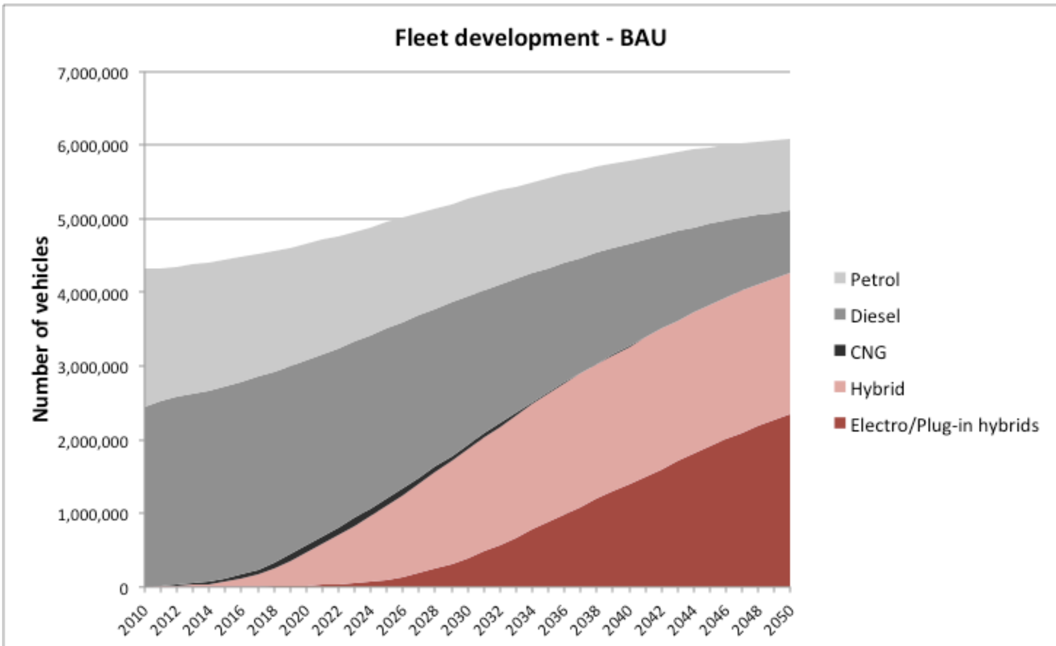

Figure 33 Fleet development of the BAU scenario. Source: (Kloess 27.10.2011), authors own representation

Figure 34 shows the CO_2 emissions for petrol/diesel/hybrid and electro cars for the BAU scenario. Due to efficiency gains in the fuel consumption, the emissions decrease by 2050. The CO_2 emissions of electric vehicles, which are dependent on the energy mix, are depicted in Figure 30.

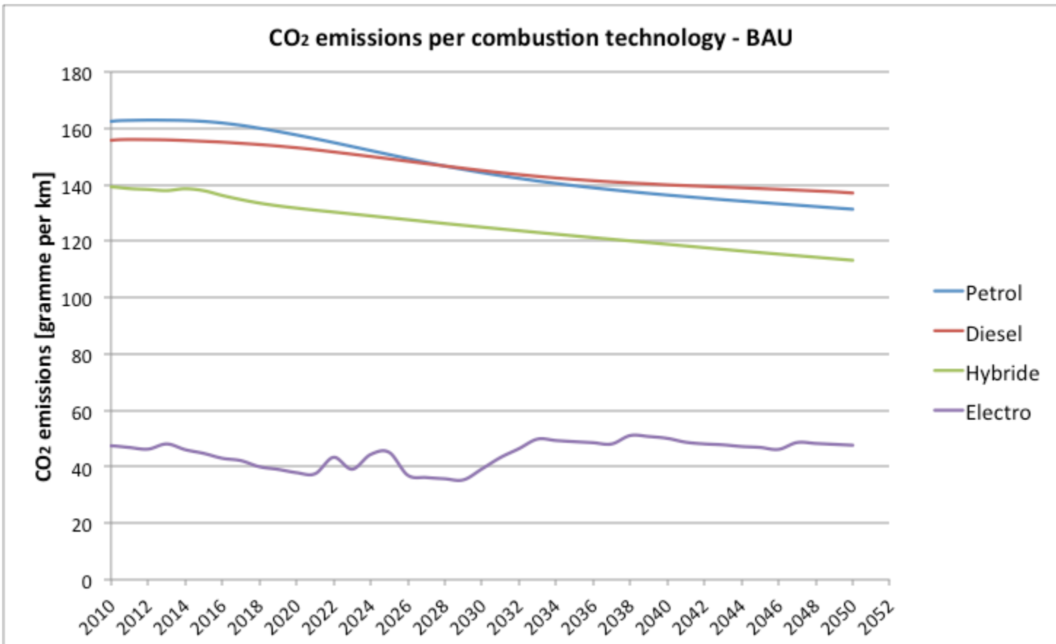

Figure 34 Development of the specific CO_2 emissions per combustion technology for the scenario BAU

7.1.3 BAU transport policies

There are no explicit transport policies implemented. The status quo concerning infrastructure and level of service for all modes of transport is extrapolated into the future. Only if region type changes occur the level of service for all modes of transport changes.

7.1.4 BAU land-use policies

In the BAU scenario no land-use policies are implemented. The settlement structures follow the development of the recent years:

- In municipalities with high shares of population outside the settlement entity (municipalities with sprawling) the number of persons outside the settlement entity increases, if the population grows.
- The consumption of land per inhabitant is kept constant for new residents moving to the zone.
- The town centres in rural areas are slowly losing population as well as services like local supply of convenience goods.

Figure 35 depicts the region types per district in the base year 2010. The dark, shaded districts represent urban zones (including Vienna), the dark grey ones suburban zones. The light grey or white districts have a rural character and are either favourable or less favourable for public transport (see section 5.3.3.1).

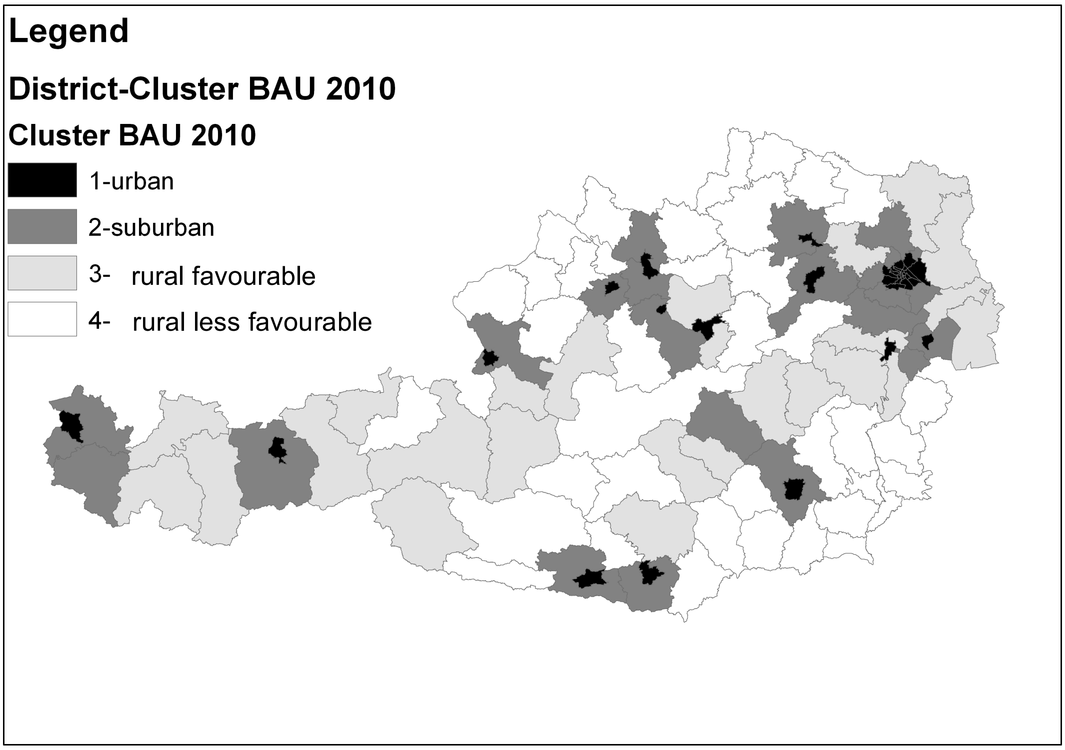

Figure 35 The region type clustering in the base year 2010

The development over time following the above pattern results in the region types shown in Figure 36.

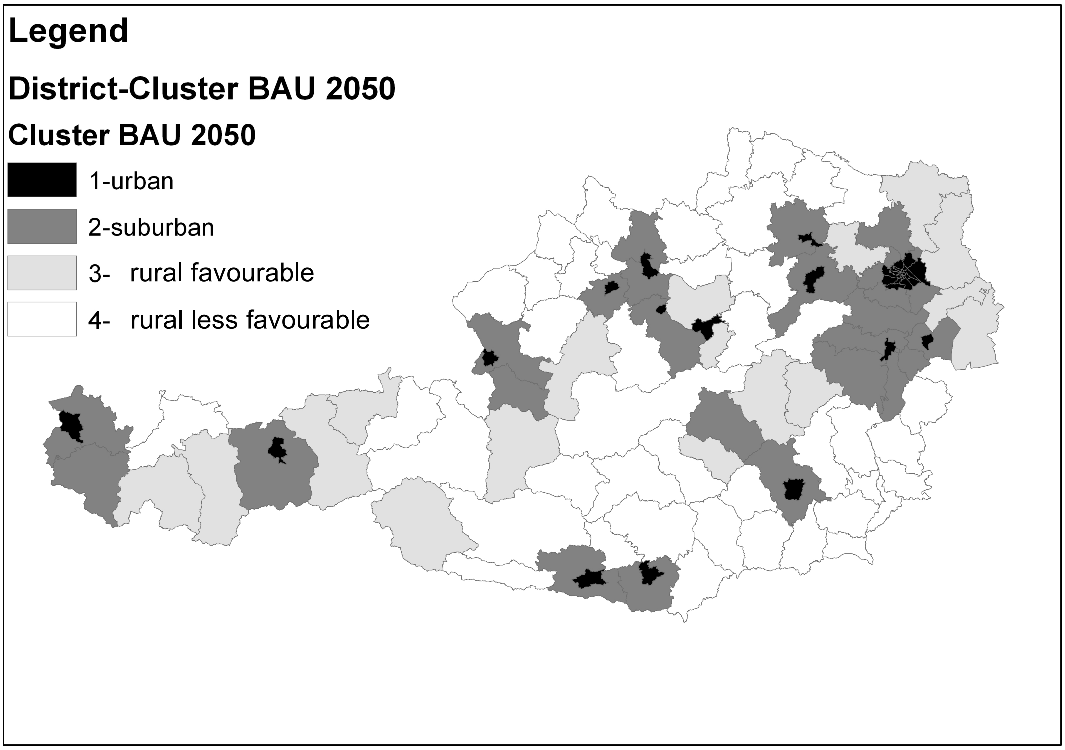

Figure 36 The region type clustering 2050 - BAU scenario

In total seven districts will change their region type until 2050.

Zone number	Zone name	Change in region type	Time of change
204	Klagenfurt Land	3 → 4	2045
318	Neunkirchen	3 → 2	2020
323	Wiener Neustadt (Land)	3 → 2	2030
502	Hallein	3 → 2	2050
506	Zell am See	3 → 4	2050
608	Judenburg	3 → 4	2045
708	Reutte	3 → 4	2020

Table 23 Region type changes of districts or the BAU scenario

Figure 37 shows the zones that change their region type in BAU. The colours display the region types (red=4, yellow=3, green=2). The regions that change their region types represent roughly 5.5% of the total population in 2050.

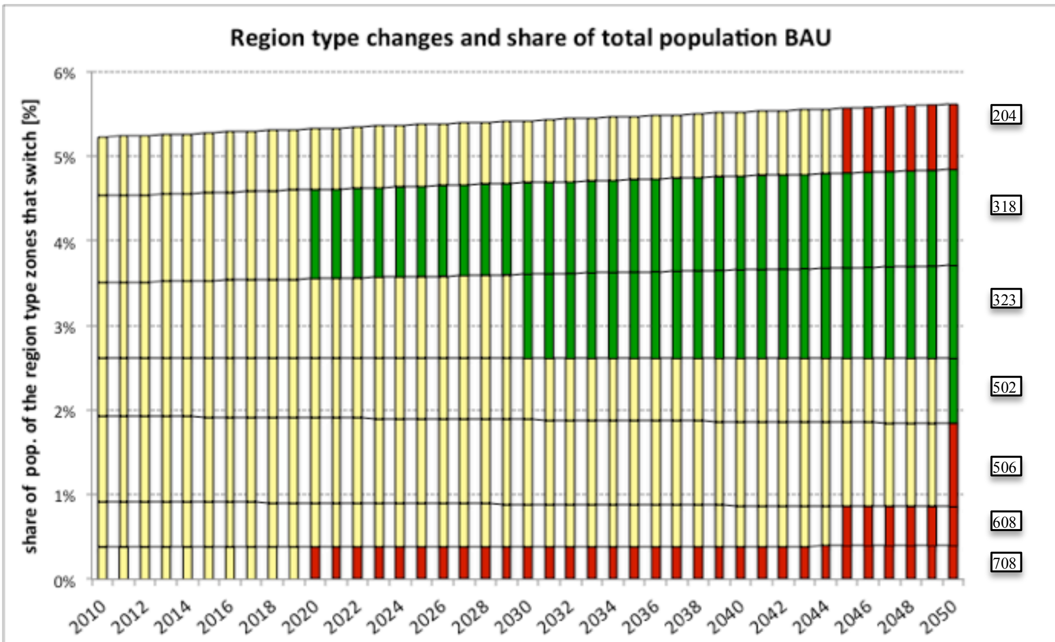

Figure 37 Zones that switch from one region type to another and their share of total population in scenario BAU. Region type codes: red=4, yellow=3, green=2

7.2 550 ppm scenario

7.2.1 550 ppm fuel an electricity price developments

In Figure 38, the price developments for the 550 ppm scenario are shown. There are two points in time when policies are activated (see section 7.2.3), which makes the slope of the curves steeper and puts the curves onto a higher level. In the year 2050, petrol and diesel prices are roughly 2.7 EUR/litre while the electricity price is about 0.28 EUR/kWh.

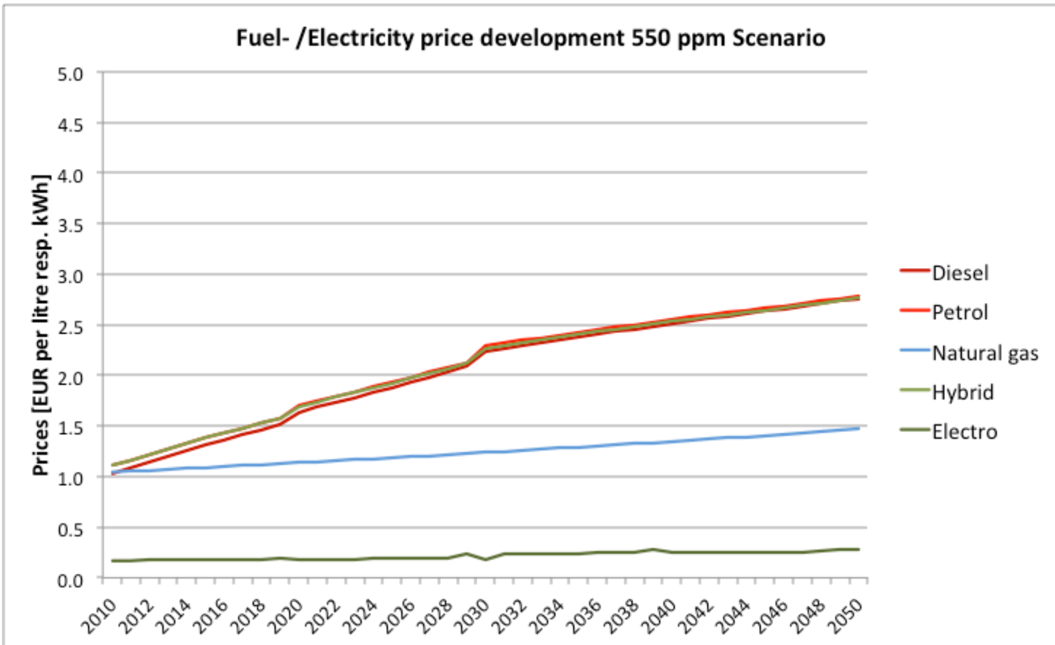

Figure 38 Fuel- and electricity price development including tax 550 ppm scenario

7.2.2 550 ppm fleet development and emissions per combustion technology

The fleet development is characterized by a stronger diffusion of hybrid and electric cars than in the BAU scenario. The share of hybrid cars is 36% in 2050, while the one of electric vehicles is 44%. Compared to the BAU scenario, the level of motorization grows moderately to 589 cars/1000 inhabitants.

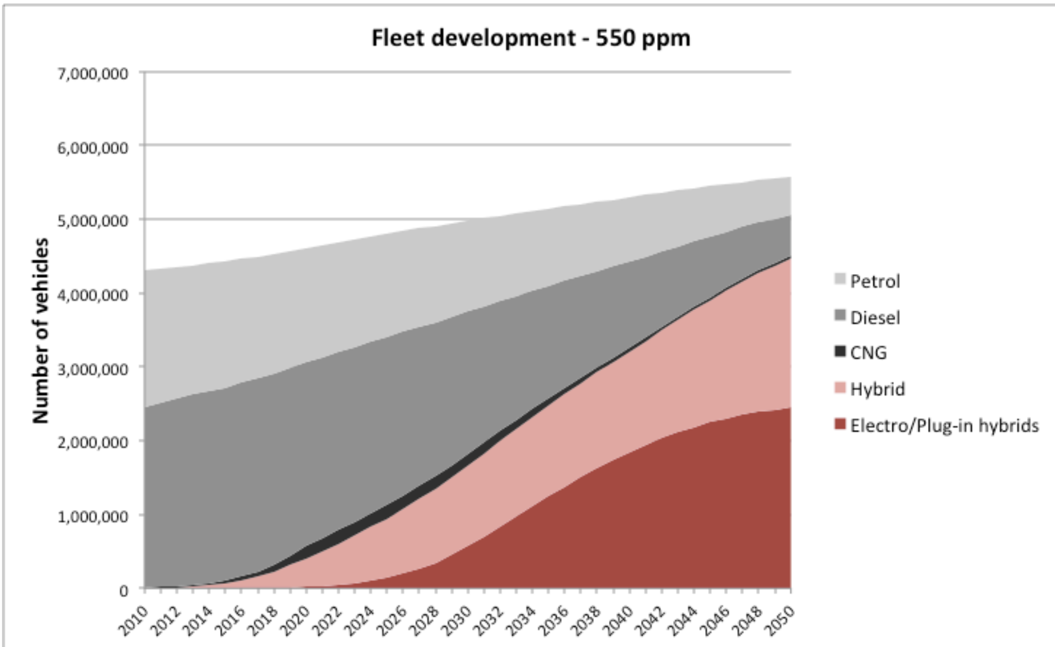

Figure 39 The fleet development of the 550 ppm scenario. Source: (Kloess 27.10.2011), authors own representation

In the 550 ppm scenario, the decrease of combustion technology specific emissions is bigger for petrol cars than in the BAU scenario (Figure 40). Hybrid and diesel cars have almost the same emissions in 2050 as in the BAU scenario. The reason lies in the fact that compact- and middle-class cars are replaced by larger cars. This substitution effect almost compensates the efficiency gain achieved through technological development.

The CO_2 emissions of electric vehicles are dependent on the energy mix. The reason for the increase in CO_2 emissions between 2037 and 2038 is described at the beginning of chapter 7 on page 113.

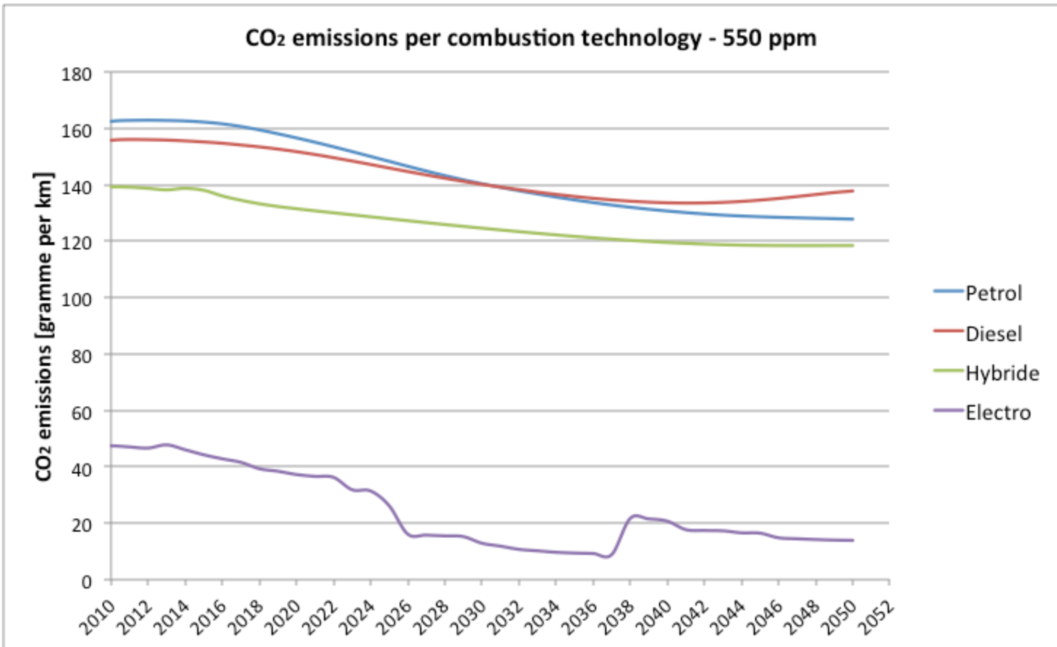

Figure 40 Development of the specific CO_2 emissions per combustion technology for the scenario 550 ppm

7.2.3 550 ppm transport policies

The transport policies implemented start at three given points in time. The state-funded policy (reduction of public transport fares) is the most feasible one, starting in 2015. The nationwide infrastructure toll[34] starts in the year 2020 respectively 2030 for e-Cars (before 2030 the share of e-Cars is below 10%). The debited amount is paid directly by the user of the infrastructure (PMT diver), needing longer preparation time for realization on the part of the politicians.

The transport polices in detail:

1. In the year 2015, the public transport toll are reduced by -25% nationwide measured against the base value of 2010 (roughly 0.14 EUR/km, which matches the average standard fee).
2. Nationwide infrastructure toll on petrol – (0.05 EUR/litre), diesel (0.06 EUR/litre) and hybrids (0.05 EUR/litre) in the year 2020 – rises to 0.12 EUR/litre, 0.14 EUR/litre and 0.13 EUR/litre in the year 2030. This corresponds to an increase of +12% in the year 2020 and +30% in 2030 compared with 2010.

[34] toll for using all roads in the network, implemented as toll per litre.

3. Nationwide infrastructure toll for E-cars amount to 0.05 EUR/kilometre beginning in 2030.

7.2.4 550 ppm land-use policies

Concerning the land-use policies, the settlement structure follows the pattern of the BAU scenario (see Figure 36).

7.3 500 ppm scenario

7.3.1 500 ppm fuel an electricity price developments

In the 500 ppm scenario, the price increase is even bigger than in the scenarios before (see Figure 41). In the year 2050, the price for petrol and diesel is higher than 3.5 EUR/litre. The electricity price is 0.36 EUR/kWh. In this scenario, there are also two points in time when additional policies are active, which can be seen in the two steps of the functions (see section 7.3.3 where the transport policies are described).

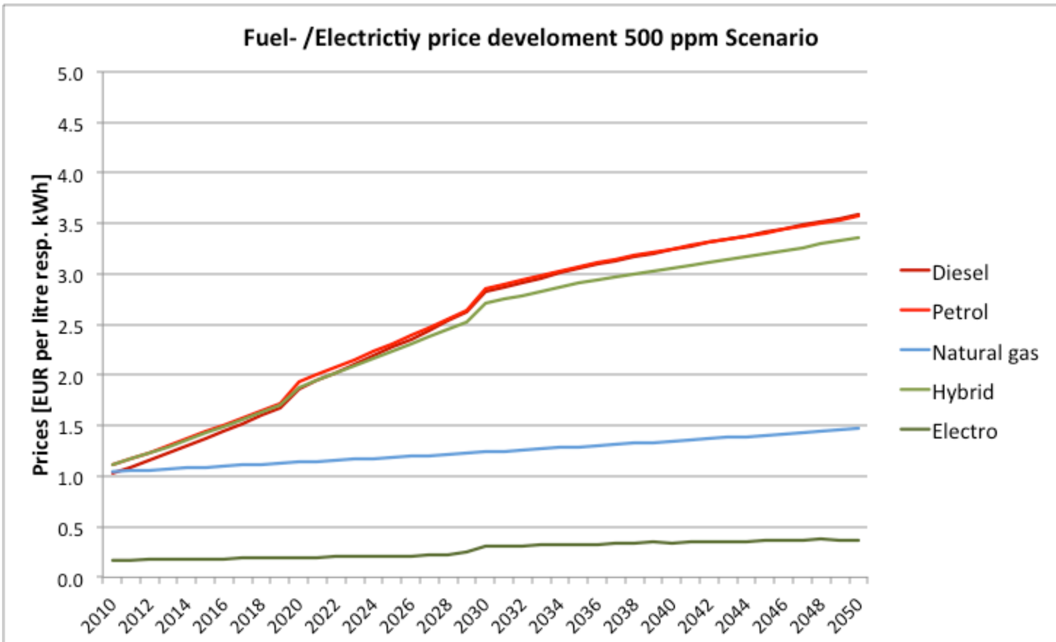

Figure 41 Fuel- and electricity price development including tax 500 ppm scenario

7.3.2 500 ppm fleet development and emissions per combustion technology

The fleet development in the 500 ppm scenario shows a share of 12% of hybrid cars in 2050. The growth in share of E-cars is more powerful, leading to a share of 50% in 2050. The overall level of motorization stays on the actual level of Austria in 2010, which is 515 cars/1000 inhabitants.

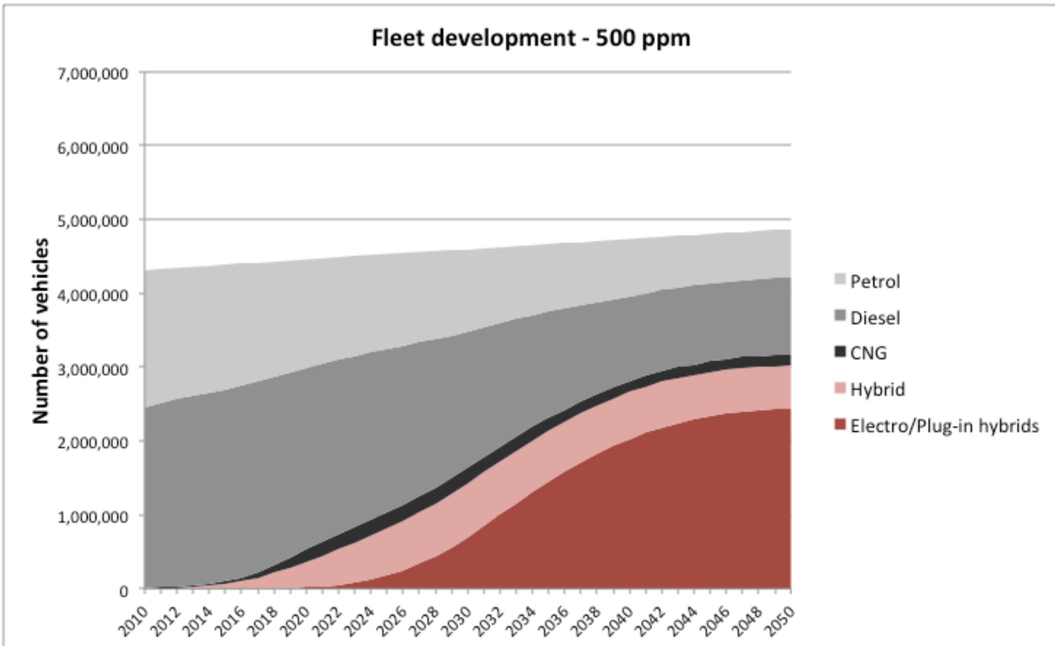

Figure 42 The fleet development of the 500 ppm scenario. Source: Source: (Kloess 27.10.2011), authors own representation

Figure 43 presents the development path for the 500 ppm scenario. The substitution effect described in section 7.2.2 is even stronger, which leads not only to a compensation but deterioration of the CO_2 emissions per combustion technology over time. Compact- and middle-class hybrid and diesel cars are substituted by larger cars, which explains the positive slope of the curves from 2040 to 2050. The overall effect concerning CO_2 emissions for the fleet is still a decline in emissions. From 2040 to 2050 about 24% - 20% of all vehicles are diesel cars, while the share of hybrid cars is between 13.5% and 12%.

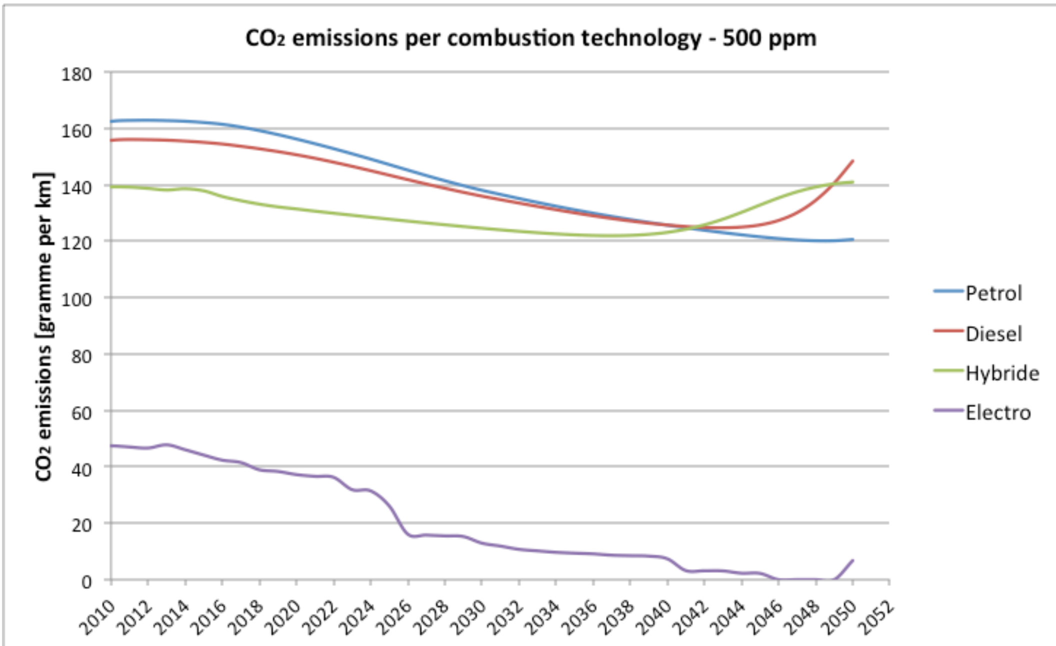

Figure 43 Development of the specific CO_2 emissions per combustion technology for the scenario 500 ppm

7.3.3 500 ppm transport policies

The set of policies implemented in this scenario cover pricing measures (public transport fees, parking fees and infrastructure tolls for the road network) as well as physical measures (building up cycling infrastructure). The policy mix covers state-funded measures (public transport fees and extension of cycling infrastructure) as well as privately funded measures (parking fees and infrastructure tolls). Parking fees and infrastructure tolls are implemented to internalise the external cost caused by car traffic[35]. Numbers from 2008 reveal that the total earnings from private motorized traffic cover roughly 44% of the caused costs (VCÖ 2008).

The public transport fee reduction policy and the increase in parking fees are implemented in 2015. This point in time is chosen assuming that these two policies are taking less lead-time than other measures. For example the coalition in Vienna implemented a reduction of the price of the so-called “Jahreskarte” (annual ticket) by roughly -22% and extended the parking fees in Vienna to

[35] Costs for accidents, air pollution, noise, traffic jams, etc.

another five districts (additional to the existing 10 districts) within two years of government.

The implementation of infrastructure tolls start in the year 2020 respectively 2030 for e-Cars. To date eight European countries have tolls for their highway road network[36] (six of special tolls for tunnel, bridges or city tolls), nine have a vignette obligation[37] (five of them special tolls for tunnel, bridges or city tolls) and one nation an emission sticker[38] (tolltickets GmbH 2013). The infrastructure tolls are implemented as tolls per litre with the advantage to give an incentive to car user to switch to more fuel-efficient car models and avoiding the necessity to built up infrastructure, like for length (km) dependent tolls.

The cycling infrastructure policy has no single starting point, but is implemented steadily, with the assumption that each year improvements in cycling infrastructure take place.

The transport policies in detail:

1. The public transport fees are reduced in 2015 by -25% and in 2030 by -50%, always compared with the base value in 2010 (see section 7.2.3).
2. In all Viennese, urban and suburban districts (58)[39], the parking fees per stay are increased by +15% in 2015. The base values in 2010 are:
   - Vienna (23)[40]: roughly 4 Euro/stay
   - Urban zones (14): 2.88 Euro/stay
   - Suburban zones (21): 1.76 Euro/stay
3. Nationwide infrastructure tolls on petrol- (0.08 EUR/litre), diesel (0.10 EUR/litre) and hybrids (0.09 EUR/litre) in the year 2020, and 0.16 EUR/litre, 0.19 EUR/litre and 0.17 EUR/litre in the year 2030. This

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[36] Croatia, France, Italy, Macedonia, Norway, Portugal, Serbia and Spain

[37] Austria, Bulgaria, Czech Republic, Hungary, Moldova, Romania, Slovakia, Slovenia, Switzerland

[38] Germany

[39] 86 municipalities in Austria have parking fees, which in the district level of MARS Austria 2010 corresponds to 58 districts (model zones).

[40] The assumption here is parking fees in all 23 Viennese districts, since 01.01.2013 in 15 of the Viennese districts parking fees are collected.

corresponds to an increase of +20% in the year 2020 and +40% in 2030 compared with 2010.

4. Nationwide infrastructure tolls for E-cars amount to 0.08 EUR/kilometre beginning in 2030.
5. Due to major improvements in cycling infrastructure (building of new cycling lanes and cycling highways) the average cycling speed in Austria over time can increase to 18 km/hour. The base value is 15.5km/hour at peak and 14.9km/hour at off-peak hours.

7.3.4 500 ppm land-use policies

The land-use policies in this scenario cover:

- No more sprawling within the municipality, new settlements are connected to the existing settlement entity
- Reduced consumption of land for new residents (-20% of the actual per capita consumption)
- The population decrease in shrinking municipalities is proportional to the population distribution, causing denser municipalities to loose relatively fewer population than less denser.

This policies influence the development of the districts. The region types resulting from these policies are shown in Figure 44.

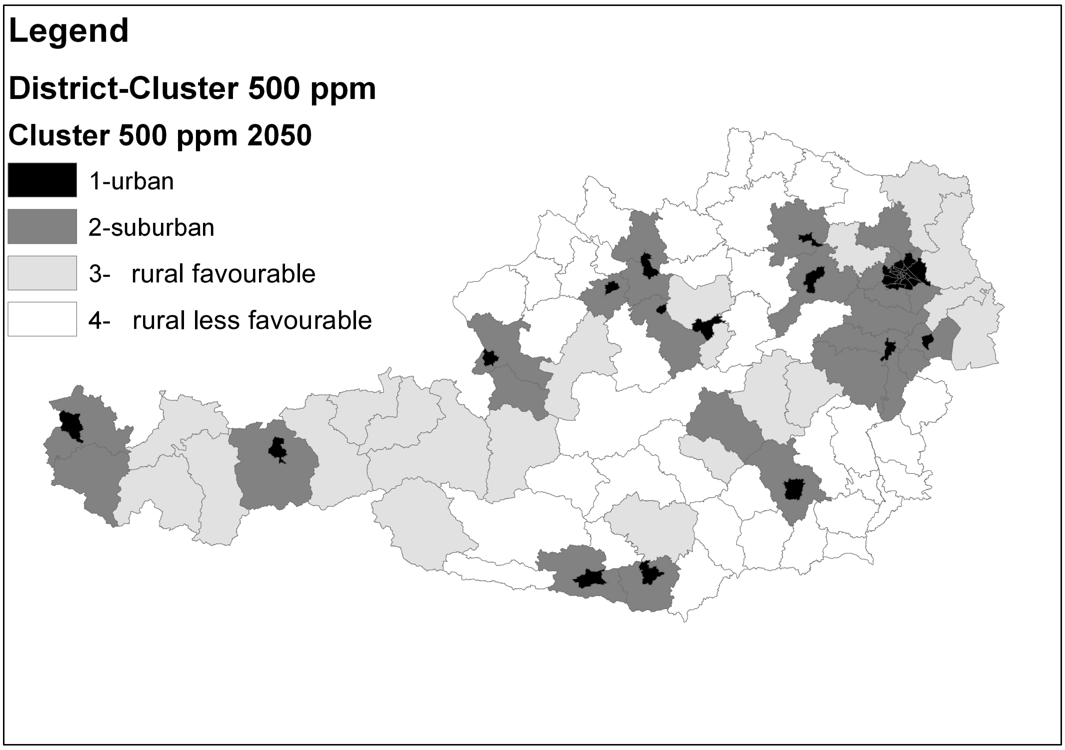

Figure 44 The region type clustering 2050 - 500 ppm scenario

In this scenario five district change in their region type. Compared to the BAU scenario where two zones changed from region type 3 to 4 and three zones changed from 3 to 2, in the 500ppm scenario three zones switch from 3 to 2 and one from type 4 to 3. Only one zone is downgrading from type 3 to 4. It can be seen that the policies implemented decrease sprawling and enhance possible public transport connectivity.

Zone number	Zone name	Change in region type	Time of change
318	Neunkirchen	3 → 2	2015
324	Wiener Neustadt (Land)	3 → 2	2030
502	Hallein	3 → 2	2040
608	Judenburg	3 → 4	2050
704	Kitzbühel	4 → 3	2045

Table 24 Region type changes of districts or the 500 ppm scenario

Figure 45 shows the zones that change their region type in the 500 ppm scenario. The colours display the region types (red=4, yellow=3, green=2). The regions which change their region types represent roughly 4% of the total population in 2050.

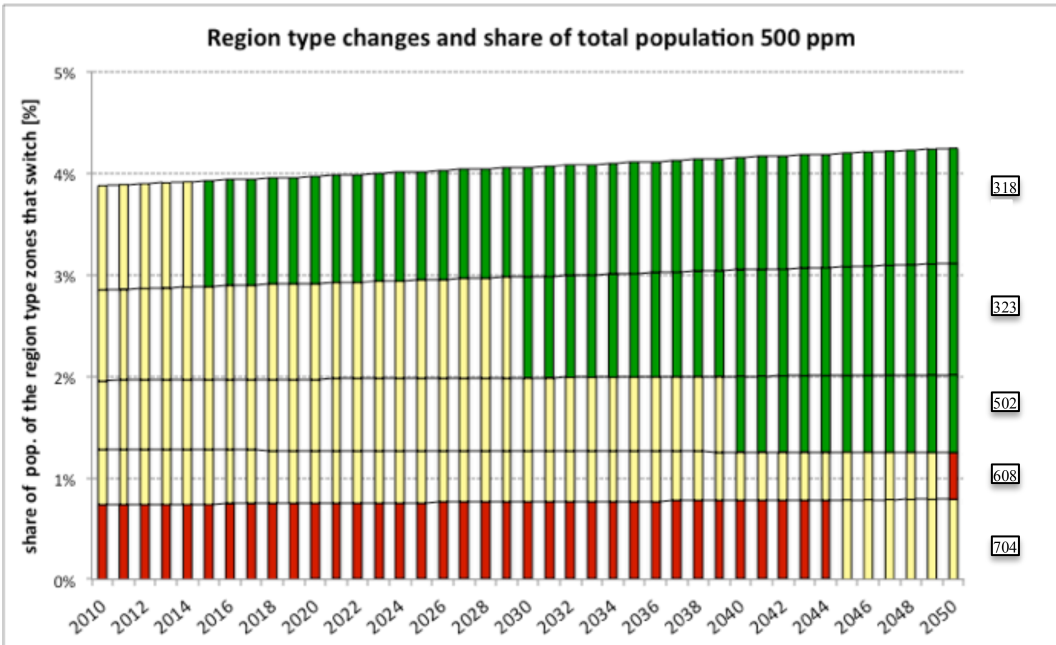

Figure 45 Zones that switch from one region type to another and their share of total population in scenario 500 ppm. Region type codes: red=4, yellow=3, green=2

7.4 450 ppm scenario

The 450 ppm scenario is the most ambitious scenario covering a huge shift in technology towards electric vehicles as well as serious transport- and land-use policies, implying a real paradigm change. Here the focus does not lie so much on political feasibility, it is a reference scenario showing a possible outcome with massive changes implemented.

7.4.1 450 ppm fuel an electricity price developments

Figure 46 depicts the price development of fuel end electricity for the 450 ppm scenario. The assumption is a price of roughly 4.5 EUR/litre for petrol and diesel in the year 2050. The electricity price for E-cars will be 0.35 EUR/kWh in 2050. As in the previous scenarios there are two time points when policies increase the prices for fuels (2020 and 2030) (see section 7.4.3 where the transport policies are described).

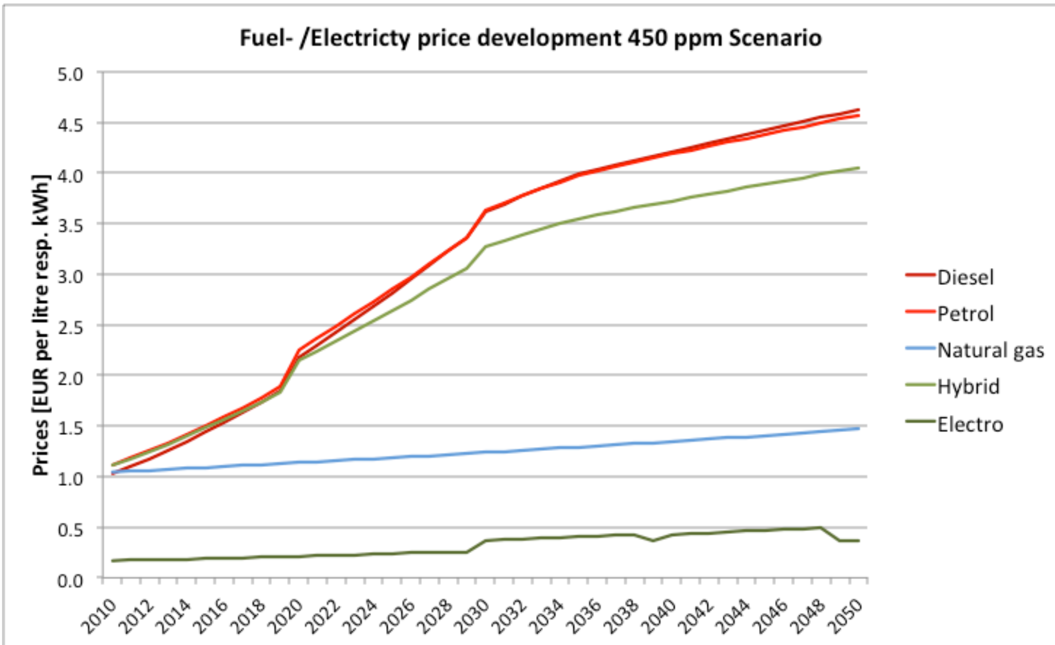

Figure 46 Fuel- and electricity price development including tax 450 ppm scenario

7.4.2 450 ppm fleet development and emissions per combustion technology

In the 450 ppm scenario E-cars are the dominating technology by 2050, which is illustrated by their share of 98%. This scenario is the only one in which the level of motorization decreases. 2050, 450 people out of 1000 own a car or an E-car. The underlying assumption for a decrease in vehicle ownership is that the ambitious transport and land-use policies influence vehicle ownership negatively, resulting in a lower overall level of motorization.

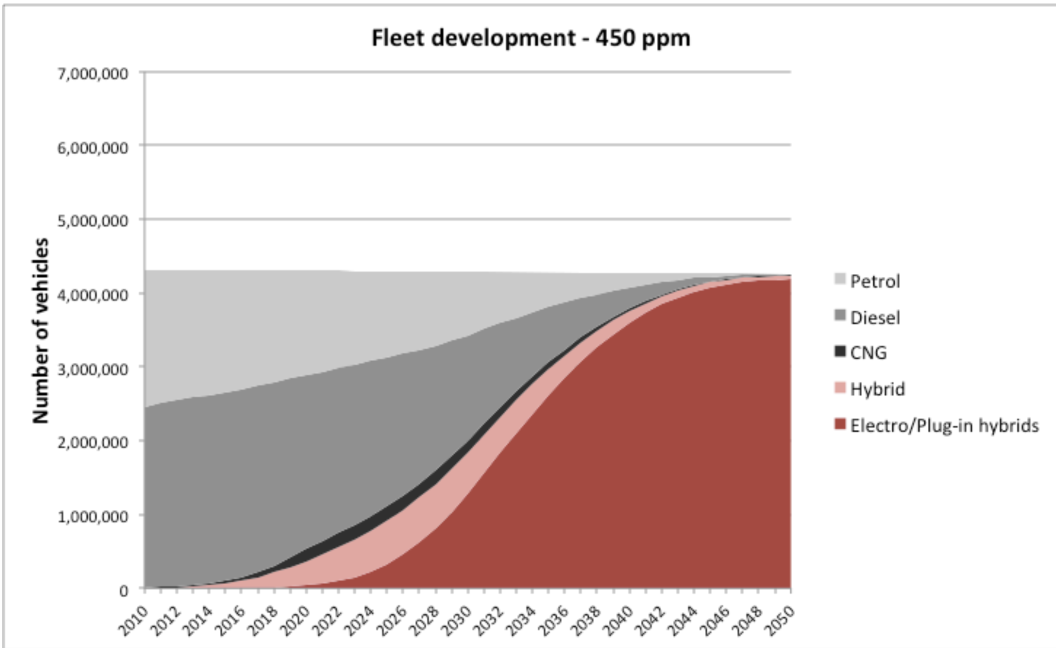

Figure 47 The fleet development of the 450 ppm scenario. Soure: (Kloess 27.10.2011), authors own representation

The CO_2 emissions per combustion technology in the 450 ppm scenario follow the pattern of the 500 ppm scenario. Again the overall CO_2 emissions the underlying fleet produces are lower than in the scenarios before.

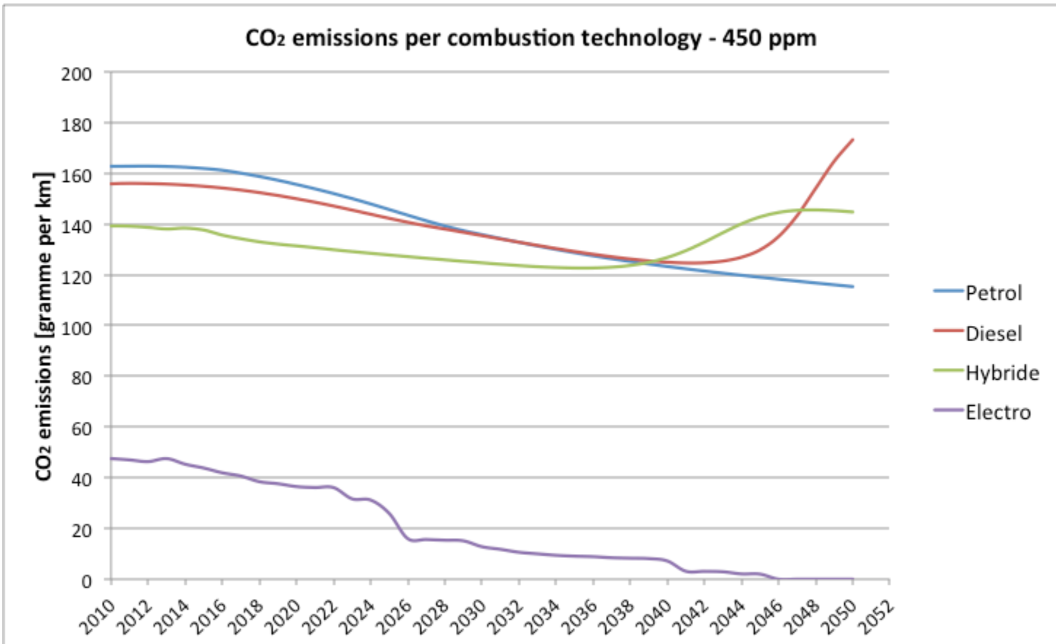

Figure 48 Development of the specific CO_2 emissions per combustion technology for the scenario 450 ppm

7.4.3 450 ppm transport policies

As in the 500 ppm scenario the set of policies implemented in this scenario cover pricing measures (public transport fees, parking fees and infrastructure tolls for the road network) as well as physical measures (building up cycling infrastructure, collective garages policy, regular interval timetable reducing changing times, road capacity reduction and speed limits for road traffic and an increase in rail network).

The public transport fares scenario is exactly the same than in the 500 ppm scenario.

Three of the described policy measures are of the same kind like in the 500 ppm scenario but differ in magnitude. In 2015 respectively 2030 the parking fares still implemented but increased higher. The improvement in cycling infrastructure, increasing the average speed, is traced even more intensive. The infrastructure tolls are still implemented but at higher levels.

Four of the policies are new. The collective garages policy gradually substitutes surface parking with collective garages. This increases the average walking times from and to the parking places. This policy simulates equal distance to public transport on the one hand and the car/E-car on the other hand.

The regular interval timetable for public transport rail is implemented in 2025. This policy is in line with the “overall traffic plan (Gesamtverkehrsplan)” 2012 from the federal ministry of transport, innovation and technology where a gradual implementation of a regular interval timetable for public transport (Bundesministerium für Verkehr Innovation und Technologie 2012, p.58) is planned.

The policy reducing the overall average speed in peak time is argued with road capacity reductions and the implementation of lower speed limits. This policy is implemented gradually. The speed reduction potential is assumed to be -30% from the base value of 52 km/hour.

For the average speed of the public transport mode rail a steady improvement in rail network is assumed, leading to an increase in speed of +25% from the base average speed of 49 km/hour.

The policies for the most ambitious scenario in detail:

1. The public transport fees are reduced by -25% in 2015 and by -50% in 2030, always compared to the base value in 2010 (see section 7.2.3).
2. In all Viennese, urban and suburban districts (58), the parking fees per stay are increased by +20% in 2015 and by +50% in 2030.
3. Due to major increases in cycling infrastructure (building of new cycling lanes and cycling highways), the average cycling speed in Austria can increase to 20 km/hour.
4. Nationwide infrastructure tolls on petrol- (0.16 EUR/litre), diesel (0.19 EUR/litre) and hybrids (0.17 EUR/litre) in the year 2020, respectively 0.24 EUR/litre, 0.29 EUR/litre and 0.26 EUR/litre in the year 2030. This corresponds to an increase of +40% in the year 2020 and +60% in 2030 compared with 2010.
5. Nationwide infrastructure tolls for E-cars amount to 0.10 EUR/kilometre beginning in 2030.
6. Additionally, a collective garages policy is implemented.

   The average time to reach the car from home is assumed to be 4 minutes in peak time and 3.5 minutes in off-peak time in urban districts. Over time, this access time increases to 7 and 5.5 minutes. In Vienna the access time is assumed to be 7 minutes in peak and 6 minutes in off-peak time, and increases further to 9 and 8 minutes in 2050. This corresponds to a walking distance of a maximum of 525 meters (9 minutes) and a minimum of 290 meters (5.5 minutes). The average walking distance in Vienna to reach the next tram stop is about 300 meters, while average walking distances to the metro is roughly 500 meters.
7. Implementation of a regular interval timetable for public transport rail in 2025. In MARS this policy is modelled as reduction in changing times (10% for peak) mapping the connection security.
8. It is assumed that the expansion of the road network comes to a halt, that road capacity is reduced and that lower maximum speed limits are introduced, reducing the average speed in peak time for PMT by 15 km/h until 2050.
9. In turn the rail network is steadily improved, leading to an increase of the average speed by 10 km/h until 2050.

7.4.4 450 ppm land-use policies

The assumed land-use policy is the most ambitious one compared to the scenarios described before. It combines the following assumptions:

- 70% of all new developments are within the settlement entity (in BAU municipalities were sprawling), where 30% of the new inhabitants settle in connection to the settlement entity. This policy substantially reduces the land consumption.
- The land-consumption for new residents is reduced by -50% compared to the BAU scenario (where consumption of land per inhabitant was kept constant for new residents).
- Even in shrinking municipalities, town centres are strengthened (In BAU town centres in rural areas where losing population as well as services lice local supply of convenience goods).

These policies result in a different region type clustering in 2050 compared to the other scenarios.

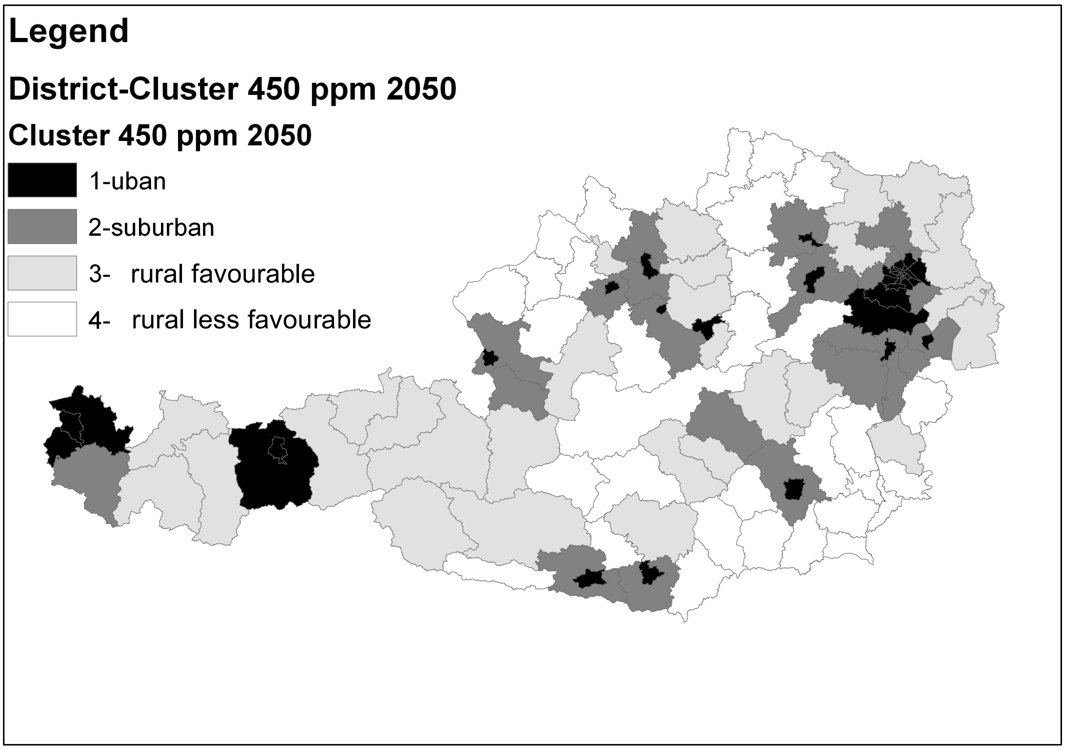

Figure 49 The region type clustering 2050 - 450 ppm scenario

In this scenario not only regions from type 4 switch to type 3 but also suburban districts change to urban ones. All in all, 15 regions change their region type. In these 15 districts 1.4 m. people are living in 2050 (the overall population prognosis are 9.5 m. inhabitants for Austria). Five zones switch before or at 2030, the other 10 after 2030. Though this is the most ambitious land-use policy scenario, land-use changes take a long time.

Zone number	Zone name	Change in region type	Time of change
109	Oberwart	4 → 3	2050
206	Sankt Veit an der Glan	4 → 3	2050
306	Baden	2 → 1	2040
310	Hollabrunn	4 → 3	2050
317	Mödling	2 → 1	2030
318	Neunkirchen	3 → 2	2015
323	Wiener Neustadt (Land)	3 → 2	2030
405	Eferding	4 → 3	2035
406	Freistadt	4 → 3	2040
411	Perg	4 → 3	2025
502	Hallein	3 → 2	2040
703	Innsbruck-land	2 → 1	2015
704	Kitzbühel	4 → 3	2035
802	Bregenz	2 → 1	2045
804	Feldkirch	2 → 1	2040

Table 25 Region type changes of districts or the 450 ppm scenario

Figure 50 shows the zones that change their region type in the 450 ppm scenario. The colours display the region types (red=4, yellow=3, green=2, dark green=1). The regions that change their region types represent roughly 15% of the total population in 2050.

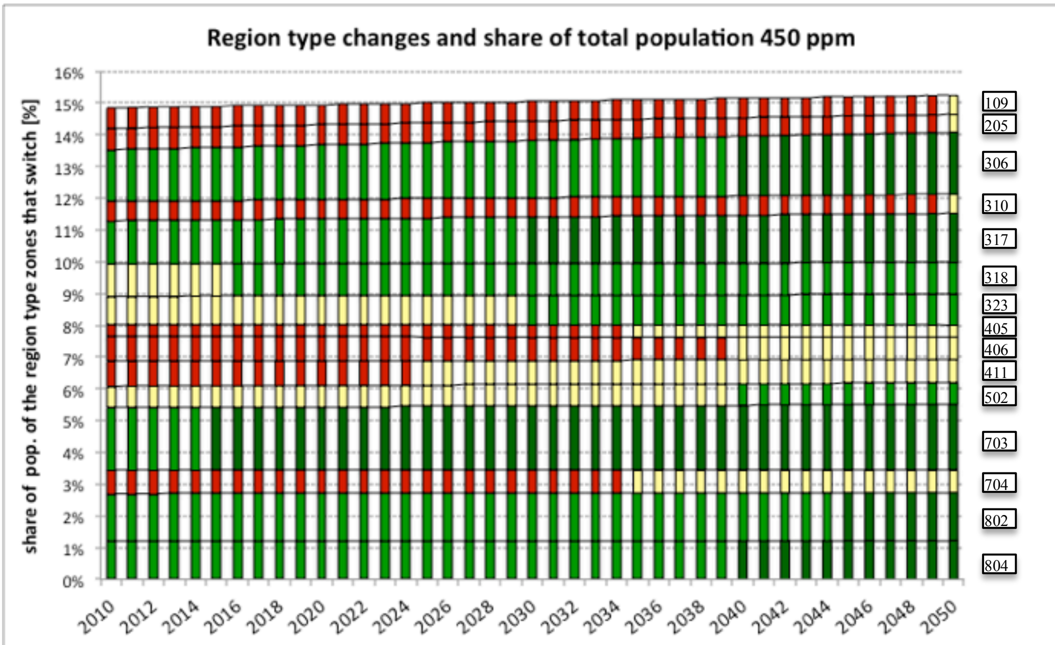

Figure 50 Zones that switch from one region type to another and their share of total population in scenario 450 ppm. Region type codes: red=4, yellow=3, green=2, dark green=1

7.5 Technology scenario – tech.

The fuel and electricity price developments in the tech. scenario are assumed to be the same as in the 450 ppm scenario.

The fleet development follows the 450 ppm development (see section 7.4.2) as well as the specific CO_2 emissions per combustion technology.

There are no transport and land-use policies implemented.

7.6 BAU-frozen technology

The fleet development of the BAU-frozen technology scenario follows the BAU fleet level of motorization development but keeps the shares of the combustion technologies constant over time. All other assumptions (fuel and electricity price developments, specific CO_2 emissions per combustion technology, transport- and land-use policies) follow the BAU scenario.

7.7 TPO

The transport policy only scenario has the same fuel and electricity price development s as the 450 ppm scenario.

7.7.1 TPO fleet development and emissions per combustion technology

The fleet development in the TPO scenario is assumed to follow the negative growth rates of the 450 ppm scenario but to keep the shares of the different combustion technologies constant over time, corresponding to the 2010 shares. The fleet development is depicted in Figure 51.

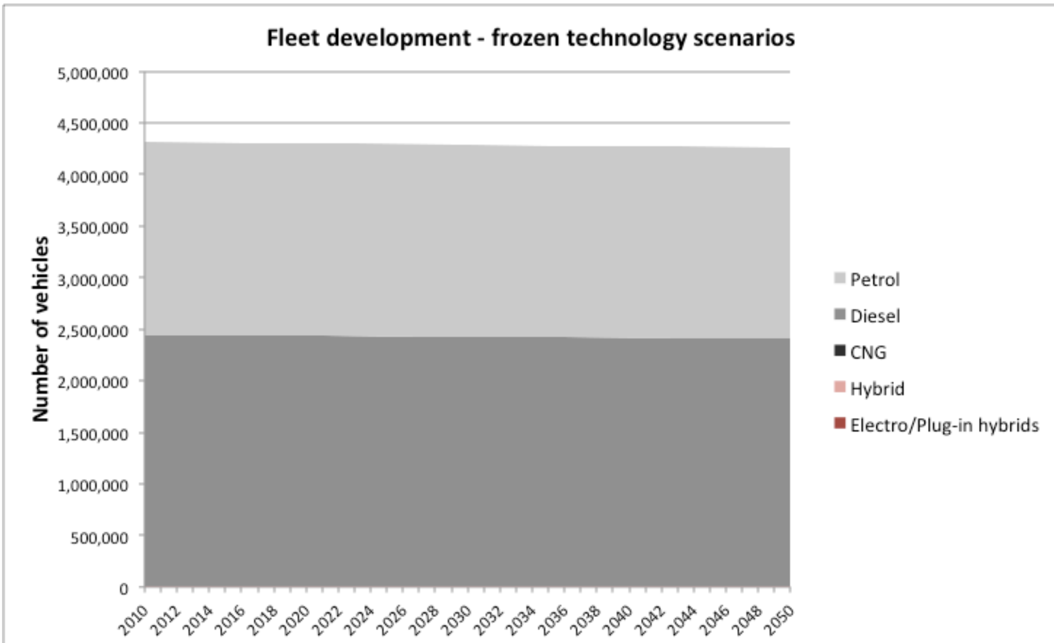

Figure 51 The fleet development of the frozen technology scenarios (TPO and LPO)

The CO_2 emissions per combustion technology in the TPO scenario follow the 450ppm development (see section 7.4.2).

7.7.2 TPO transport and land-use policies

The transport policies implemented follow the 450 ppm scenario. In this scenario there are no land-use policies implemented, the BAU development is assumed.

7.8 LPO

The land-use policy only scenario has the same fuel and electricity price development s as the 450 ppm scenario.

7.8.1 LPO fleet development and emissions per combustion technology

The fleet development follows the development depicted in Figure 51, negative growth rates of the 450 ppm scenario and constant shares of 2010 for the different combustion technologies.

The CO_2 emissions per combustion technology in the LPO scenario follow the 450ppm development (see section 7.4.2).

7.8.2 LPO transport and land-use policies

In the land-use policy only scenario no transport policies are implemented. The land-use policies follow the land-use policies implemented in the 450 ppm scenario (see section 7.4.4)

8 RESULTS OF THE MODELLED SCENARIOS

This chapter presents the evaluation framework for the assessment of the modelled scenarios. Further the results per scenario are presented.

8.1 Evaluation framework

According to the research questions in section 1.3, there is a need for indicators to evaluate the development of transport behaviour and CO_2 emissions.

A sole reduction of emissions can be achieved by substituting fuel combustion technologies with electric vehicles (assuming a 100% renewable production of electricity). The question is whether that is a desired outcome or not. E-cars are much “greener” than conventional cars, but other problems remain. They still consume a lot more space than would be needed for pedestrians, cyclists or public transport. Figure 52 presents the space consumption per means of transport in m2 per person.

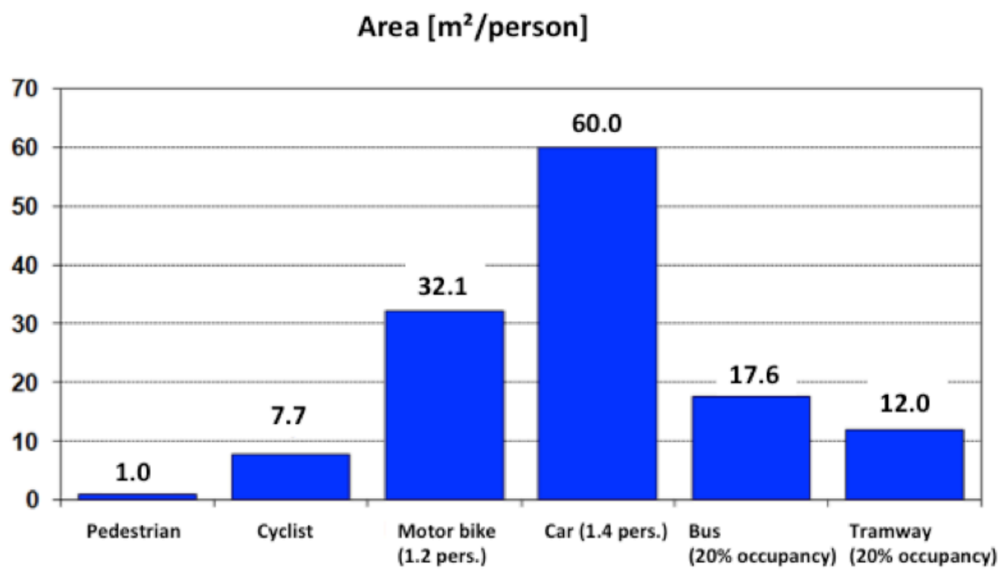

Figure 52 Space consumption per means of transport. Source: (Pfaffenbichler 2001)

For the pedestrian the space consumption with high traffic volume is calculated. For all other means of transport, space consumption is calculated with vehicle length, width requirement and necessary stopping distance.

Especially in cities, the allocation of public space is a criterion for quality of living and security within the transport system. Should space again be at the disposal of pedestrians and cyclists? The development of the settlement structures over time has shown, that cars (as the fastest individual terrestrial mode of travel) enabled humans to cover longer distances spending the same time for daily travel, as previous to the development of the car. This fact produces spatial impacts such as suburbanisation processes.

As far as the energy consumption is concerned, walking, cycling and public transport are still more efficient than E-cars. Figure 53 shows the primary energy demand for different modes of transport per trip (calculated with typical trip distances per mode) and differentiated for production and running the modes of transport. It is easy to see that a conventional car has the highest primary energy demand, compared to all other modes of transport.

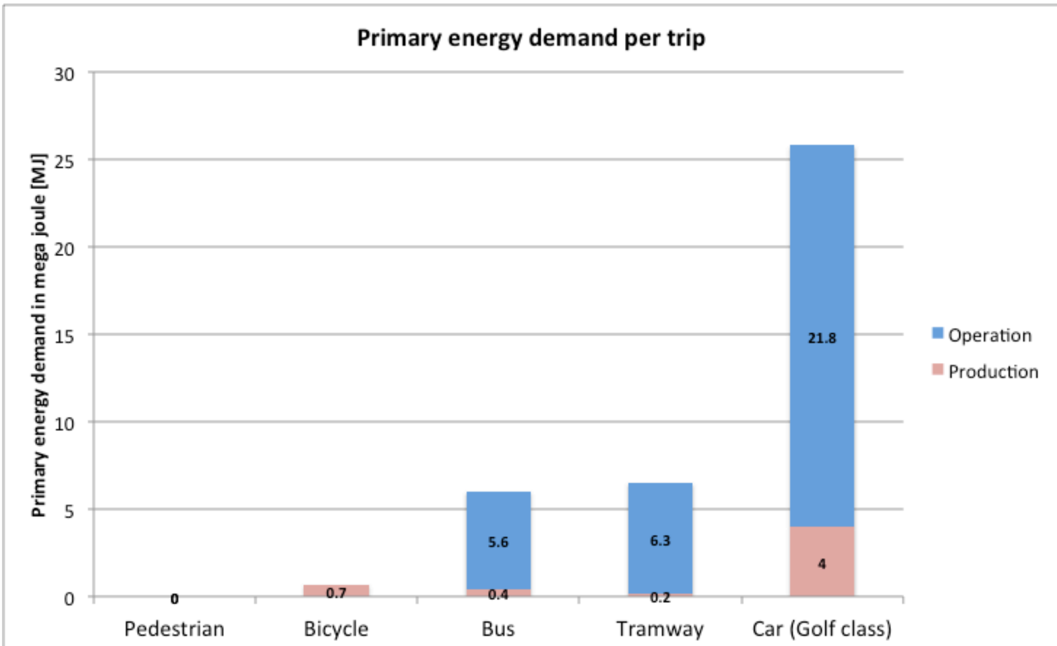

Figure 53 Primary energy demand for different modes of transport per trip. Source: (Pfaffenbichler 2001)

To sum up, I want to state that the ideal transport system (in terms of space- and energy consumption) would not imply a pure substitution of technology but a reorganization of the transport system in order to enhance the environmental friendly modes. This reorganisation of the transport system can be shown with indicators for transport behaviour.

8.1.1 CO2 emissions (pump to wheel)

The presented CO_2 emissions (passenger transport without air) are always emissions emerging from running the vehicles (pump to wheel). The emissions from E-cars are presented separately because in national emission accounting, they would be assigned to the electricity-generating sector. They are calculated with zero for running the vehicles. The mandatory admixture of biofuels (5.75% in 2010) according to the EU legislation (European Parliament and the Council of the Europen Union 2003) is considered, which lowers the accounted emissions for diesel. The life cycle analysis for biofuels is missing.

The grey energy for electric vehicles and the use of biofuels is not taken into account. The lifecycle analysis would change the CO_2 emission output, but this analysis would go beyond the scope of the thesis.

The advantage of this approach is the comparability of the resulting emissions with the historical data from the Federal Environment Agency (Umweltbundesamt).

Emissions passenger transport road	Tonnes of CO_2 per year
1950	319,001
1960	1,707,000
1970	5,121,000
1980	8,223,001
1990	8,987,000
2000	10,815,000
2009	10,191,000
2010	10,029,000

Table 26 CO_2 emissions passenger transport road 1950,1960,1970,1980,1990, 2000 2009 and 2010. Source: (Österreichische Luftschadstoffinventur (OLI) 2011)

The CO_2 emissions per scenario are compared to the targets described in the sections 1.1.1.1 and 1.1.1.2 and are depicted in the presentation of the results.

8.1.2 Indicators of transport behaviour

For the description of transport behaviour the modal split will be provided for the scenarios in the time steps 2010, 2025 and 2050.

Passenger kilometres for each mode, the vehicle kilometres driven by car and E-car and the average trip length will then be presented for the whole of Austria.

In addition, the passenger kilometres per mode and destination region type are presented for all scenarios for the base year and the year 2050. The passenger kilometres for 2025 are not presented, the policies (transport- and land-use) influencing transport behaviour are mostly implemented beyond 2025, and take effect after this point in time.

8.2 BAU

8.2.1 CO_2 emissions - BAU

Figure 54 presents the development of the CO_2 emissions over time. In 2010, 11,646,876 tonnes of CO_2 were emitted. In 2032, the emissions are smaller than in the base year for the first time. Until 2050, the CO_2 emissions are reduced to 7,507,421 tonnes. This value is smaller than the calculated emissions in 1980 but higher than in 1970 (see Table 26). Without additional efforts like transport or land-use policies the emissions cannot be reduced to the targets formulated in the Kyoto protocol, the White Paper 2011 and the EU Roadmap 2050[41], depicted by the grey, black and blue lines in the figure. The implemented fleet development alone is not sufficient to achieve the necessary reduction.

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[41] In the Roadmap 2050 three pathways of decarbonizing the economy have been formulated. In this thesis the 80% reduction path is depicted (see section 1.1.1.2).

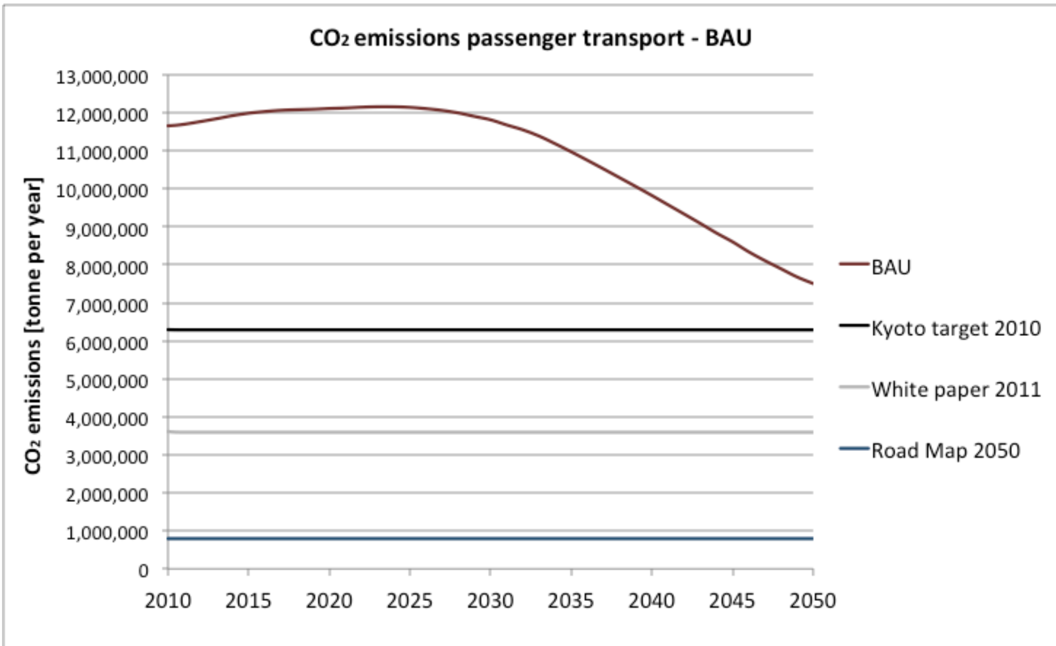

Figure 54 CO_2 emissions per year - BAU

In Figure 55, the CO_2 emissions from E-cars are depicted. These emissions are dependent on the energy mix developments for the power generating sector (see chapter 8) as well as efficiency assumptions for the electric vehicles themselves. In 2050, the emissions from E-cars result in 1,673,766 tonnes of CO_2.

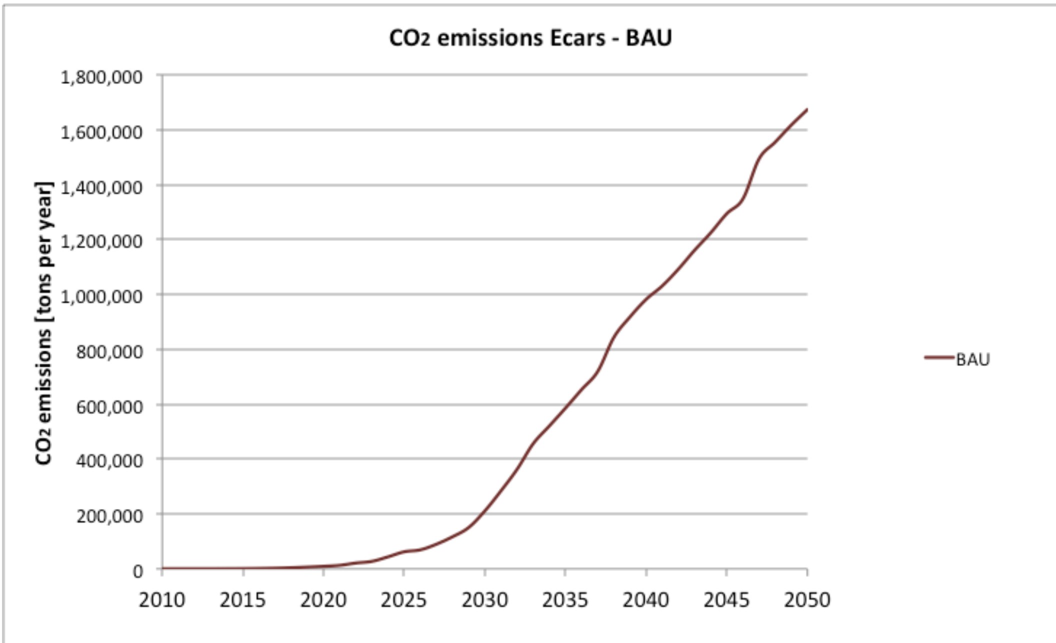

Figure 55 CO_2 emissions from E-cars - BAU

8.2.2 Modal split - BAU

Figure 56 depicts the modal split for the trip purpose commuting of the years 2010, 2025 and 2050. Walking, cycling and public transport are depicted in the different green colours. The development shows a reduction of the shares of these modes until the year 2050.

Until 2025, cars gain shares from pedestrians, cyclists and public transport. After 2030, the increase of E-cars in the fleet composition is visible in the modal split, too. E-cars increase their share to 29% in 2050. The total share of the private motorized transport (PMT) in 2050 is 77%, 11 percentage points higher than in 2010. Pedestrians and bicycles suffer from the biggest losses. In total, these modes lose about seven percentage points until 2050.

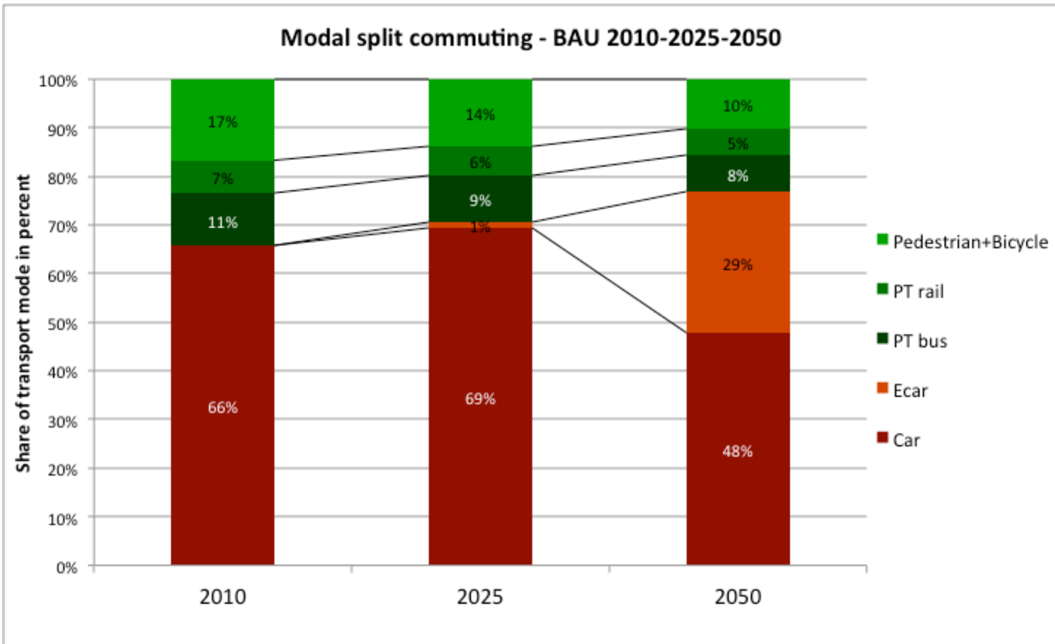

Figure 56 Modal split trip purpose commuting for the scenario BAU, years 2010, 2025 and 2050

For all other trip purposes the pedestrian and bicycle share decreases until 2025, whereas from 2025 to 2050, there is regain of two percentage points. In total the car and E-car share increase to 58% in 2050. In contrast to the trip purpose commuting, the public transport modes can keep their shares constant, only PT bus experiences a slight loss of one percentage point until 2025.

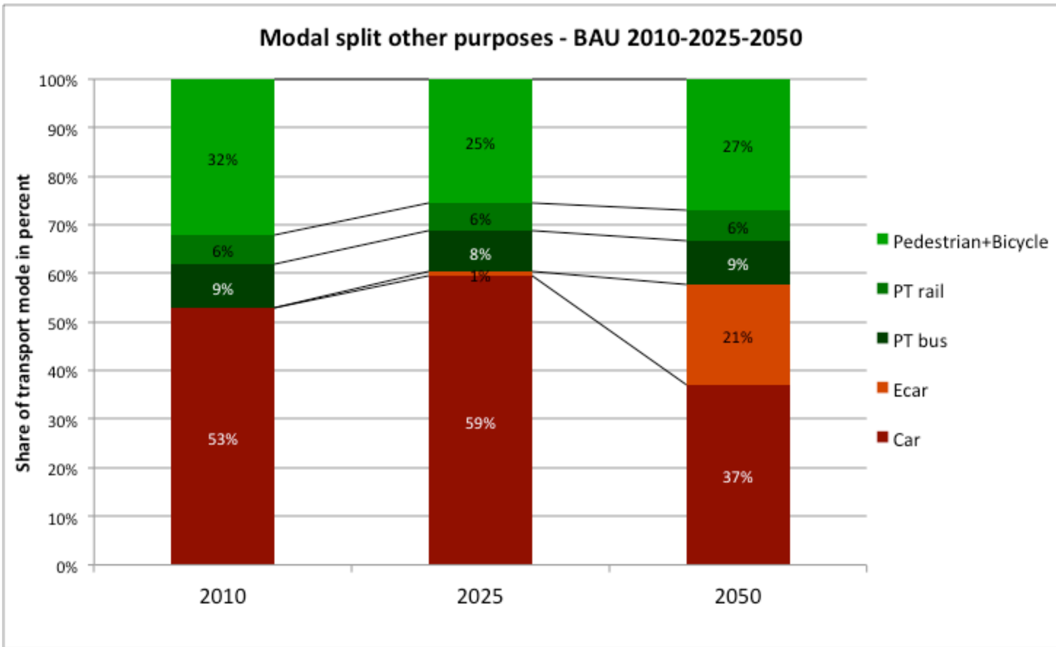

Figure 57 Modal split for all other trip purposes for the scenario BAU, years 2010, 2025 and 2050

Looking at the overall modal split (Figure 58), pedestrians and bicycles lose 6% until 2050. As far as public transport is concerned, public transport bus loses one percentage point. In 2050, 65% of all trips are either E-car or car trips.

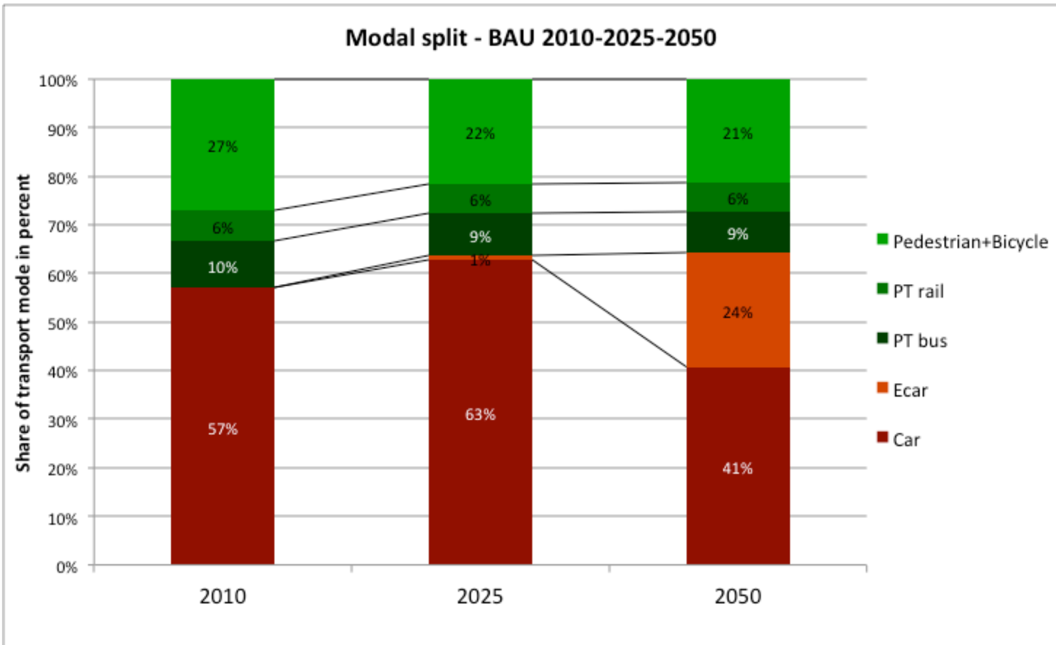

Figure 58 Modal split in total for the scenario BAU, years 2010, 2015 and 2050

8.2.3 Passenger/vehicle kilometres and average trip length – BAU

Figure 59 presents the passenger kilometres for the scenario BAU. The shift in combustion technology is also visible in the decrease of passenger kilometres by car and the increase of passenger kilometres by E-car.

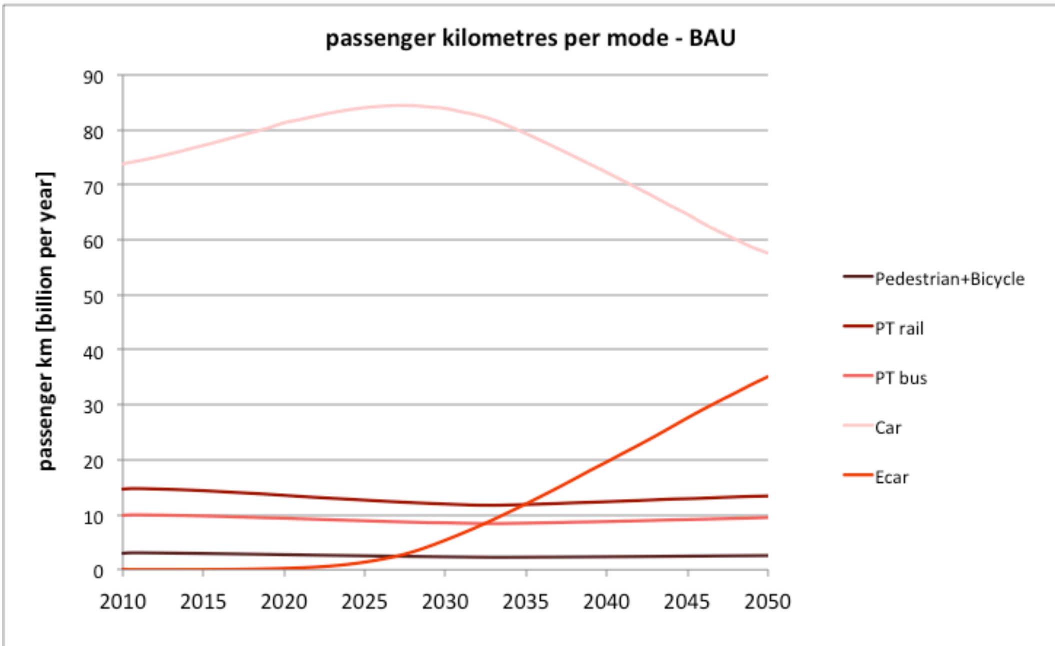

Figure 59 Passenger kilometres for the scenario BAU

In total the passenger kilometres rise till 2050 to 118 billion (see Figure 60).

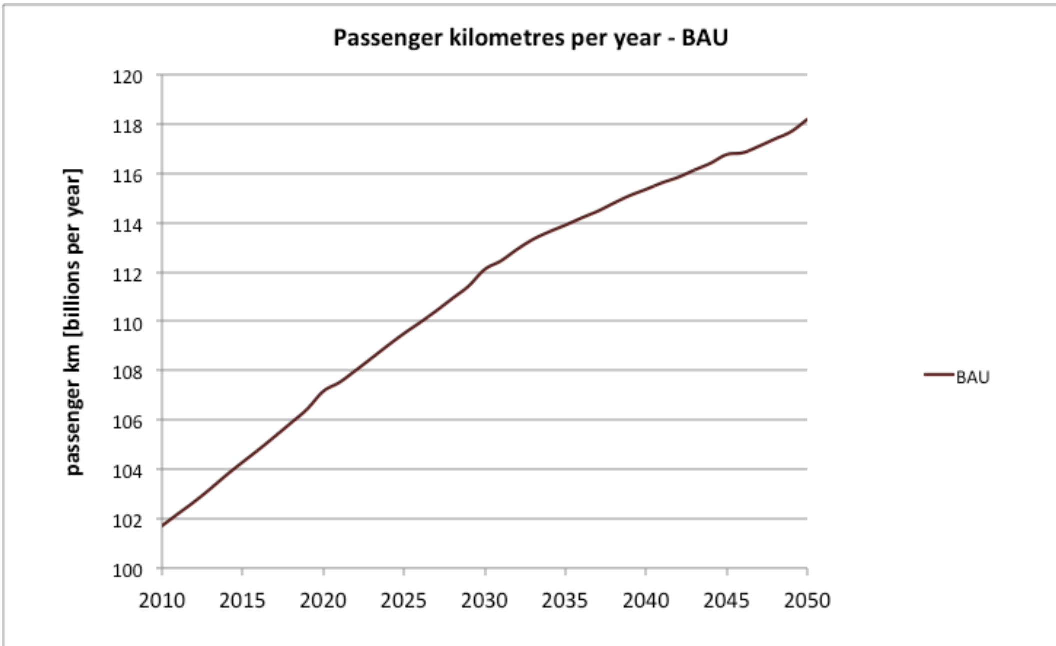

Figure 60 Passenger kilometres in total BAU

Figure 61 depicts the share of passenger kilometres per mode and region type for the year 2010. The shares represent the passenger kilometres resulting from all trips going to one of the region types as destination. For example the share of passenger kilometres for trips going to Vienna by car is 60%. The car shares increase for the region types urban, suburban, rural favourable for public transport and rural less favourable for public transport.

The shares of passenger kilometres per mode and region type are an indicator for transport behaviour in a unit of length. The indicator mirrors the influence of the region type and its implied level of service for public transport. In the base year 2010 the highest share of passenger kilometres by car are to rural zones with less favourable conditions for public transport supply.

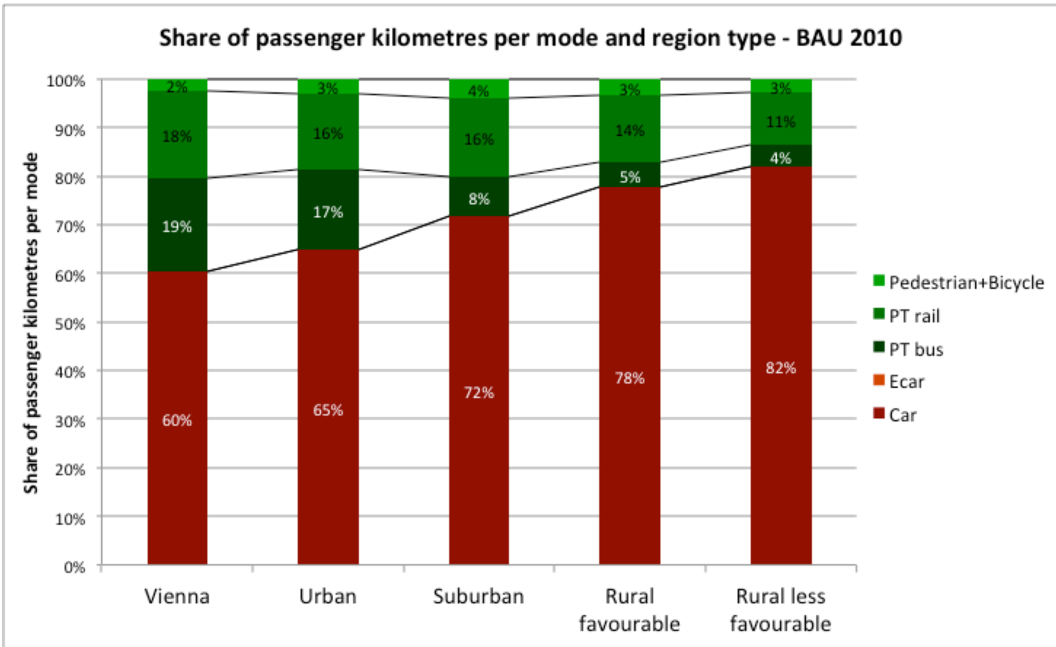

Figure 61 Share of passenger kilometres per mode and region type in 2010 for the scenario BAU

Figure 62 also presents the passenger kilometres per mode and region type, but for the year 2050. The PMT shares increased in all region types, reaching nearly 90% in rural zones with bad public transport supply. But also for trips with the destination Vienna, the share increased to 67%.

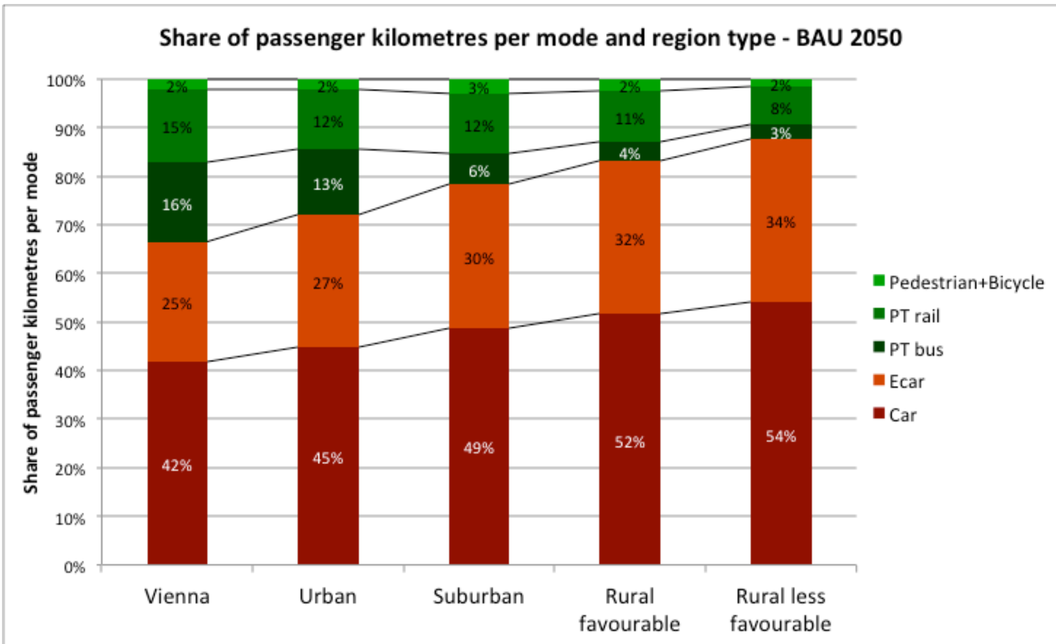

Figure 62 Share of passenger kilometres per mode and region type in 2050 for the scenario BAU

Table 27 sums up the changes in passenger kilometres per mode and region type between 2010 and 2050. Without transport or land-use policies the shares of passenger kilometres for car increases in all region types, as a result of the development of settlement structures (see section 7.1.4).

Mode/ region type	Vienna	Urban	Suburban	Rural favourable	Rural less favourable
Ped. + Bike	≈	↓	↓	↓	↓
PT rail	↓	↓	↓	↓	↓
PT bus	↓	↓	↓	↓	↓
PMT	↑	↑	↑	↑	↑

Table 27 Change in passenger kilometres per mode and region type between 2010 and 2050 for the scenario BAU

The vehicle kilometres start with 13,371 km per year and vehicle in 2010 and decrease to 11,964 km per year and vehicle in 2050, corresponding to a percentage change of roughly -11%.

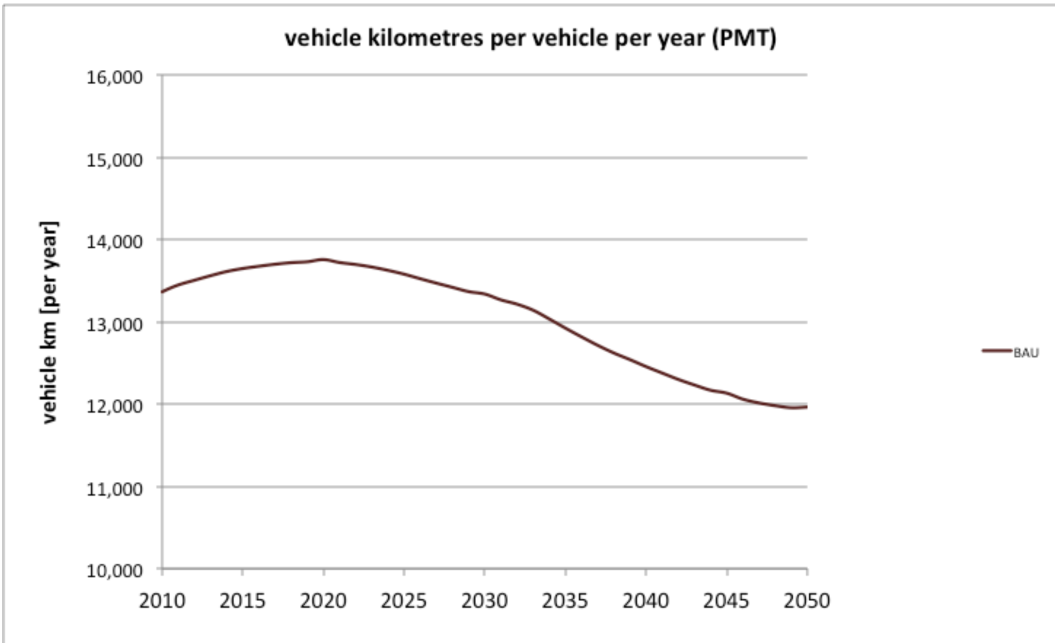

Figure 63 Vehicle kilometres per year for the scenario BAU

Figure 64 shows the average trip length per mode. For the public transport mode rail the distance decreases from 30 kilometres to 27 kilometres until 2050, accompanied by the decrease in passenger kilometres for all region types and the decrease in modals split.

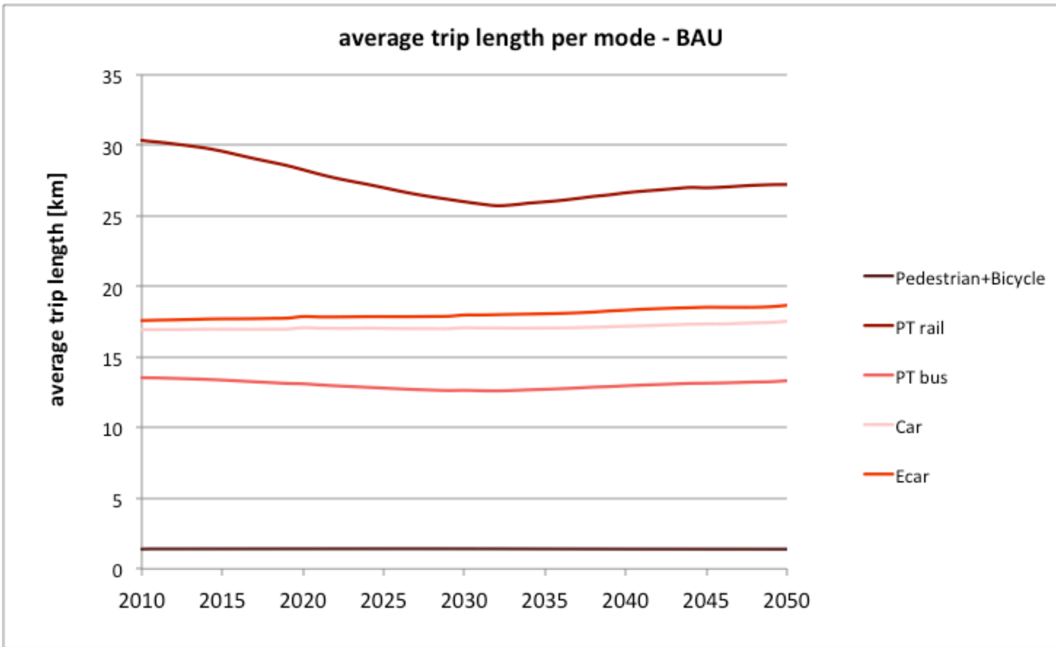

Figure 64 Average trip length per mode in kilometres for the BAU scenario

8.3 550 ppm

8.3.1 CO_2 emissions – 550 ppm

In the 550 ppm scenario, the reduction in CO_2 emissions is higher than in the BAU scenario. Here emissions increase only until 2015, the year in which the policy measures (reduction of public transport fees, increase of parking fees – see section 7.2.3) kick in. Afterwards, the emissions steadily decrease. In 2042, the Kyoto targets for 2010 are reached. In 2050, the emissions are 6,055,429 tonnes of CO_2 per year. Yet, with the policies and fleet development implemented in this scenario the White Paper and the Roadmap target is not reached.

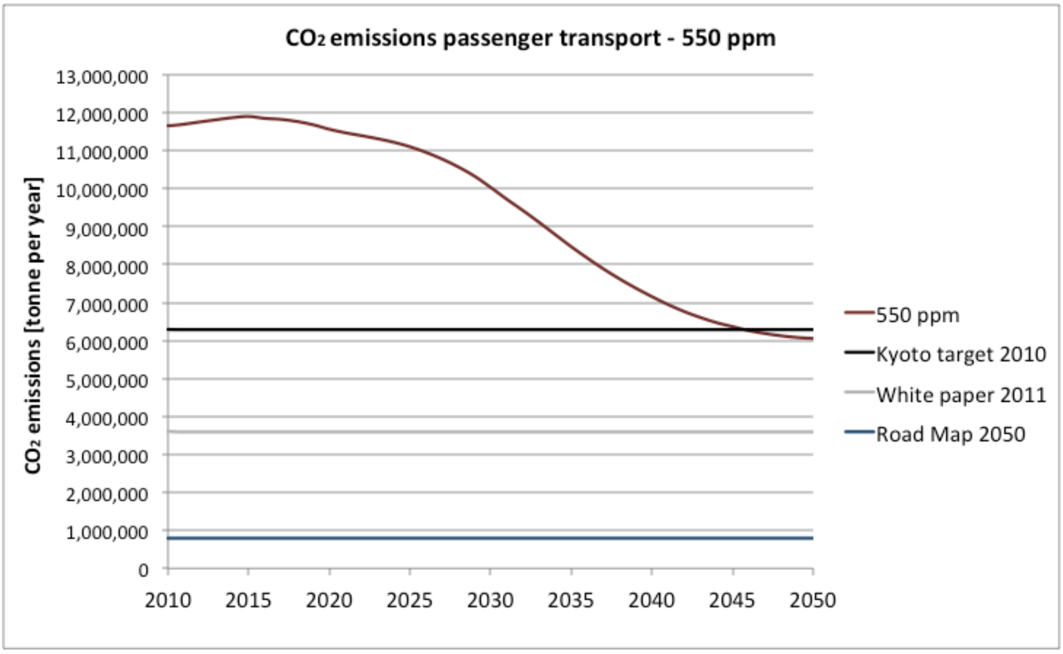

Figure 65 CO_2 emissions per year - 550 ppm

The emissions from E-cars (Figure 66) increase slowly until 2037. The increased energy demand assumed between 3038 and 2050 reduces the share of renewable energy sources, thus resulting in an increase of the specific CO_2 emissions in this scenario (see section 7.2.2). In 2050, the CO_2 emissions resulting from E-car use are roughly 570,000 tonnes.

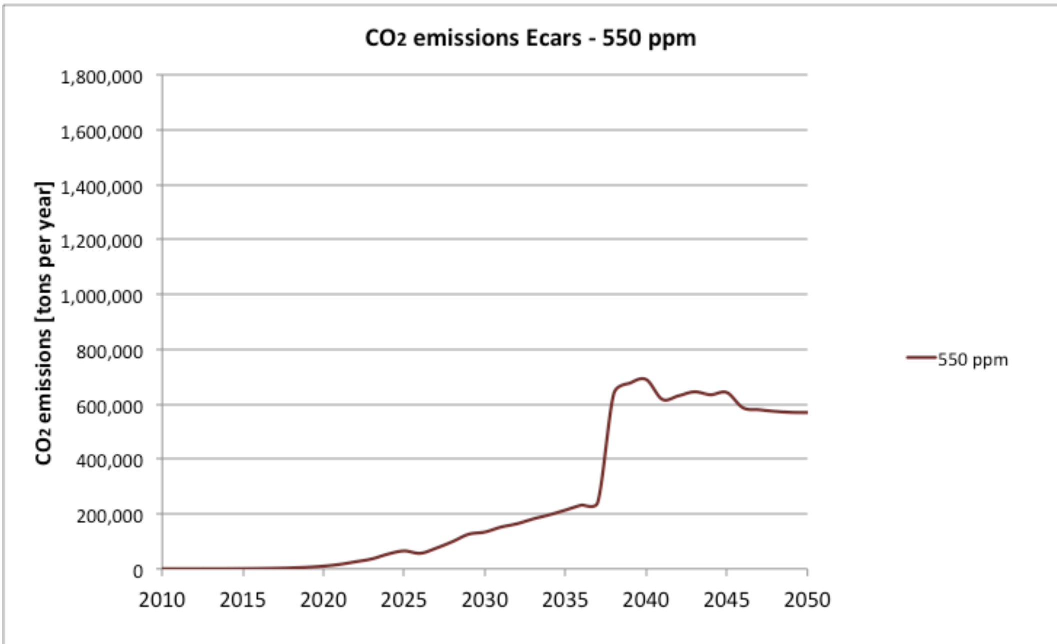

Figure 66 CO_2 emissions from E-cars - 550 ppm

8.3.2 Modal split – 550 ppm

Concerning the transport behaviour for the trip purpose commuting a similar pattern emerges as in the BAU scenario. The PMT modes increase their total share until 2050. The share of E-cars is higher in both observation points in time, reaching 32% in 2050.

Until 2050, the non-motorized modes decrease – by five percentage points for pedestrians and cyclists, by one percentage point for public transport rail, and by two percentage points for public transport bus.

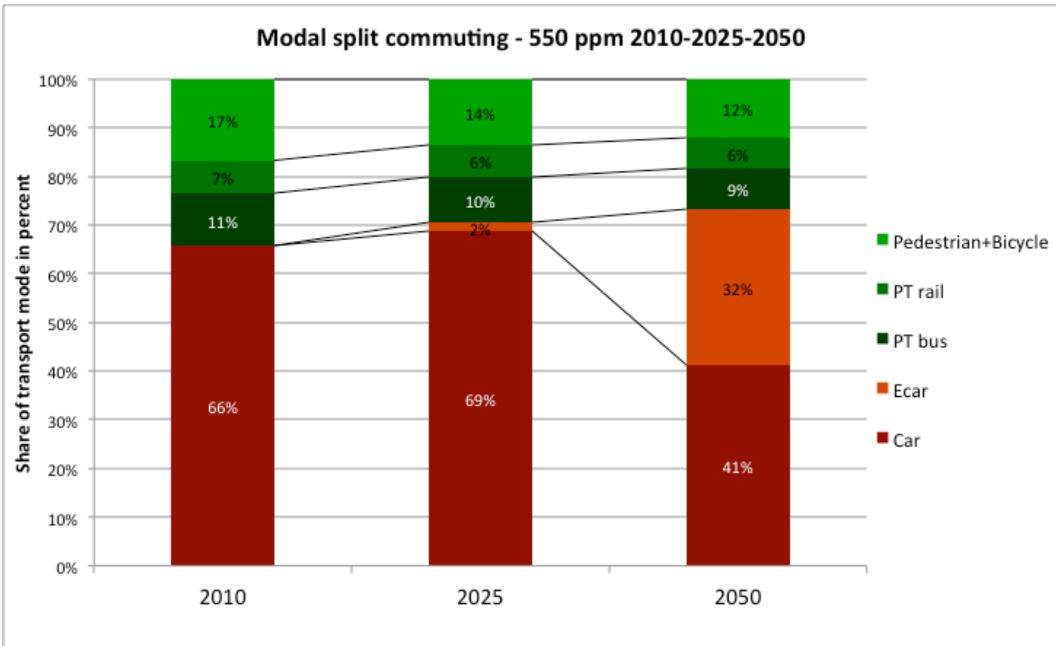

Figure 67 Modal split trip purpose commuting for the scenario 550 ppm, years 2010, 2025 and 2050

For the other trip purposes, the public transport modes keep their shares constant until 2025, and gain one percentage point until 2050. Pedestrians, however, lose two percentage points in total until 2050. E-cars increase their share up to 23% in 2050, resulting in a total share of PMT of 54%. The infrastructure fees on fuels and electricity (starting in 2020) combined with the reduction of public transport fees (starting in 2015), seems to reduce the increase of PMT shares over time.

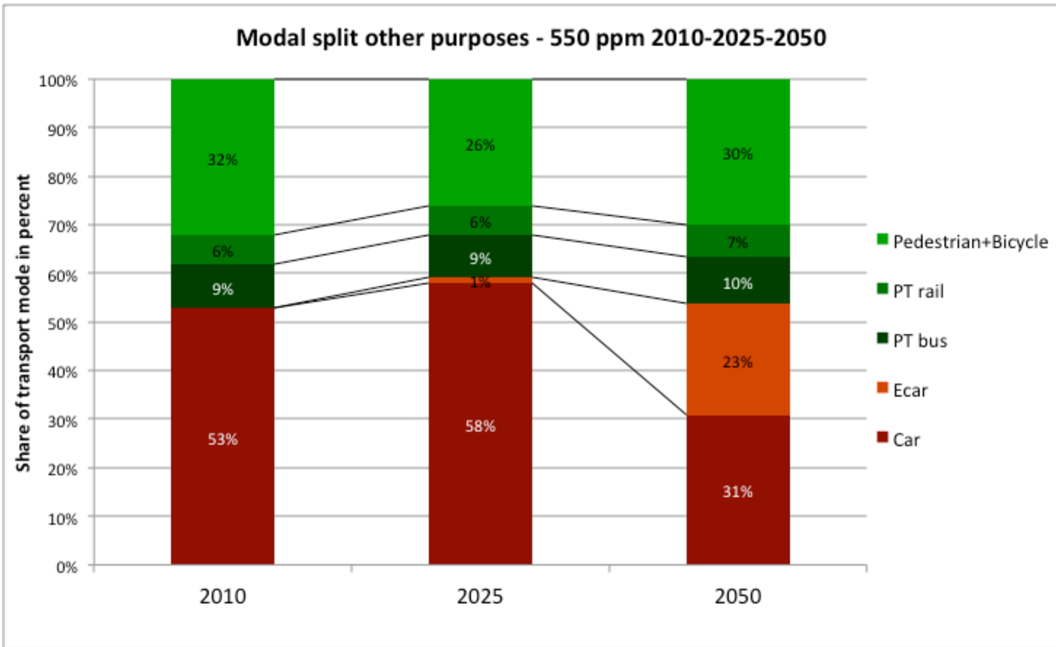

Figure 68 Modal split all other trip purposes for the scenario 550 ppm, years 2010, 2025 and 2050

The overall modal split of scenario 550 ppm is depicted in Figure 69. In this scenario, pedestrians and bicycles lose three percentage points and the public transport mode bus one percentage point. In 2050, 60% of all trips are either E-car or car trips.

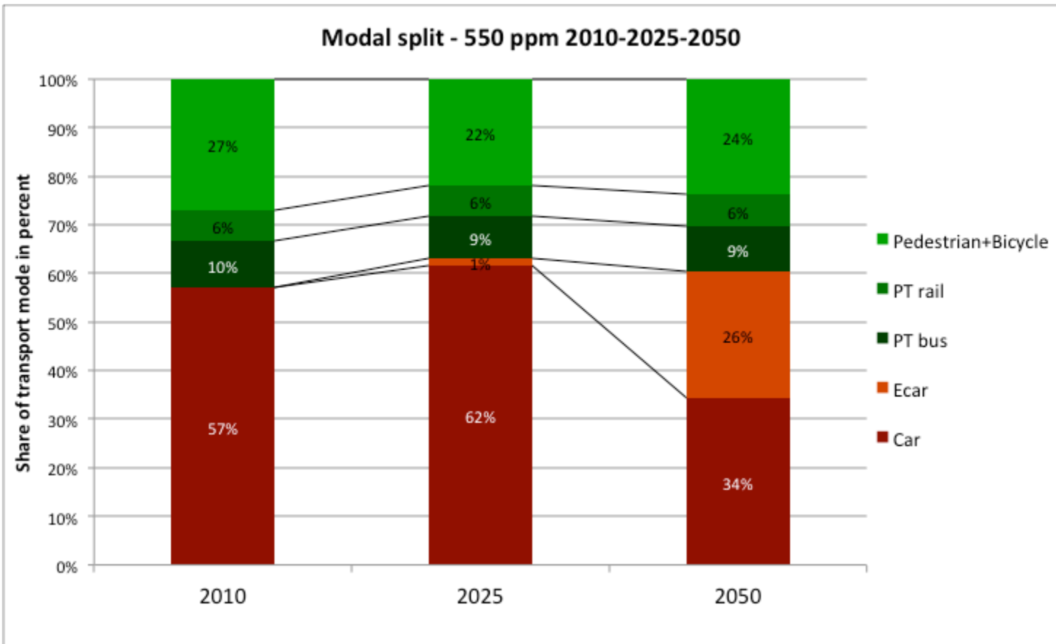

Figure 69 Modal split in total for the scenario 550 ppm, years 2010, 2025 and 2050

8.3.3 Passenger/vehicle kilometres and average trip length – 550 ppm

Figure 70 presents the passenger kilometres for the scenario 550 ppm. The shift in combustion technology is visible in the decrease of passenger kilometres by car and the increase of passenger kilometres by E-car. In total the passenger kilometres of PMT increase to 86.7 billion kilometres. For the public transport modes there is a slight increase in passenger kilometres.

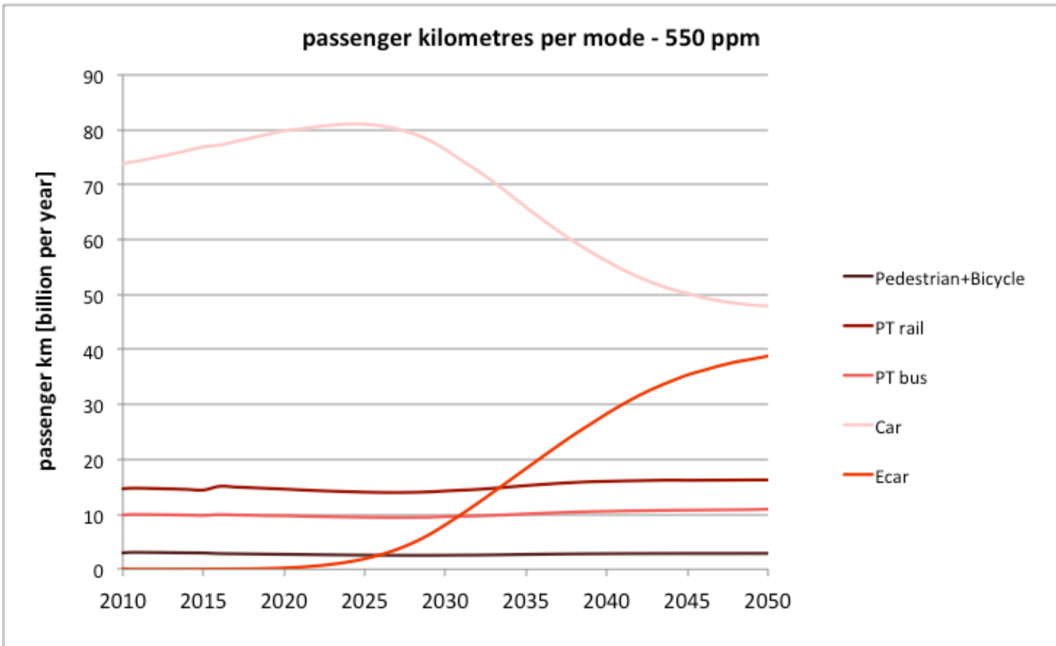

Figure 70 Passenger kilometres for the scenario 550 ppm

In total the passenger kilometres rise till 2050 to 117 billion (see Figure 71).

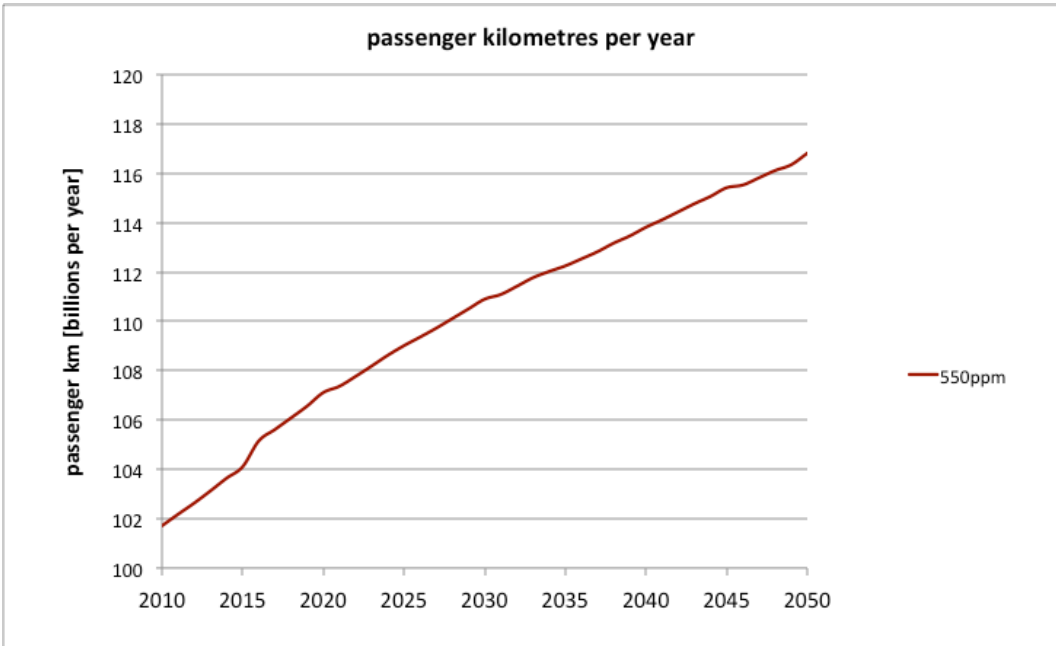

Figure 71 Passenger kilometres in total 550 ppm

Figure 72 shows the share of passenger kilometres per mode and region type for the year 2050. The 2010 shares are not depicted; they are the same for all scenarios and are presented in Figure 61.

In contrast to the BAU scenario, the increase of PMT in the passenger kilometres for trips with destination Vienna or urban zones is just one respectively two percentage points until 2050. The public transport modes in these two region types keep their shares almost constant. For the other three region types the trend of increased PMT shares until 2050 is still visible.

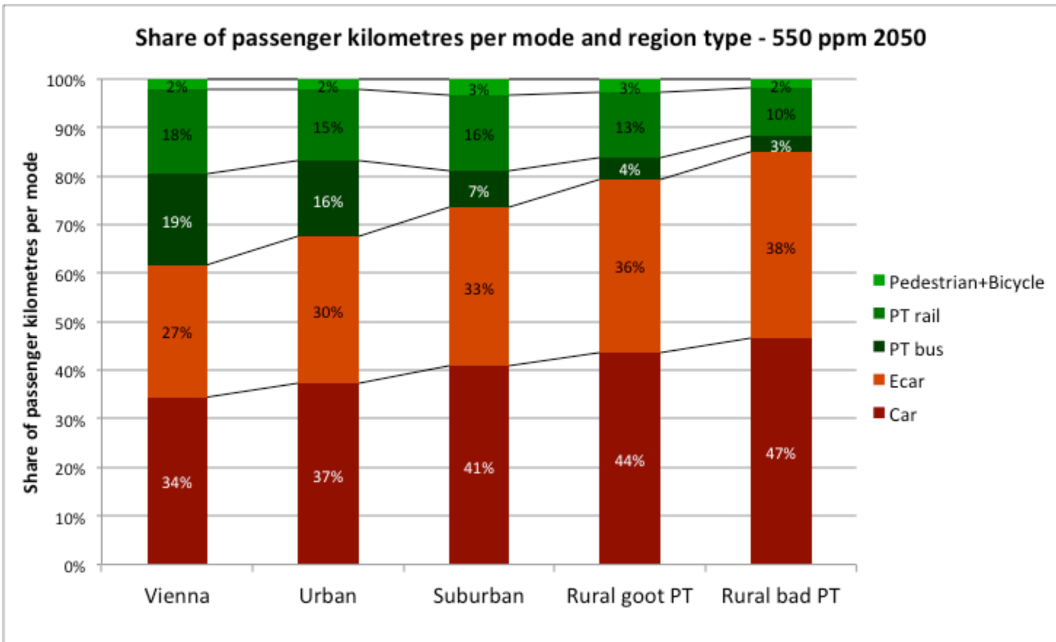

Figure 72 Share of passenger kilometres per mode and region type in 2050 for the scenario 550 ppm

Table 28 sums up the changes in passenger kilometres per mode and region type for the 550 ppm scenario between 2010 and 2050.

Mode/ region type	Vienna	Urban	Suburban	Rural favourable	Rural less favourable
Ped. + Bike	≈	↓	↓	≈	↓
PT rail	≈	↓	≈	↓	↓
PT bus	≈	↓	↓	↓	↓
PMT	↑	↑	↑	↑	↑

Table 28 Change in passenger kilometres per mode and region type between 2010 and 2050 for the scenario 550 ppm

The vehicle kilometres start with 13,371 km per year and vehicle in 2010 and decrease to 12,222 km in 2050. There is a step in 2015, when the public transport policy starts.

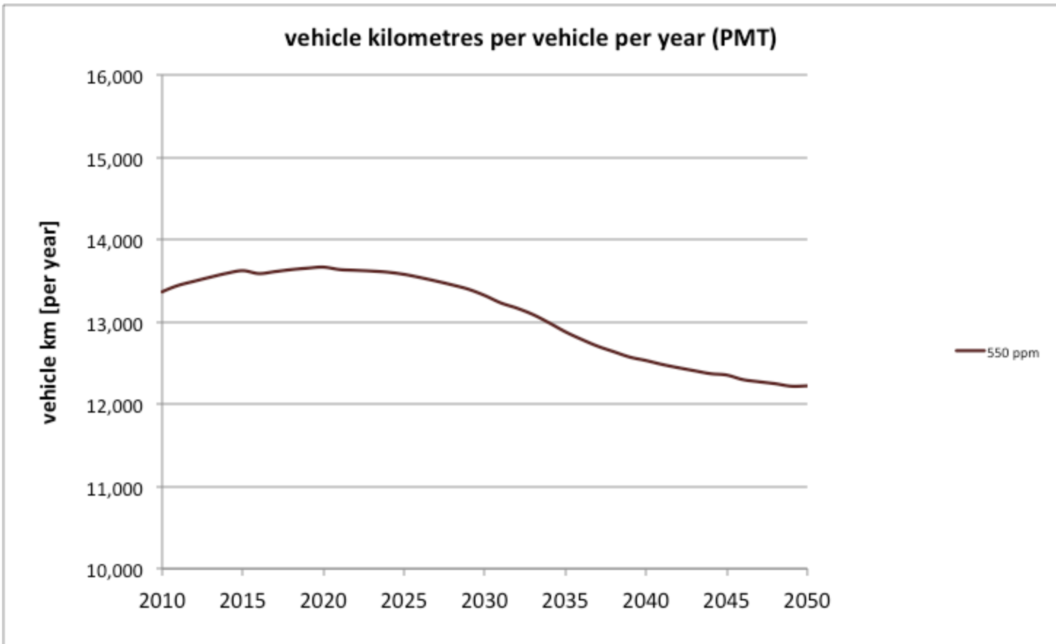

Figure 73 Vehicle kilometres per year for the scenario 550 ppm

In Figure 74 the average trip length per mode is presented. Here, too, the start of the public transport policies is visible, resulting in an increase of trip lengths in 2016, but this development does not continue until 2050. The average trip lengths of car and E-car increase compensating the decrease in vehicle kilometres, resulting in a total increase of passenger kilometres for PMT.

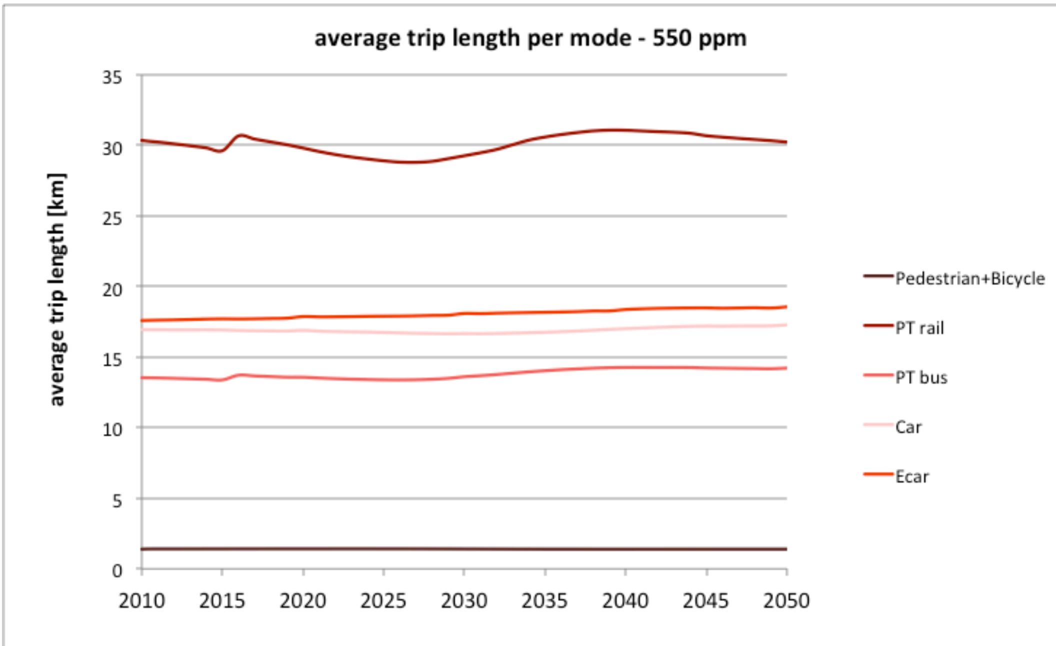

Figure 74 Average trip length per mode in kilometres for the 550 ppm scenario

8.4 500 ppm

8.4.1 CO_2 emissions - 500 ppm

The policy combinations of the 500 ppm scenario with the underlying fleet development result in a reduction curve shown in Figure 75. In 2037, the Kyoto targets can be met, whereas the White Paper and the Roadmap 2050 targets are still not met. The increase of the emissions from 2046 until 2050 is the result of change in fleet composition among the hybrid cars (see section 7.2.2). There is a substantial shift from compact and middle class hybrid cars to large cars as described in section 7.3.2. The resulting CO_2 emissions in 2050 are 5,125,929 tonnes.

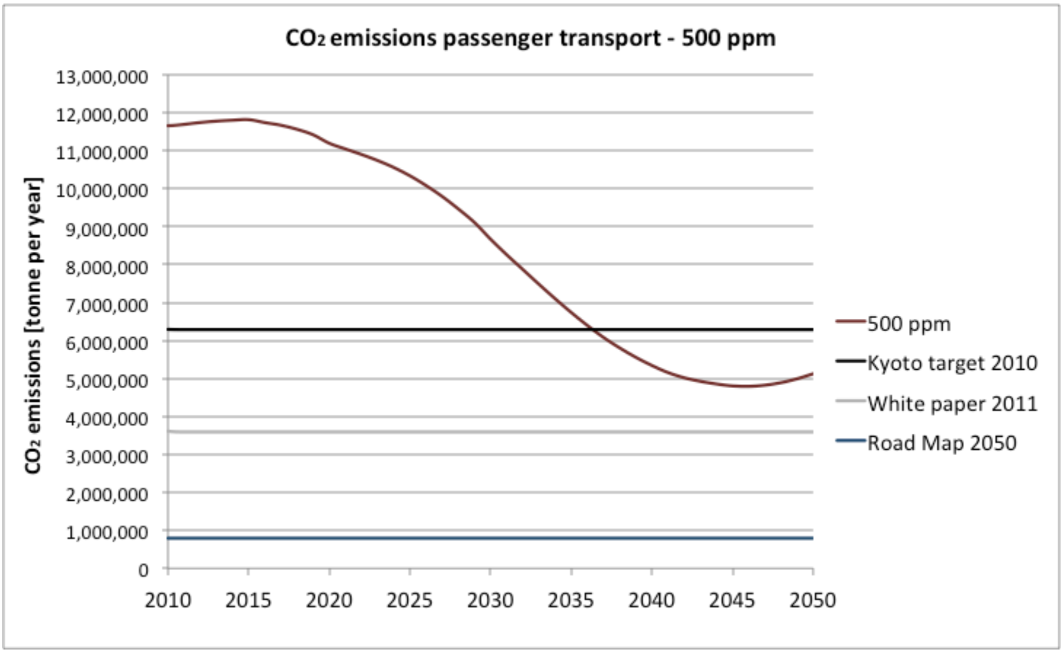

Figure 75 CO_2 emissions per year - 500 ppm

Figure 76 shows the resulting CO_2 emissions from E-cars. It can be seen that the slope is very similar to the curve depicting the development in the 550 ppm scenario until 2037. In 2046, the energy supply is 100% renewable resulting in zero emissions for the E-cars. In 2050, there is an increase again (see Figure 30), assuming that not all the demand can be covered by renewable energy. In 2050, the CO_2 emissions are 536,555 tonnes.

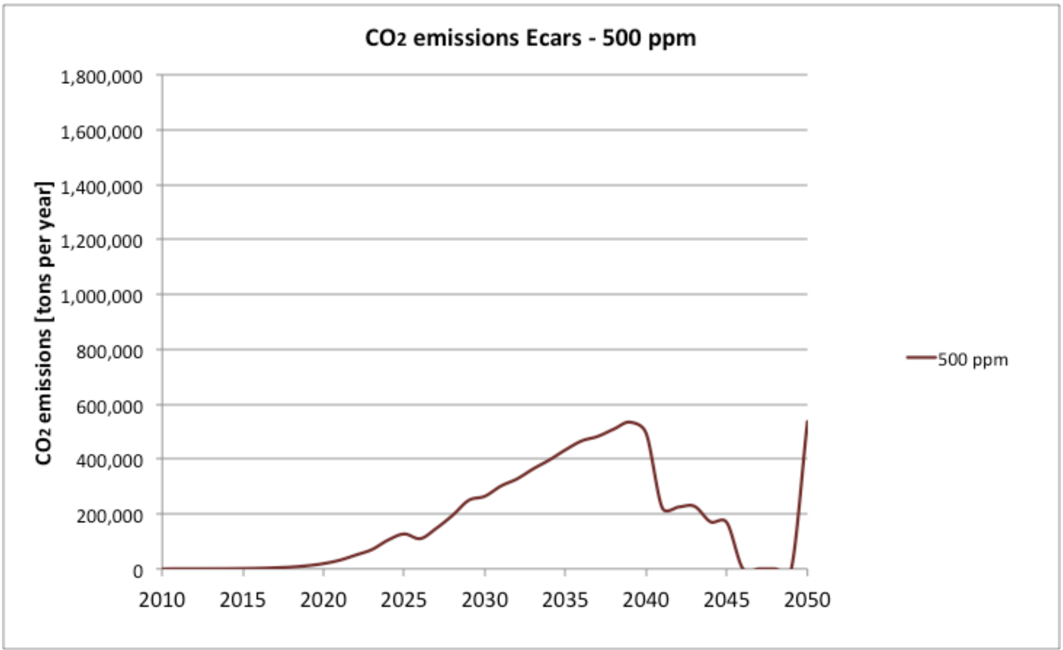

Figure 76 CO_2 emissions from E-cars - 500 ppm

8.4.2 Modal split – 500 ppm

The 500 ppm scenario is the first one where the trend of the increase of PMT is reversed for commuting trips after 2025. Until 2025, the share of cars and E-cars increases to 69%, while in 2050, this share is down to 67%. The eco mobility modes (pedestrians, cyclists and public transport) can keep their shares almost constant.

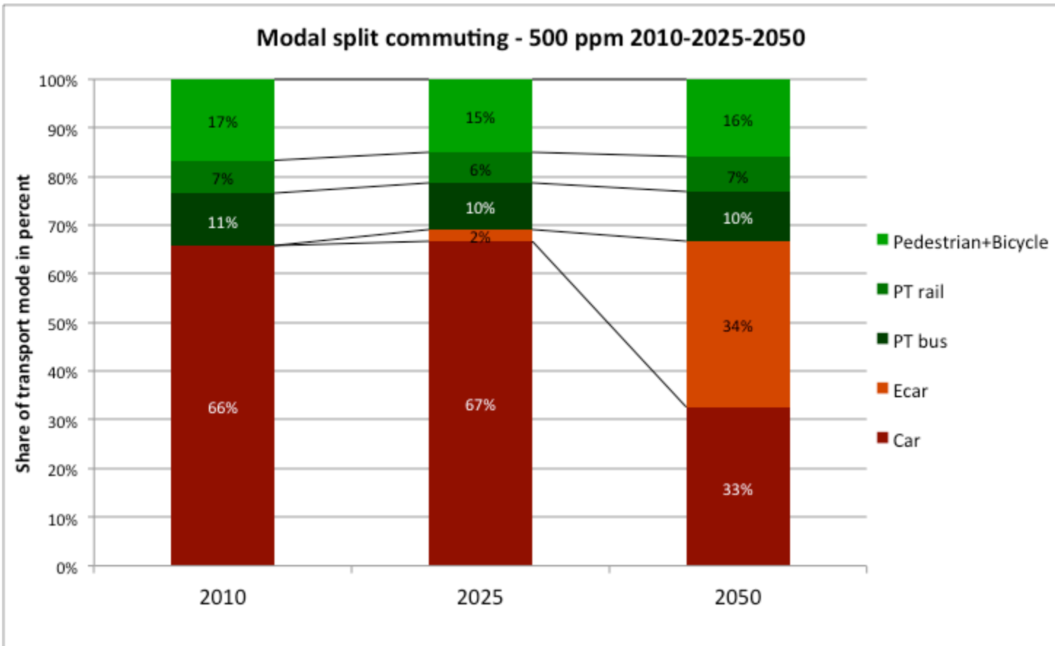

Figure 77 Modal split trip purpose commuting for the scenario 500 ppm, years 2010, 2025 and 2050

For the other trip purposes this is the first scenario where the overall PMT share is smaller than in 2050. 47% of all trips are made either by car or E-car. 24% are trips by E-car. Within the eco mobility modes there is a slight increase for the public transport modes whereas pedestrians and cyclists gain four percentage points. In this scenario, there is no noticeable substitution effect between PMT and eco mobility[42].

[42] Referred to as the modes pedestrian, bicycle, public transport bus and public transport rail.

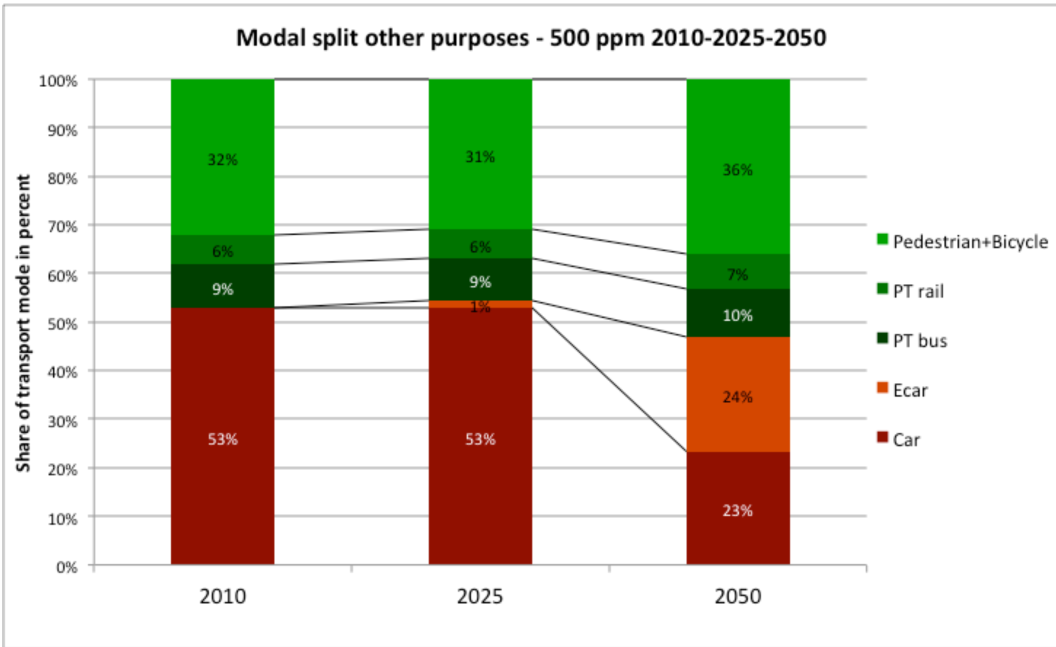

Figure 78 Modal split all other trip purposes for the scenario 500 ppm, years 2010, 2025 and 2050

The overall modal split in Figure 79 shows an increase of the modes pedestrian and bicycle by two percentage points until 2050. The public transport bus mode can keep the shares constant, while public transport rail gains one percentage point. In 2050, 43% of all trips are either E-car or car trips.

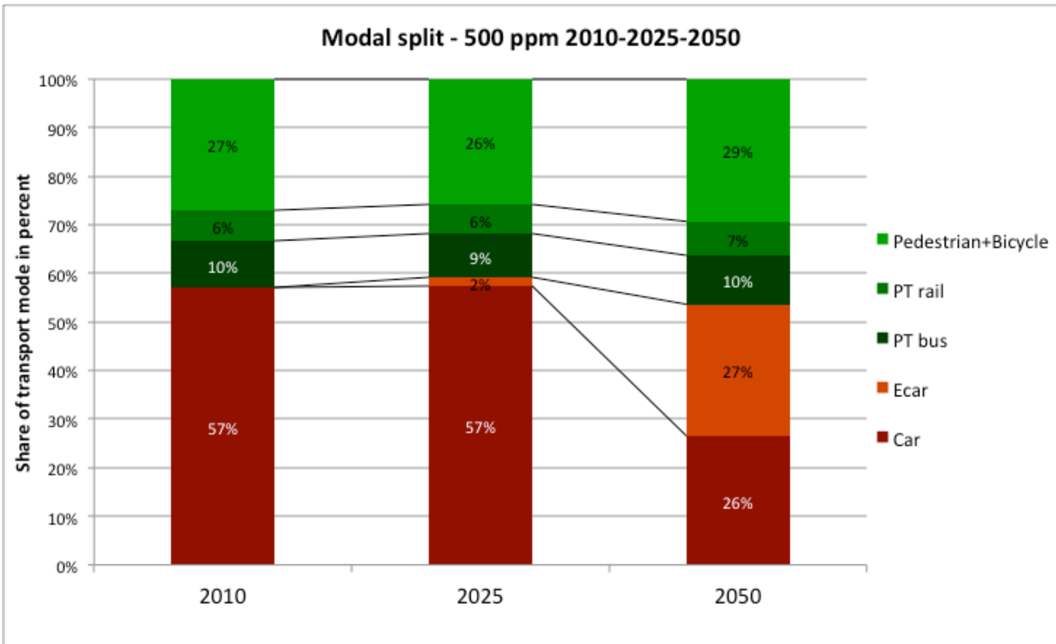

Figure 79 Modal split in total for the scenario 500 ppm, years 2010, 2025 and 2050

8.4.3 Passenger/vehicle kilometres and average trip length – 500 ppm

Figure 80 presents the passenger kilometres for the scenario 500 ppm. In this scenario the passenger kilometres by E-car are higher than the passenger kilometres by car in 2050. The main reason is the underlying fleet development (see section 7.2.2), additionally the transport policies affecting the mode car (see section 7.3.3) have a stronger effect on the reduction of the passenger kilometres for the mode car than on the mode E-car.

For the public transport modes there is an increase in passenger kilometres, resulting in 12.5 billion kilometres for public transport bus and 20 billion for public transport rail. In total the eco modes gain 30% in passenger kilometres compared to the year 2010.

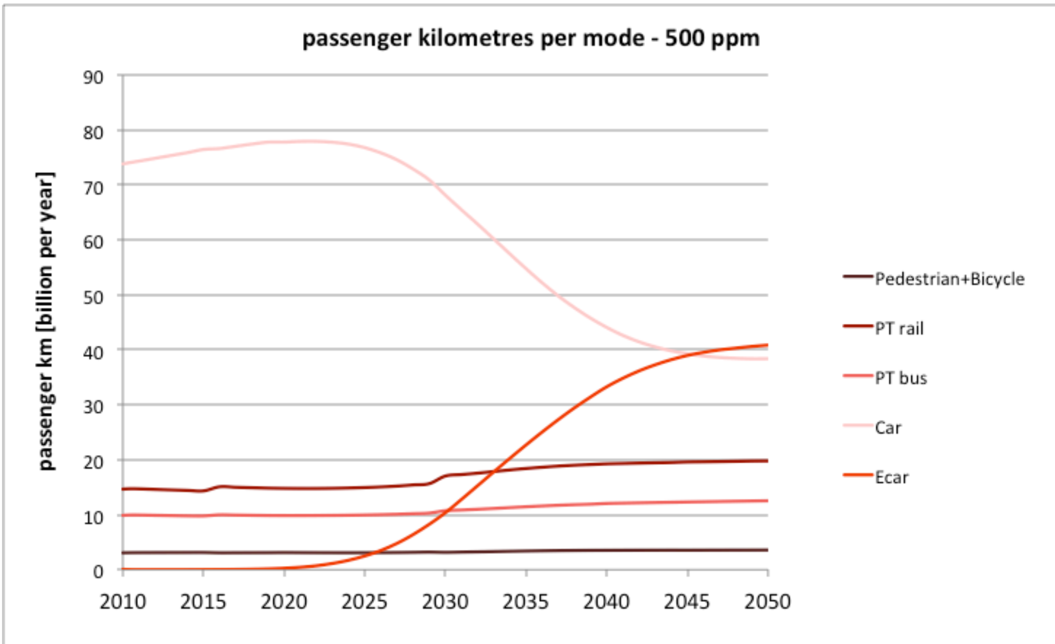

Figure 80 Passenger kilometres for the scenario 500 ppm

In the 500 ppm scenario the total passenger kilometres rise to 115 billion in 2050. This corresponds to a 13% rise compared to the 2010 value. PMT contributes about 40% to this rise, while 60% of the increase in passenger kilometres comes from the eco modes.

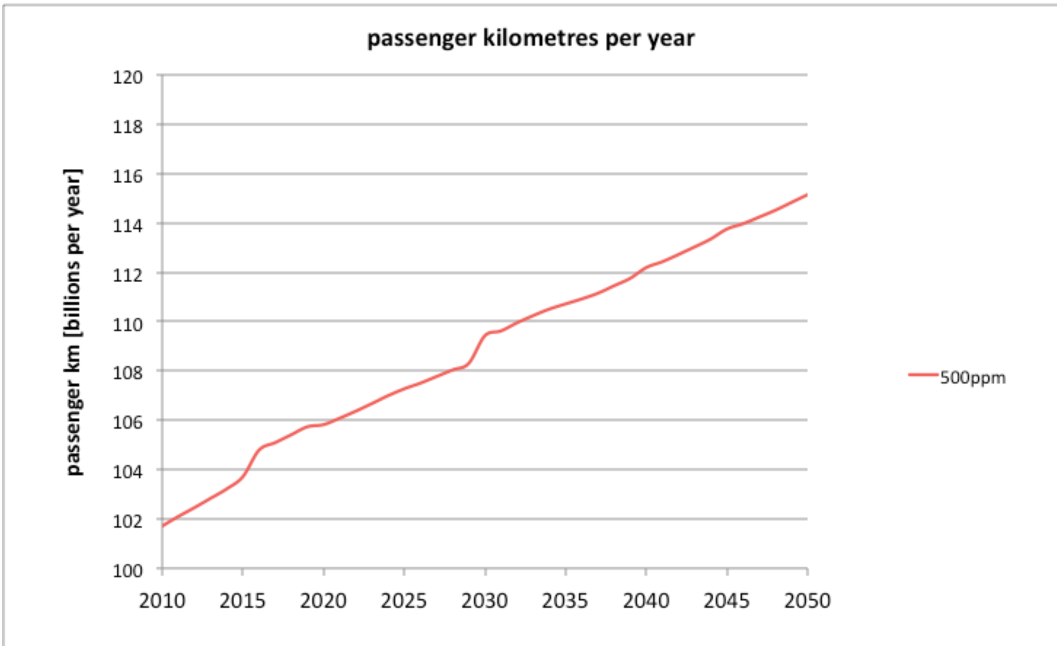

Figure 81 Passenger kilometres in total 500 ppm

Figure 82 shows the share of passenger kilometres per mode and region type for the year 2050. This scenario is the first one where the public transport modes gain in shares in all region types until 2050 compared to 2010, while the passenger kilometres for car and E-car decreasing for all region types except for rural regions with less favourable conditions for public transport. The shares for pedestrians and bicycle remain constant. This is the result of the parking policy in combination with the reduction of the public transport fares.

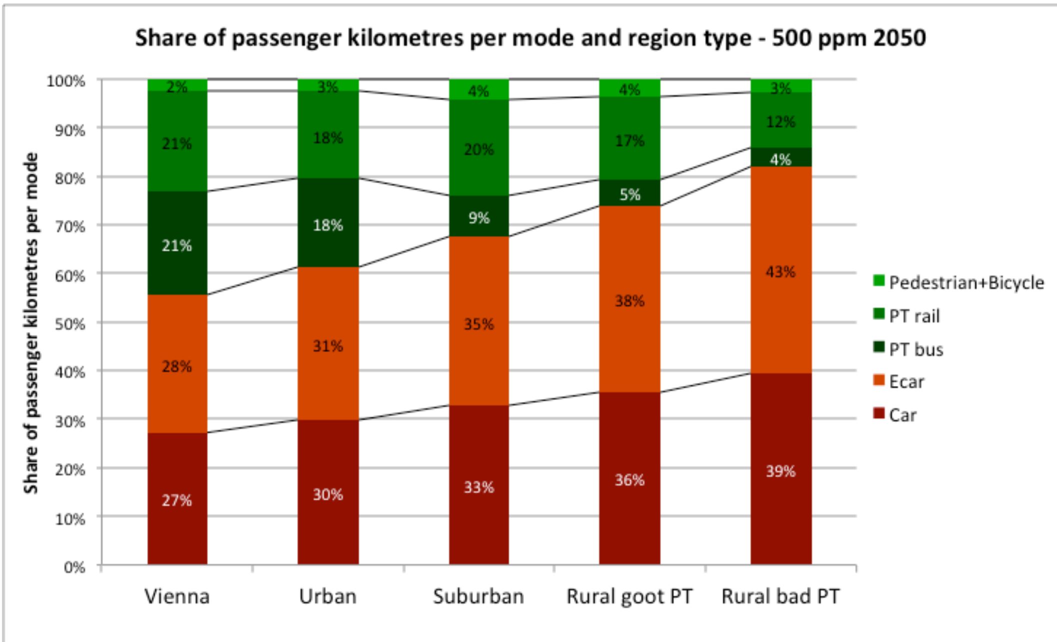

Figure 82 Share of passenger kilometres per mode and region type in 2050 for the scenario 500 ppm

Mode/ region type	Vienna	Urban	Suburban	Rural favourable	Rural less favourable
Ped. + Bike	≈	≈	≈	≈	≈
PT rail	↑	↑	↑	↑	↑
PT bus	↑	↑	↑	≈	≈
PMT	↓	↓	↓	↓	≈

Table 29 Change in passenger kilometres per mode and region type between 2010 and 2050 for the scenario 500 ppm

The development of the vehicle kilometres is shown in Figure 83. The reduction in vehicle kilometres is smaller than in the scenarios BAU and 550 ppm, resulting in 12,775 kilometres in 2050.

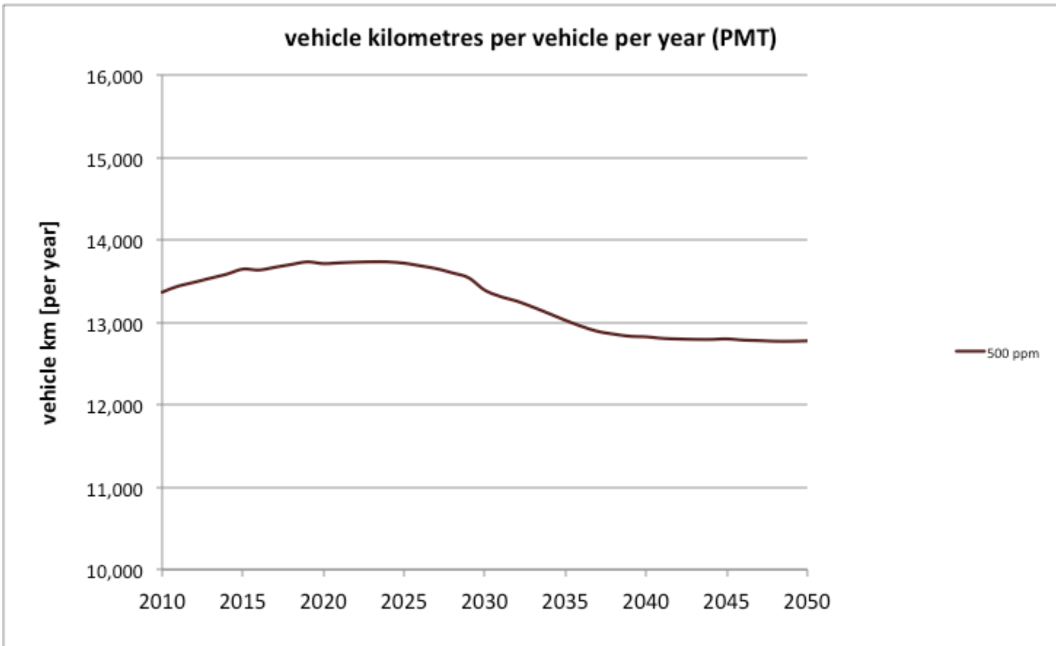

Figure 83 Vehicle kilometres per year for the scenario 500 ppm

Figure 84 presents the average trip length per mode for the 500 ppm scenario. The influence of the transport policies can be seen especially for the public transport modes rail and bus. The policies lead to an increase in average trip lengths for both public transport modes.

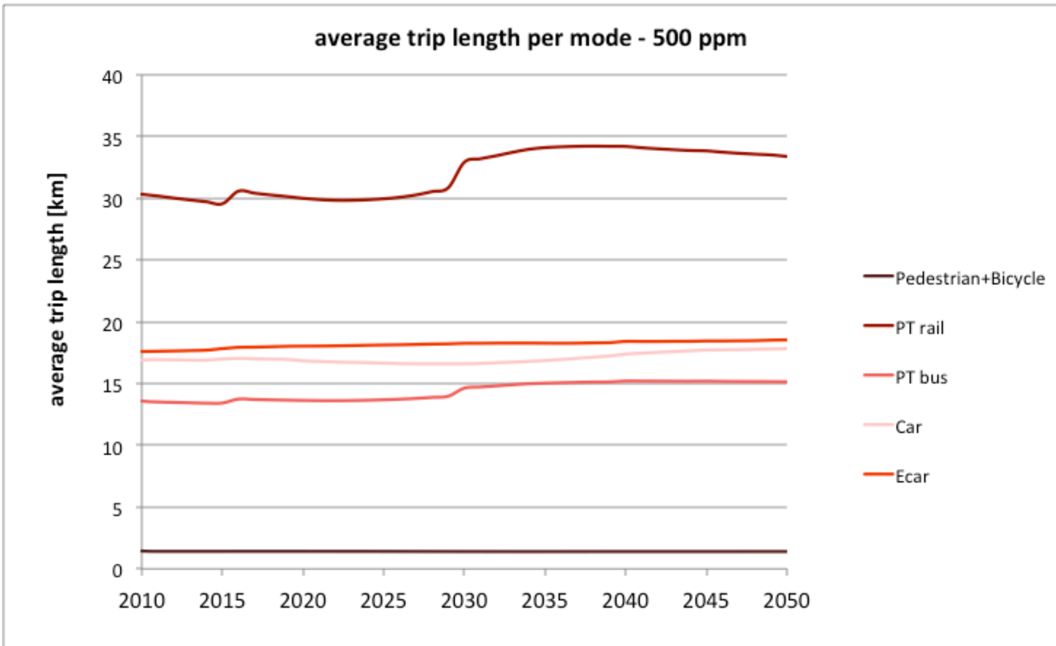

Figure 84 Average trip length per mode in kilometres for the 500 ppm scenario

8.5 450 ppm

8.5.1 CO_2 emissions – 450 ppm

The 450 ppm scenario is the only scenario in which the Kyoto target, the White Paper target and the Roadmap target are reached and undershot. The Kyoto target is reached in 2031, while the CO_2 emissions decrease below the White paper target in 2035. The Roadmap target is met in 2043. The shape of the curve is very steep because the share of E-cars in the fleet is very high beyond 2030. In 2050, the CO_2 emissions are 402,414 tonnes, still higher than the emissions in 1950 (see Table 26).

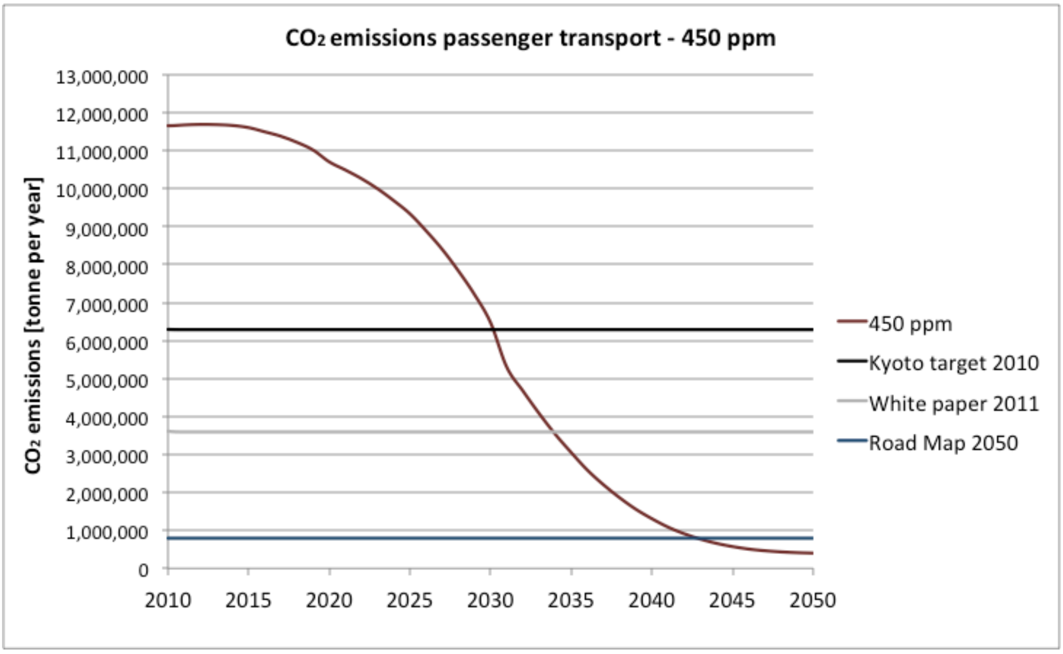

Figure 85 CO2 emissions per year - 450 ppm

The 450 ppm scenario is the scenario with the highest shares of E-cars. Simultaneously, the power generation is 100% renewable in 2046. From 2046, the power generation is assumed to be 100% made from renewables and stays this way until 2050, resulting in zero emissions from E-cars.

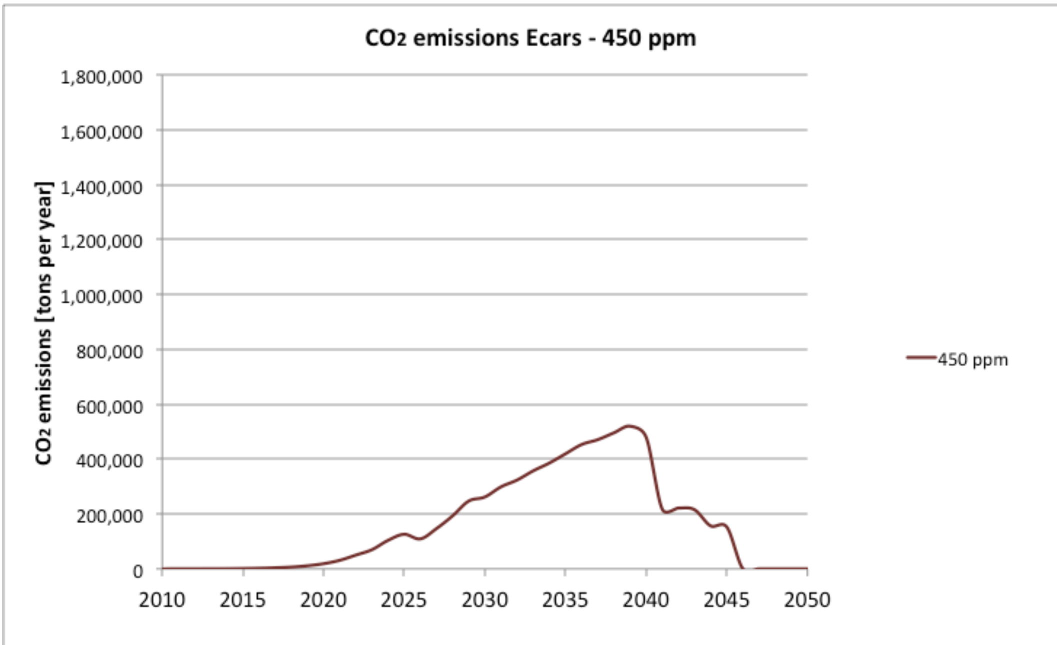

Figure 86 CO_2 emissions from E-cars - 450 ppm

8.5.2 Modal split - 450 ppm

Concerning the modal split for commuting, E-cars totally substitute conventional cars, while gaining one percentage point from the eco mobility modes. The share of PMT is one percentage point lower than in 2010. Pedestrians and cyclists lose one percentage point, while the public transport rail and bus shares gain either one percentage point each.

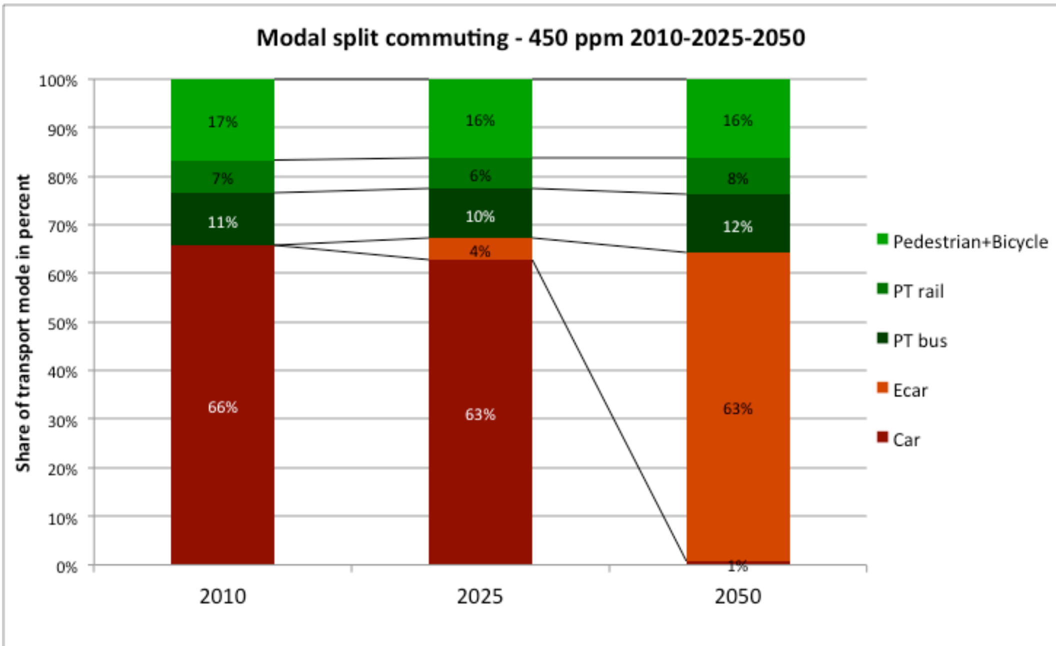

Figure 87 Modal split trip purpose commuting for the scenario 450 ppm, years 2010, 2025 and 2050

Looking at the other trip purposes, it is noticeable that the PMT shares in 2025 and in 2050 are smaller than in 2010. The eco mobility modes take over these shares.

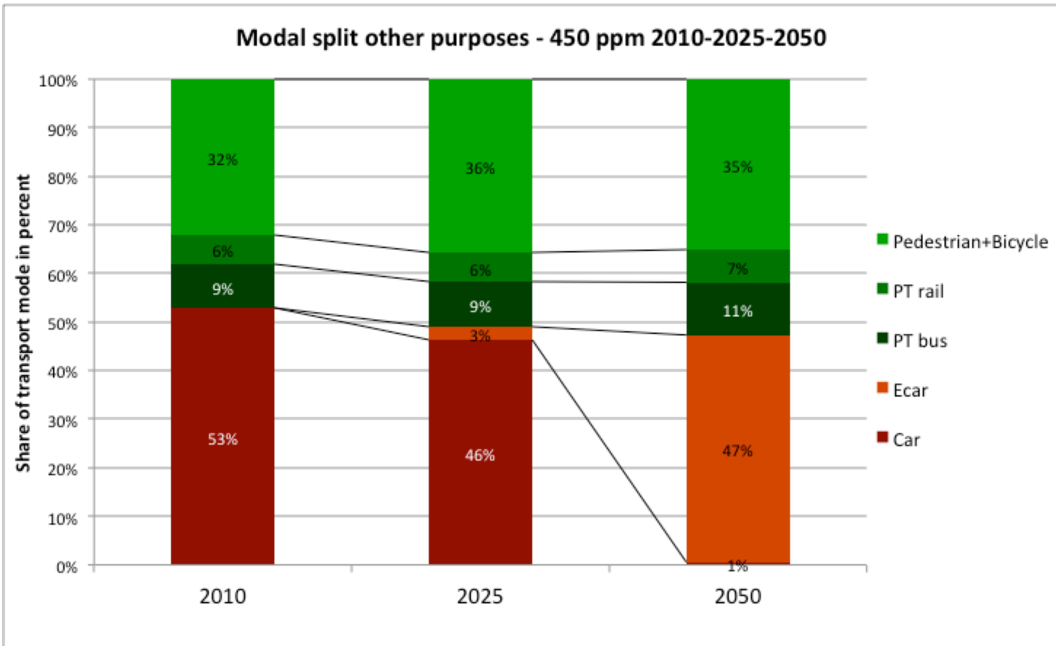

Figure 88 Modal split all other trip purposes for the scenario 450 ppm, years 2010, 2025 and 2050

In the 450 ppm scenario, the overall modal split (Figure 89) shows an increase of two percentage points for the modes pedestrian and bicycle until 2050. Public transport bus and rail also gain one percentage point. In 2050, 53% are E-car trips, while only one per cent of all trips are car trips.

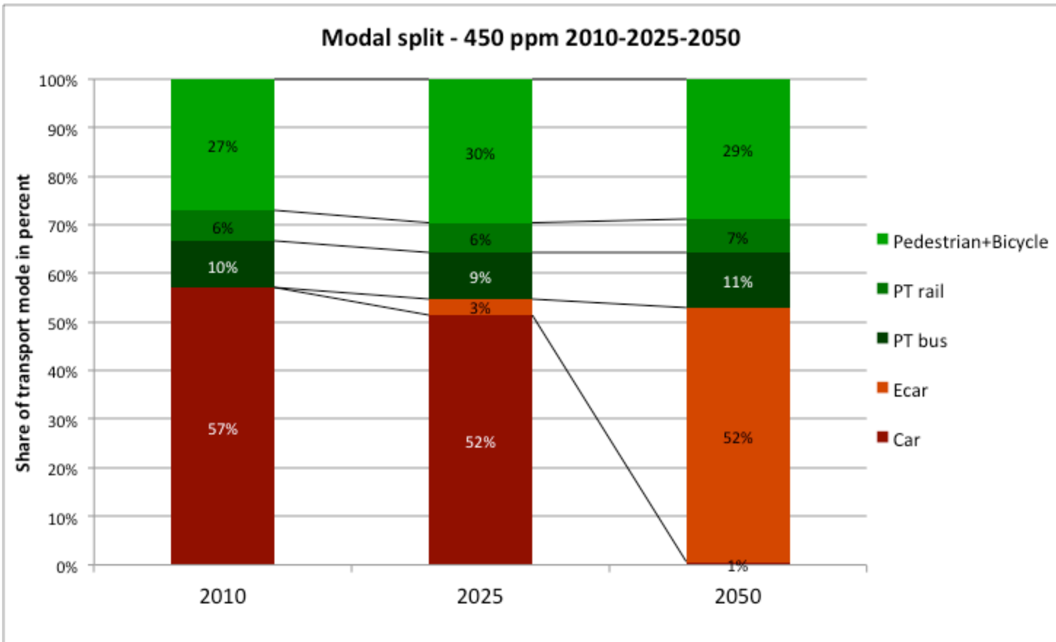

Figure 89 Modal split in total for the scenario 450 ppm, years 2010, 2025 and 2050

Figure 90 shows the development of the modal split of the 450 ppm scenario from 2020 to 2050. It is important to mention that in the phase where the car and E-car shares are converging the other modes can gain in shares. This development lasts till E-cars are established. During the technological shift the eco modes can gain in shares, this development is even increased due to the policies, which is visible through the short steep rises. This behaviour is mirrored also in the development of the passenger kilometres and the average trip lengths (see Figures 91 and 95).

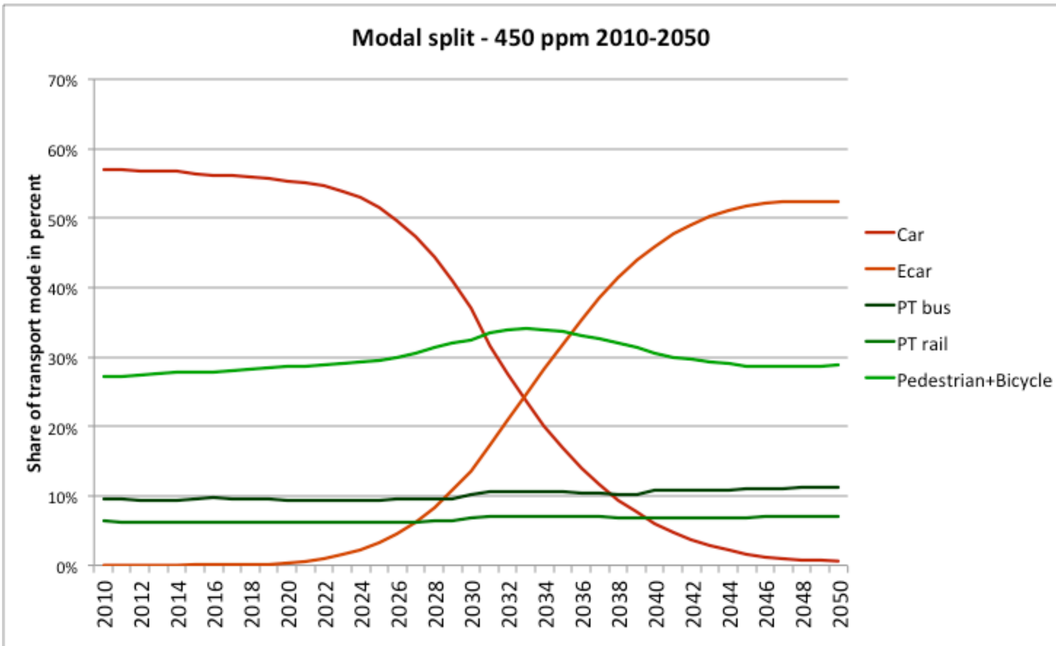

Figure 90 Modal split in total for the scenario 450 ppm from 2010 to 2050

8.5.3 Passenger/vehicle kilometres and average trip length – 450 ppm

Figure 91 presents the passenger kilometres for the scenario 450 ppm. In 2033 the passenger kilometres for the mode E-car are for the first time higher than for the mode car. There is an increase in passenger kilometres for the public transport modes compared to 2010. In contrast to the 500 ppm scenario there is a slight downward trend for the public transport mode rail from 2030 to 2050, resulting in 17.6 billion kilometres. The passenger kilometres for the public transport mode bus, however, are increasing to 13.4 billion in 2050. In 2050 the passenger kilometres for PMT are 6% higher than in 2010.

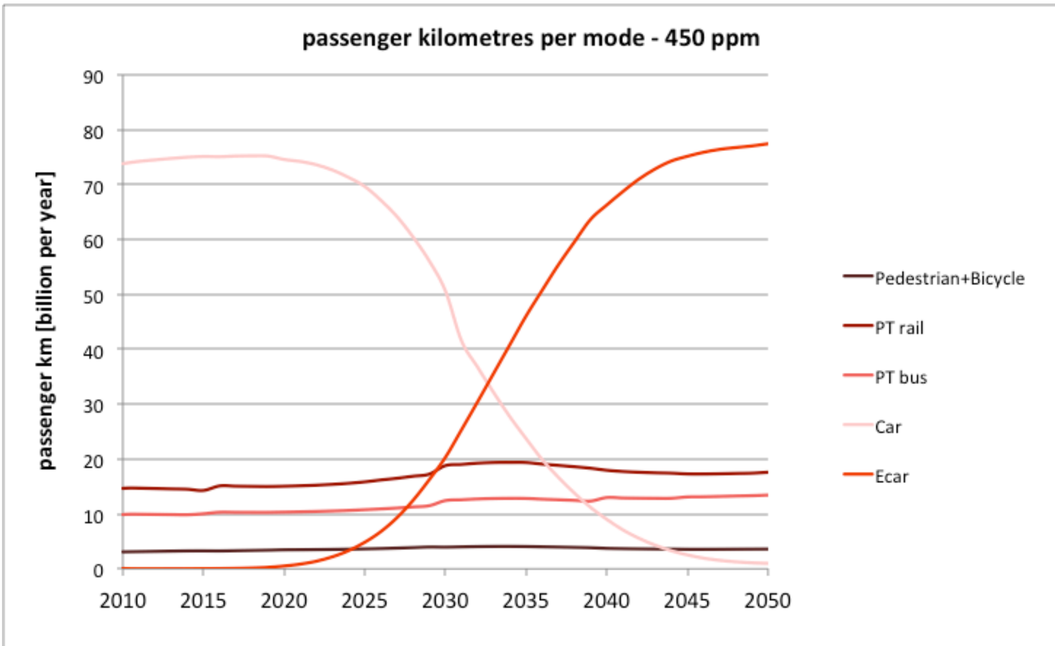

Figure 91 Passenger kilometres for the scenario 450 ppm

Figure 92 presents the total passenger kilometres for the 450 ppm scenario. They increase to 113 billion in 2050, which corresponds to an increase of 11% compared to 2010. The reason for the sharp decline in 2031 is that in 2030 the parking fees-, the public transport fees-, and the infrastructure toll policy (see section 7.4.3) change in magnitude. From 2032 to 2050 the passenger kilometres rise again, the public transport modes contribute about 60% to this rise and the PMT about 40%.

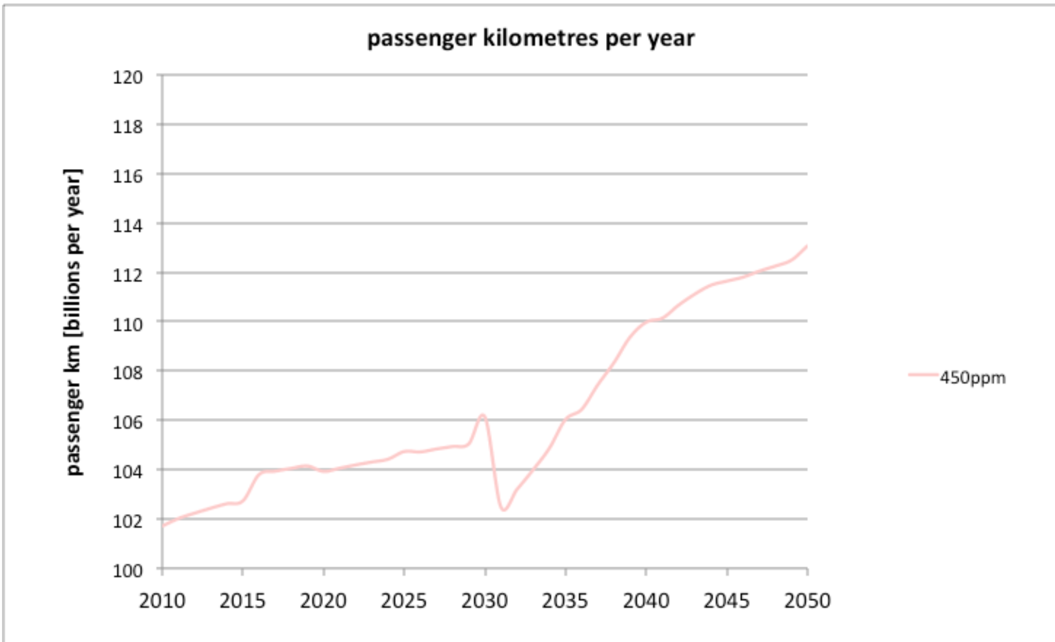

Figure 92 Passenger kilometres in total 450 ppm

Figure 93 shows the share of passenger kilometres per mode and region type for the year 2050. Compared to 2010 the PMT shares decrease in all region types except for rural zones with less favourable conditions for public transport. The eco modes[43] either increase their shares or keep the shares constant in all region types except for rural zones with less favourable conditions for public transport. The changes are depicted in Table 30.

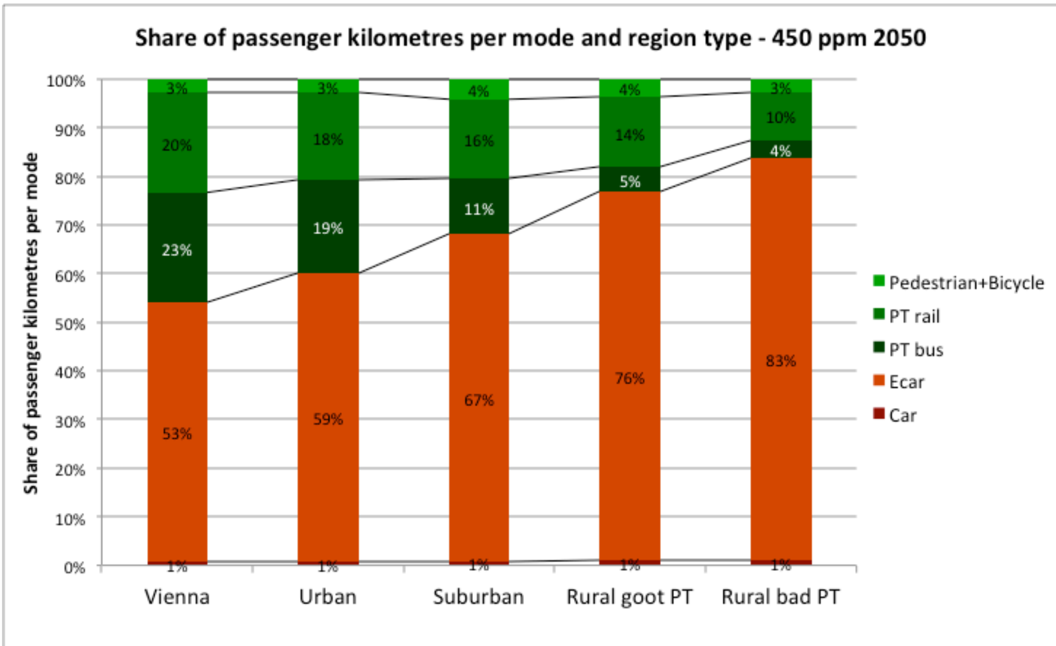

Figure 93 Share of passenger kilometres per mode and region type in 2050 for the scenario 450 ppm

Mode/ region type	Vienna	Urban	Suburban	Rural favourable	Rural less favourable
Ped. + Bike	↑	≈	≈	↑	≈
PT rail	↑	↑	≈	≈	↓
PT bus	↑	↑	↑	≈	≈
PMT	↓	↓	↓	↓	↑

Table 30 Change in passenger kilometres per mode and region type between 2010 and 2050 for the scenario 450 ppm

The development of the vehicle kilometres is shown in Figure 94. In this scenario the vehicle kilometres decrease until 2032 and then increase to 14,446 in 2050. The rise after 2032 is manly driven by rural zones with less favourable conditions for public transport (32 zones). Simultaneously the average trip length rises

[43] Referring to pedestrian, bicycle and public transport bus / rail

slightly for E-cars and rises about 3 km for cars (hybrids) (see Figure 95) and the level of motorization is decreasing (see Figure 47).

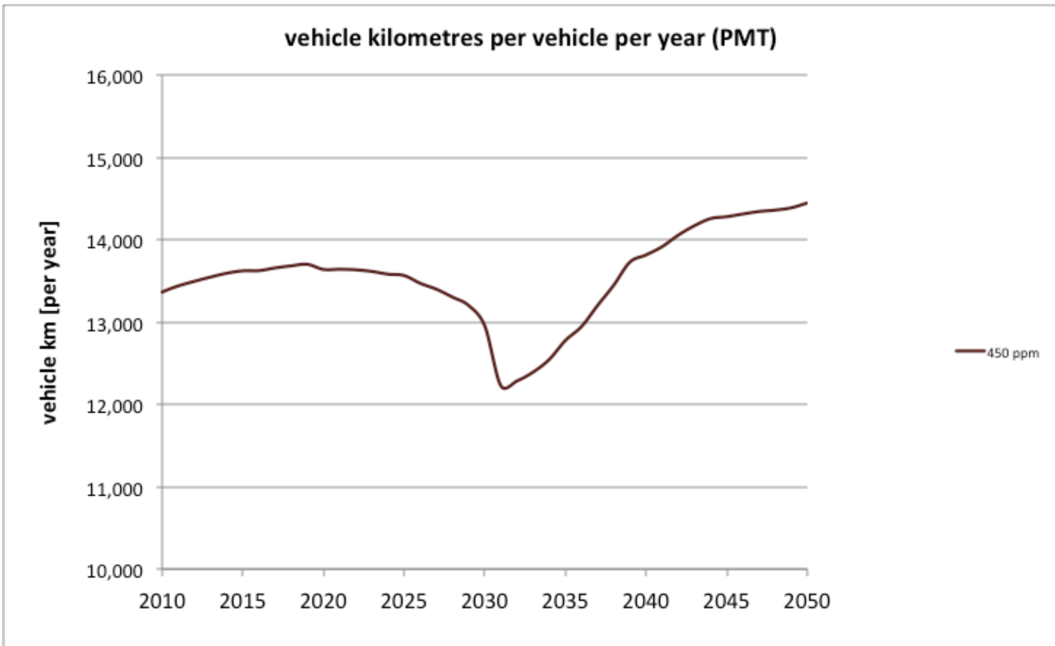

Figure 94 Vehicle kilometres per year for the scenario 450 ppm

Figure 95 presents the average trip length per mode for the 450 ppm scenario. The influence of the transport policies can be seen especially for the public transport mode rail. In 2016 and 2031 an increase of average trip length can be noted, though in this scenario the increase is not permanent, resulting in a decline back to the value of 2010. The reason for the decline are the urbanisation processes in this scenario, decreasing the distances people need to travel and the decrease of the share of rail in the modal split (see Figure 90). In rural areas with less favourable conditions for public transport the PMT shares still increase leading also to an increase in average trip length for cars (hybrids) and E-cars.

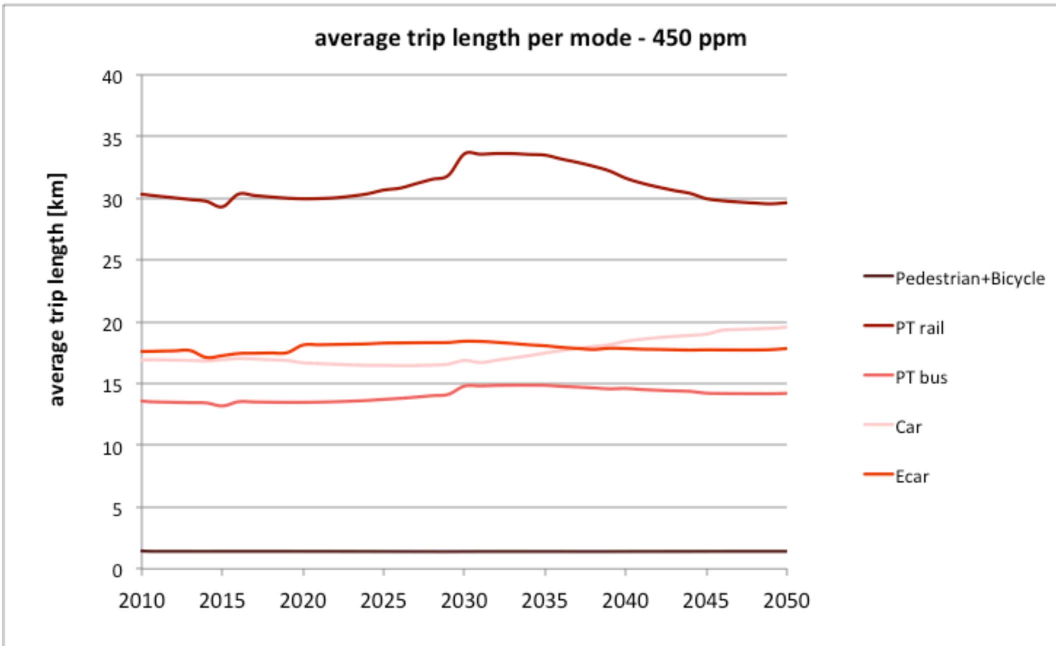

Figure 95 Average trip length per mode in kilometres for the 450 ppm scenario

8.6 Tech.

8.6.1 CO_2 emissions – tech.

Figure 96 shows the resulting CO_2 emissions from the tech. scenario. The pattern that emerges is very similar to the one of the 450 ppm scenario.

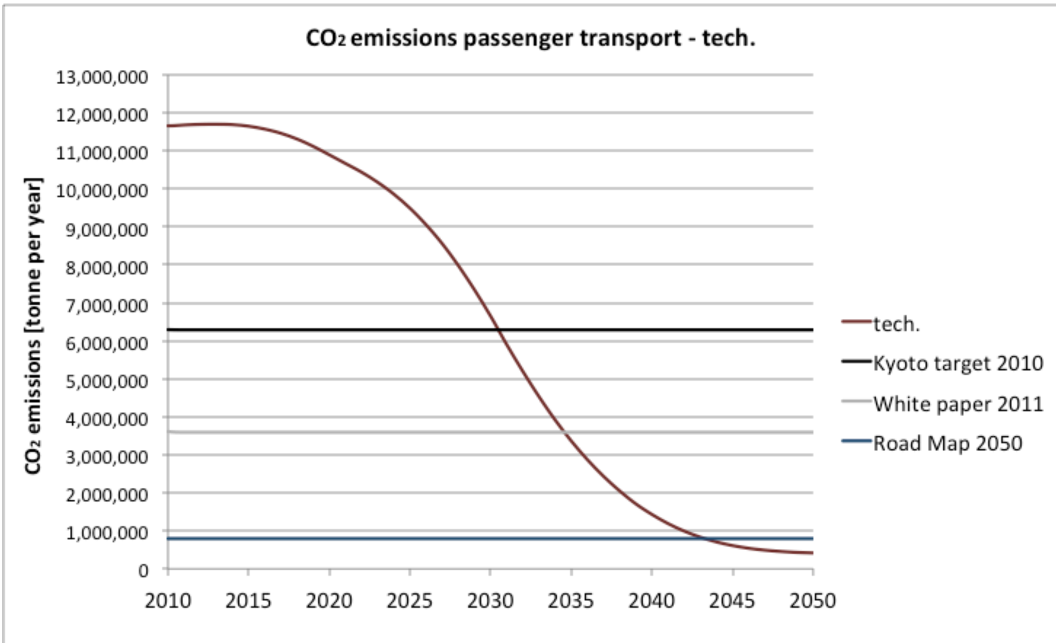

Figure 96 CO_2 emissions per year – tech.

The CO_2 emissions resulting from E-cars is depicted in Figure 97. The shape of the curve follows the curve from the 450 ppm scenario.

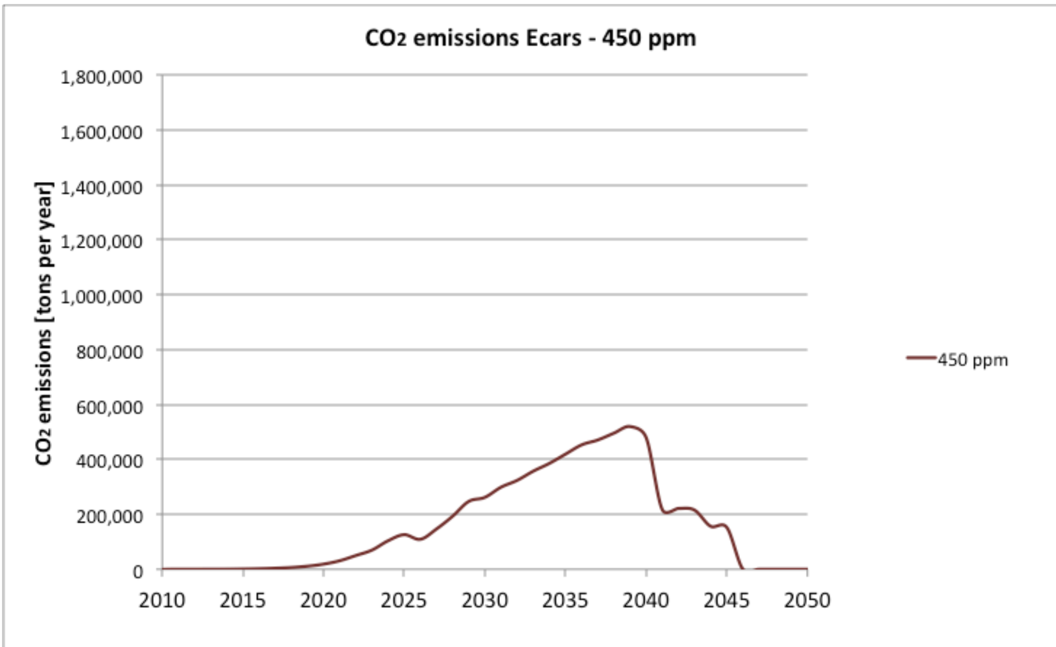

Figure 97 CO_2 emissions from E-cars – tech.

8.6.2 Modal split – tech.

In the tech. scenario, the share of PMT in 2050 is higher than in 2010, reaching 71%. In 2025, the share is 69%. The public transport modes keep their shares constant, though public transport bus loses one percentage point. Pedestrians and cyclists lose 4 percentage points until 2050.

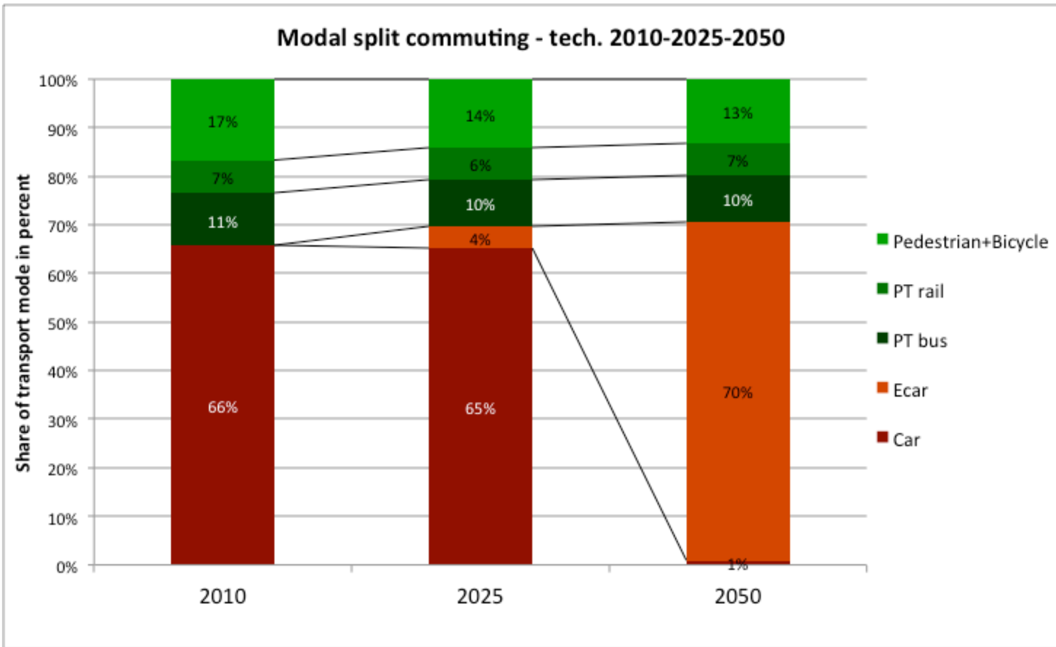

Figure 98 Modal split trip purpose commuting for the scenario tech., years 2010, 2025 and 2050

For the other trip purposes the share of PMT is decreasing over time. In 2050 50% of the trips are E-car trips, while 1% are trips made by car. Pedestrians and cyclists keep their shares constant while the public transport modes each gain one percentage point. The assumed price increases for fuel and electricity enable the shares of eco modes to slightly increase over time.

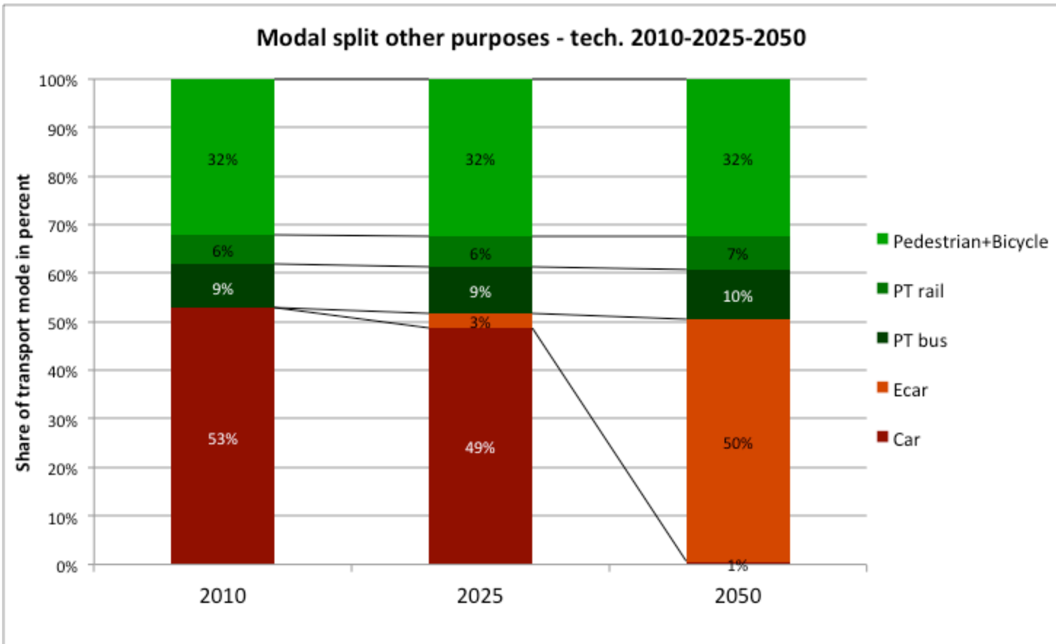

Figure 99 Modal split all other trip purposes for the scenario tech., years 2010, 2025 and 2050

Figure 100 depicts the overall modal split for the tech. scenario. In 2050, 26% of all trips are either pedestrian or bicycle trips. The public transport mode rail gains one percentage point until 2050, while the shares of public transport rail remain constant. In 2050, 57% of the trips are E-car trips, only one percentage point of the trips are car trips.

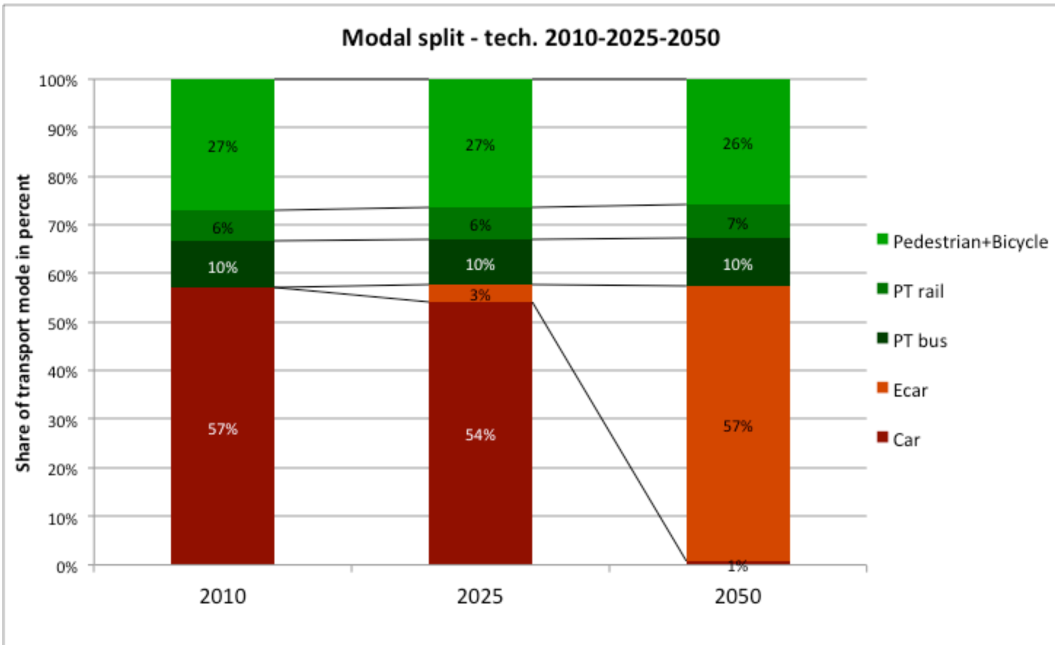

Figure 100 Modal split in total for the scenario tech., years 2010, 2025 and 2050

In the tech. scenario the same pattern occurs for the modal split development between 2024 and 2040 as for the 450 ppm scenario. As the car and E-car shares are converging the eco modes are gaining in shares, although this development is reversed as the E-Cars are established and the technological shift has taken place.

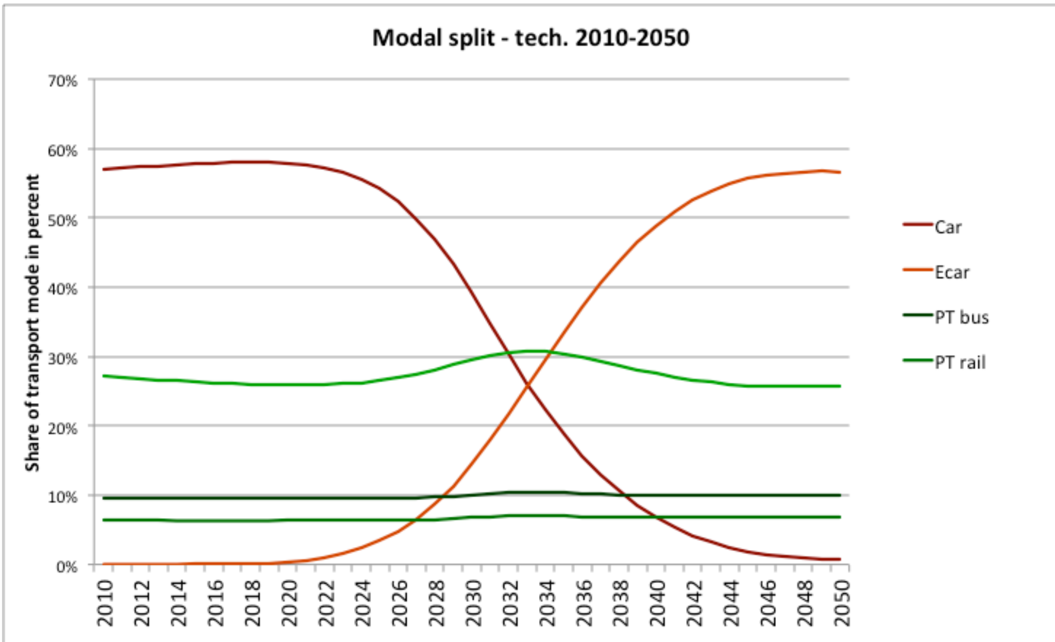

Figure 101 Modal split in total for the scenario tech. from 2010 to 2050

8.6.3 Passenger/vehicle kilometres and average trip length – tech.

Figure 102 presents the passenger kilometres for the scenario tech. The development is very similar to the 450 ppm development. The increases for the public transport modes as well as cycling and walking between 2025 and 2040 are just temporarily and decreasing again with higher shares of E-cars in the fleet development and in modal split (see Figure 102).

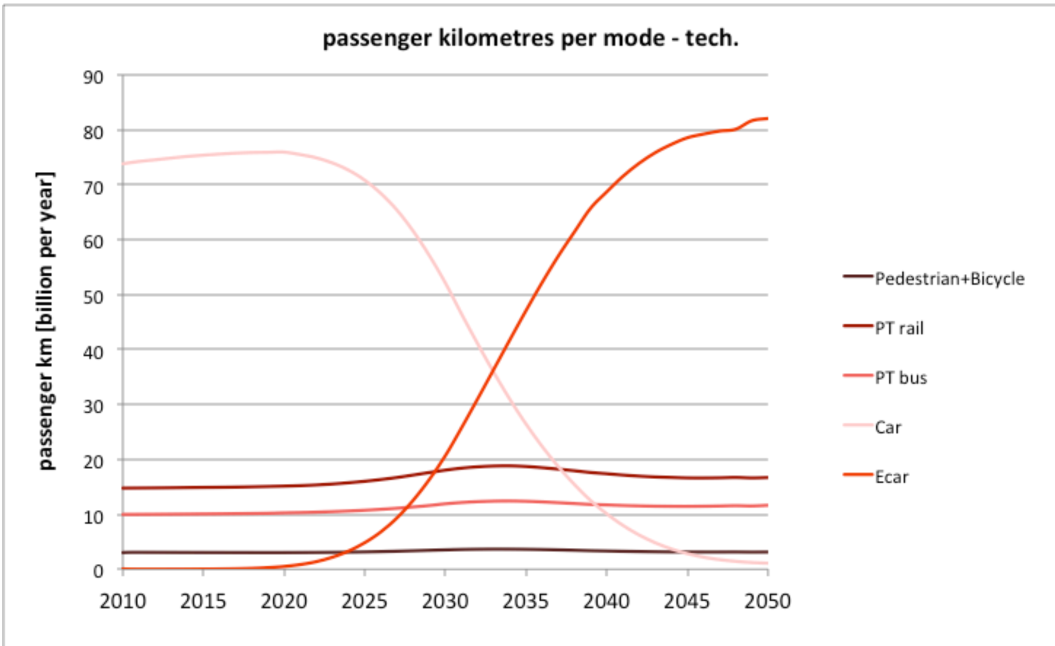

Figure 102 Passenger kilometres for the scenario tech.

Looking at the total passenger kilometres they increase to 115 billion in 2050, which corresponds to an increase of 13% compared to 2010. In this scenario the PMT contribute 72% to this increase, while the eco modes contribute 28%.

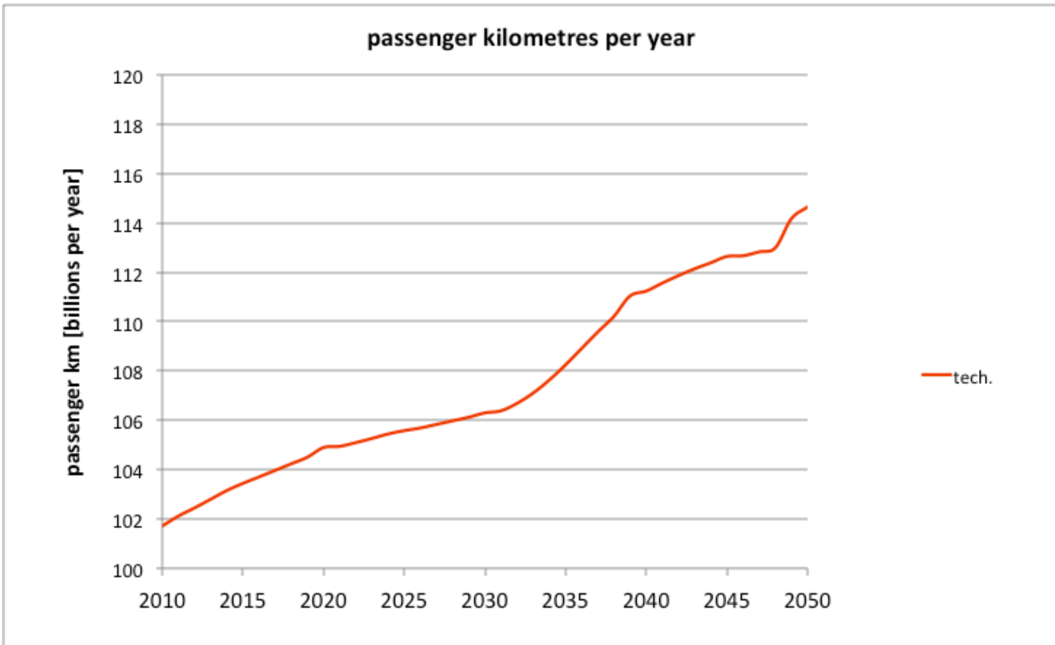

Figure 103 Passenger kilometres in total tech.

Figure 104 shows the share of passenger kilometres per mode and region type for the year 2050. Comparing 2010 to 2050 there is hardly any change in shares. In the tech. scenario a pure substitution between cars and E-cars take place. The few changes make the importance of land-use policies clear. A pure substitution of technology is not a solution for the remaining transport problems (space and energy consumption, see section 8.1) besides the CO_2 emissions.

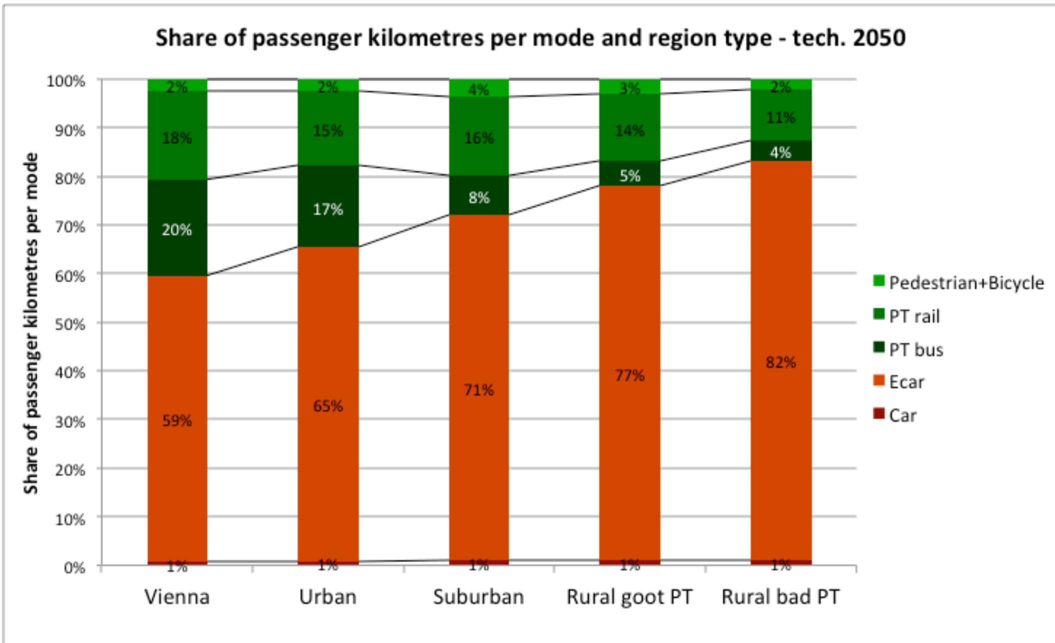

Figure 104 Share of passenger kilometres per mode and region type in 2050 for the scenario tech.

Table 31 depicts the changes in passenger kilometres per mode and region type between 2010 and 2050.

Mode/ region type	Vienna	Urban	Suburban	Rural good PT	Rural bad PT
Ped. + Bike	≈	↓	≈	≈	↓
PT rail	≈	↑	≈	≈	≈
PT bus	↑	≈	≈	≈	≈
PMT	≈	↑	≈	≈	↑

Table 31 Change in passenger kilometres per mode and region type between 2010 and 2050 for the scenario tech.

The development of the vehicle kilometres is shown in Figure 105. The development is similar to the 450 ppm scenario, but resulting in an even higher number of vehicle kilometres for the year 2050. In 2050 the number increases to 15,316.

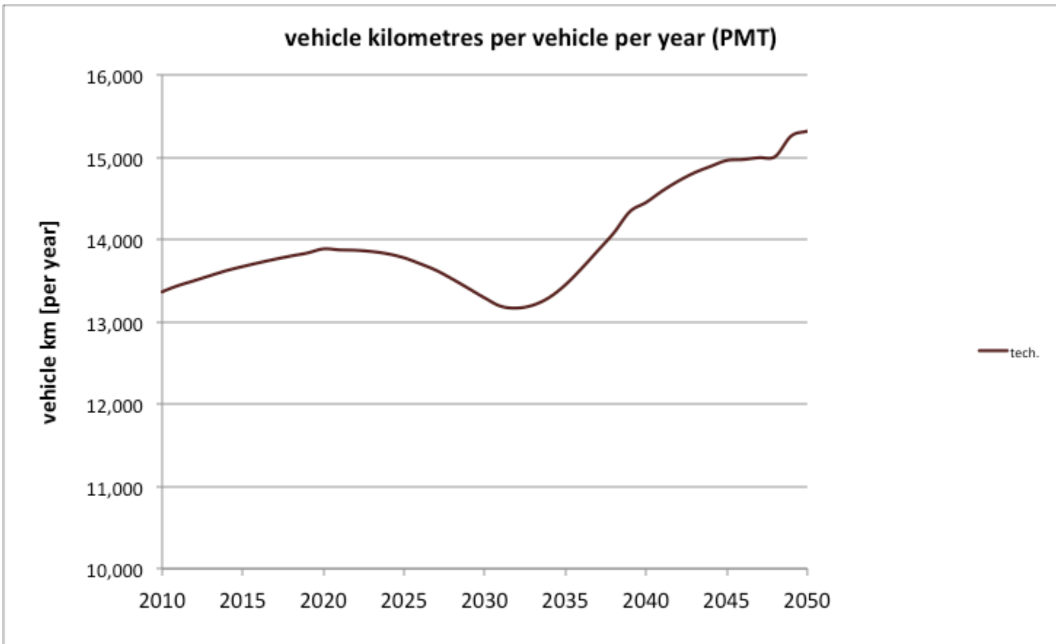

Figure 105 Vehicle kilometres per year for the scenario tech.

Figure 106 presents the average trip length per mode for the tech. scenario. For the average trip lengths the development is similar to the 450 ppm scenario. The difference is that there are no steps in the curves because of the lack of policy measures.

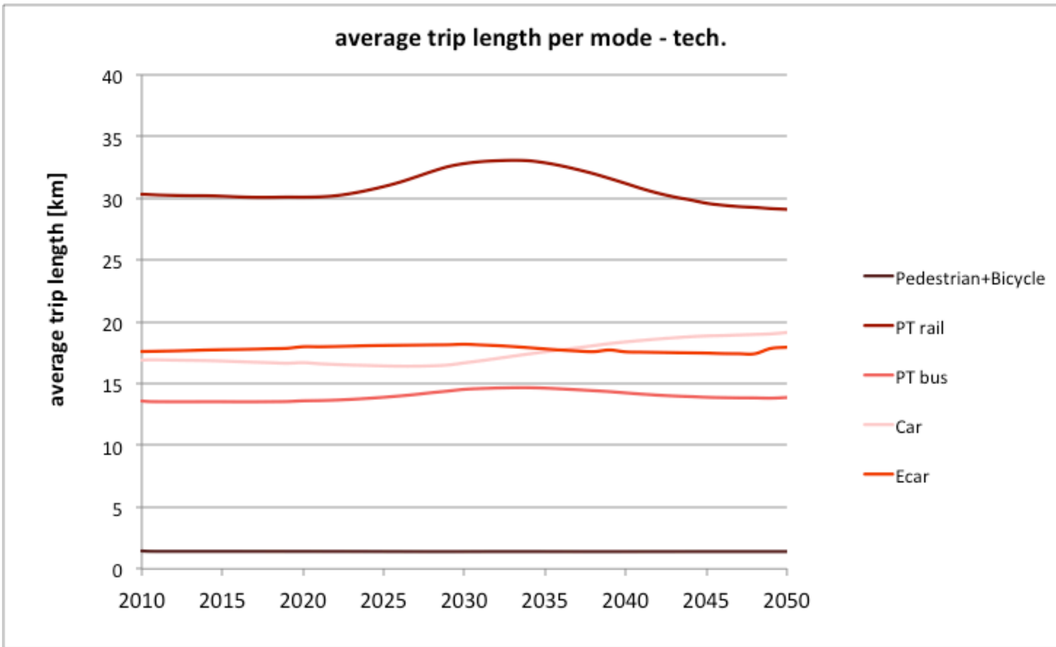

Figure 106 Average trip length per mode in kilometres for the tech. scenario

8.7 BAU-frozen technology

8.7.1 CO_2 – BAU-frozen technology

Figure 107 shows the CO_2 emissions per year for the BAU-frozen technology scenario. The emissions rise until 2020, and then decrease slightly until 2050, resulting in 11,453,567 tonnes per year in 2050.

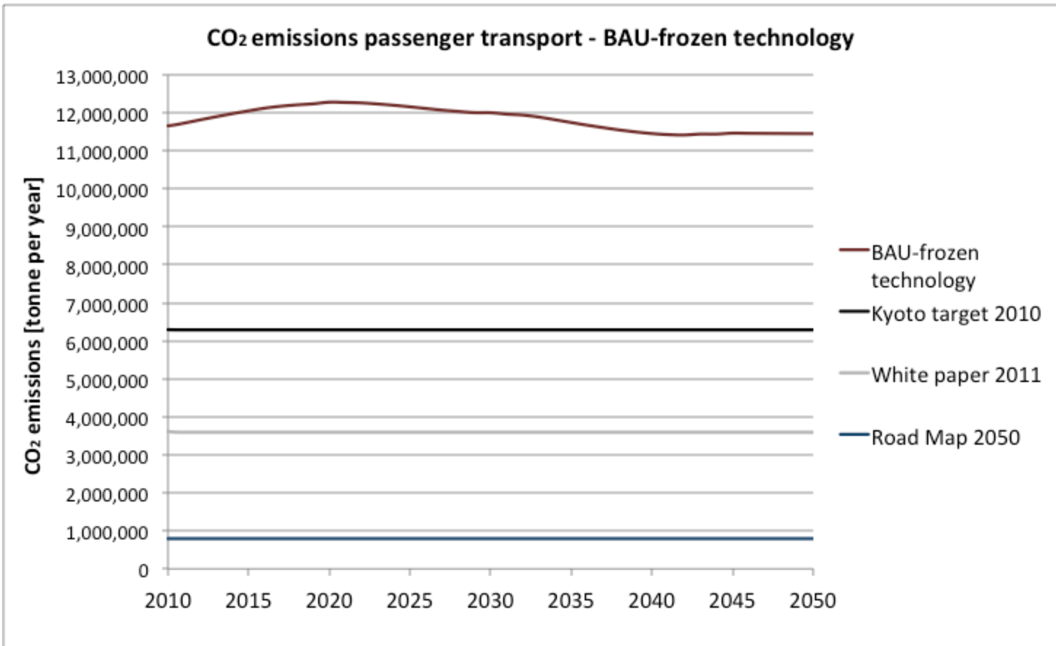

Figure 107 CO_2 emissions per year – BAU-frozen technology

8.7.2 Modal split – BAU-frozen technology

In Figure 108 the development of the modal split for commuting is depicted for the scenario BAU-frozen technology. Over time the share of cars is increasing while the share of the eco modes is decreasing. Pedestrians and bicycles lose the biggest share with 5 percentage points.

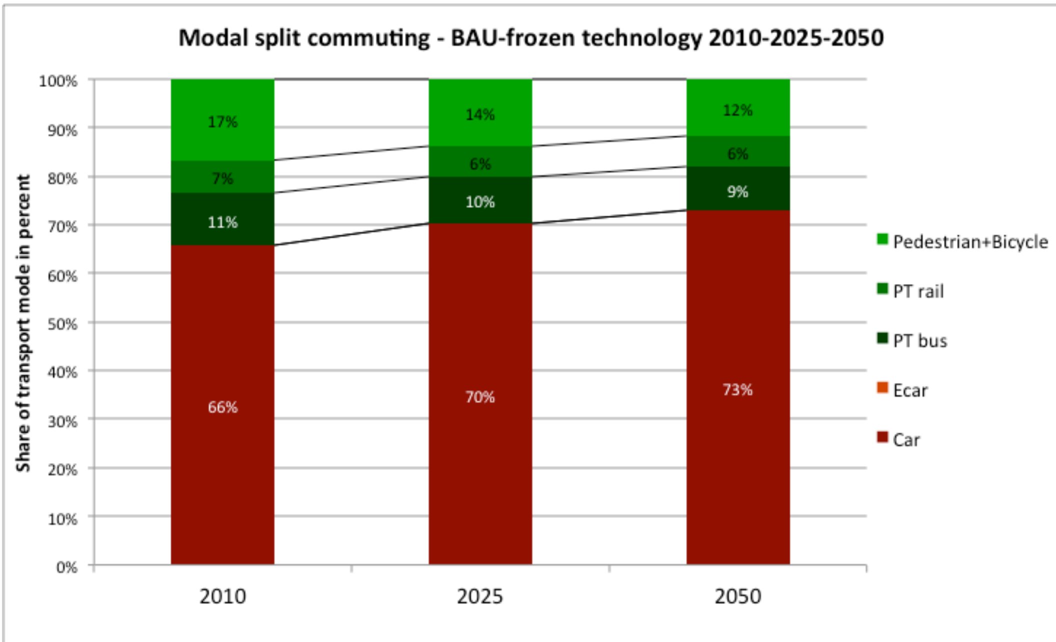

Figure 108 Modal split trip purpose commuting for the scenario BAU-frozen technology, years 2010, 2025 and 2050

The pattern for all other trip purposes is similar to the trip purpose commuting. While the share of cars is increasing until 2050, the share of the eco modes is decreasing. Again the biggest loss is registered for pedestrians and bicycles.

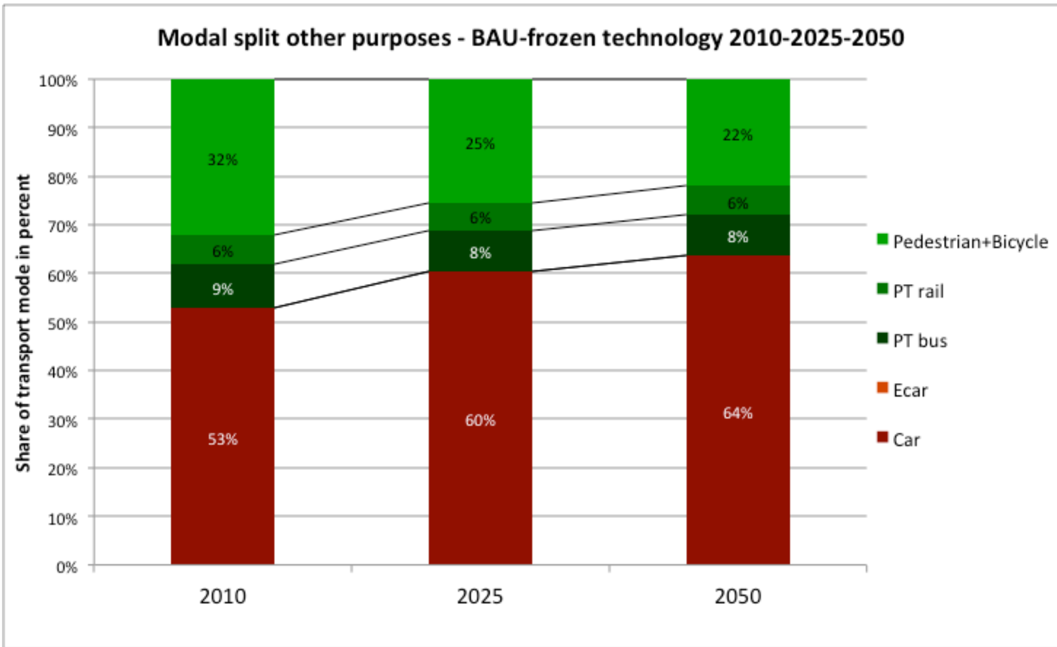

Figure 109 Modal split all other trip purposes for the scenario BAU-frozen technology, years 2010, 2025 and 2050

In total, the share of car is increasing while the share of all other modes is decreasing. In 2050 67% of all trips are car trips, this is an increase of 10 percentage points over time.

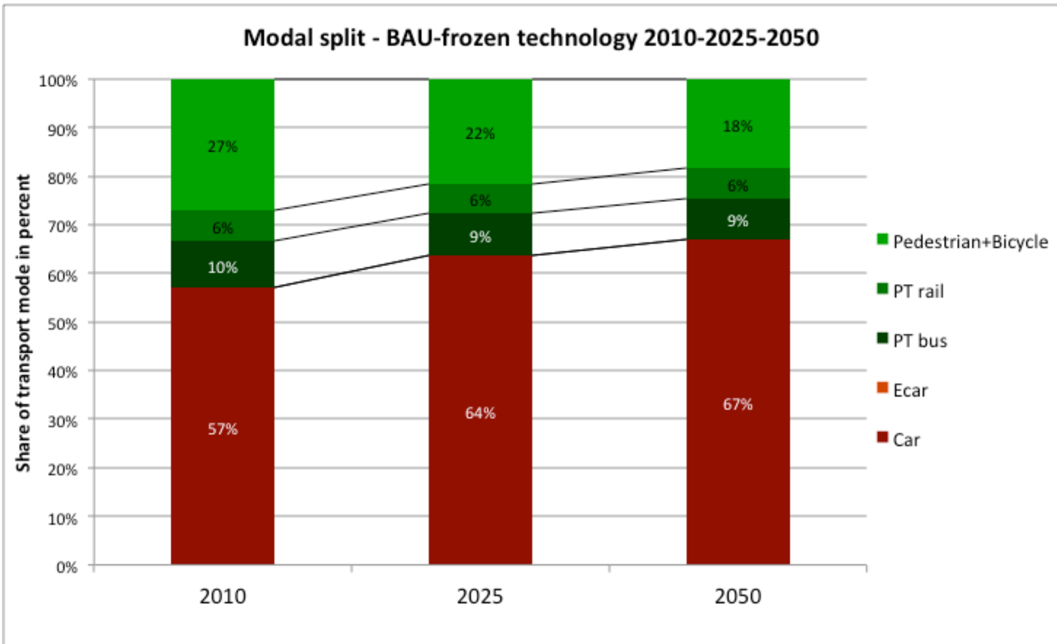

Figure 110 Modal split in total for the scenario BAU-frozen technology, years 2010, 2025 and 2050

8.7.3 Passenger/vehicle kilometres and average trip length – BAU-frozen technology

Figure 111 depicts the passenger kilometres per mode for the scenario BAU-frozen technology. In accordance with the modal split development the passenger kilometres for the mode car are increasing over time, while the passenger kilometres for the other modes are decreasing.

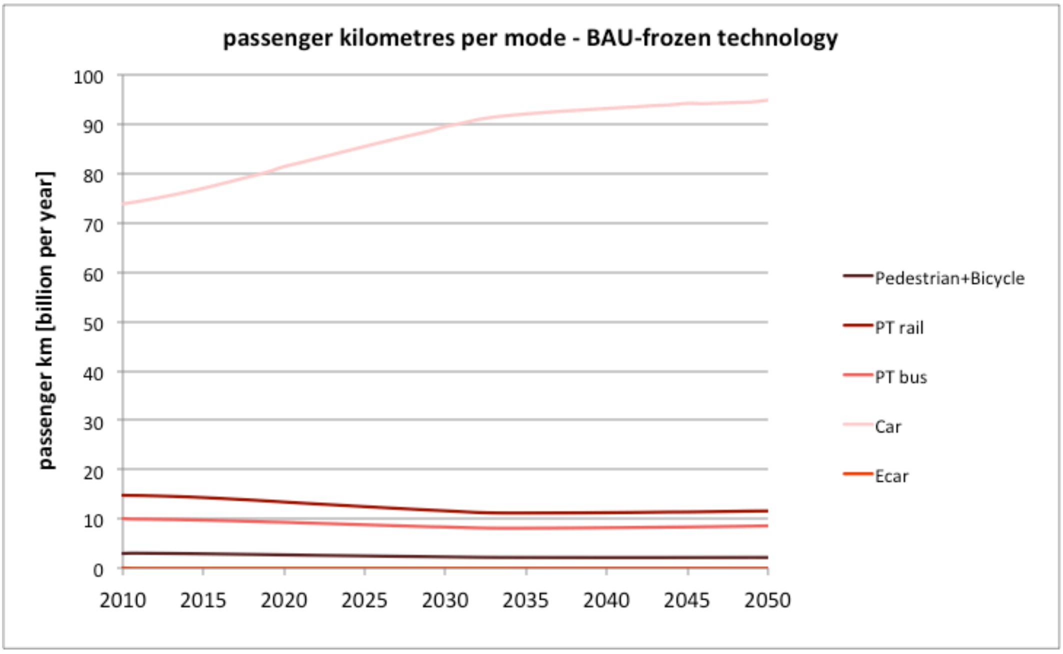

Figure 111 Passenger kilometres for the scenario BAU-frozen technology

The development of the total passenger kilometres is very similar to the BAU development. In 2050 the passenger kilometres are 117 billion, corresponding to an increase of +15% compared to the 2010 value.

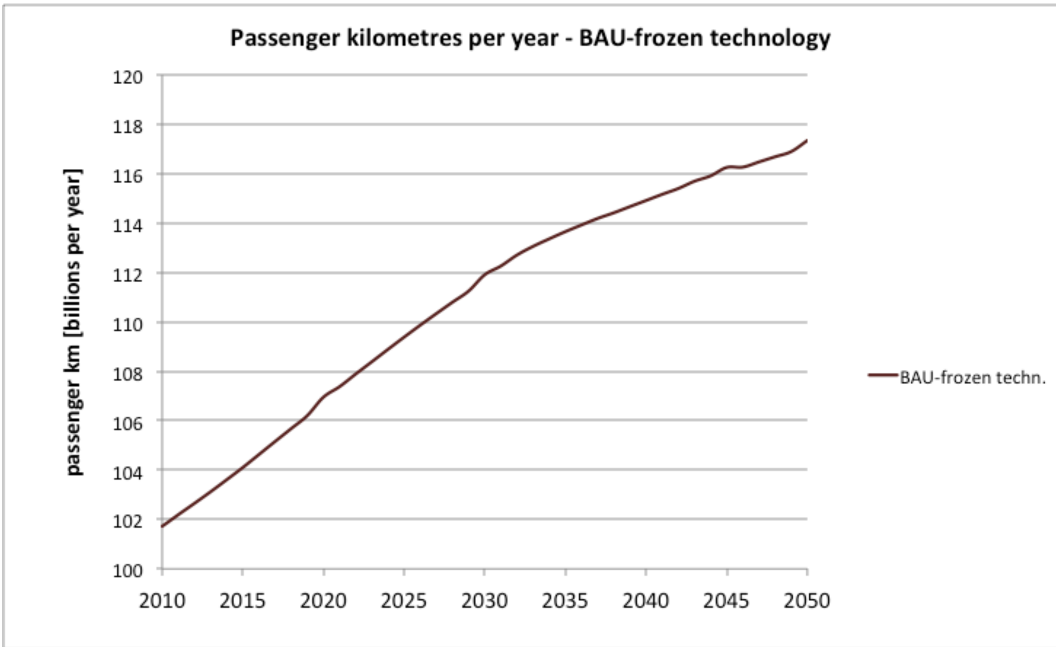

Figure 112 Passenger kilometres in total BAU-frozen technology

Figure 113 shows the share of passenger kilometres for trips with destinations in the different region types for the year 2050.

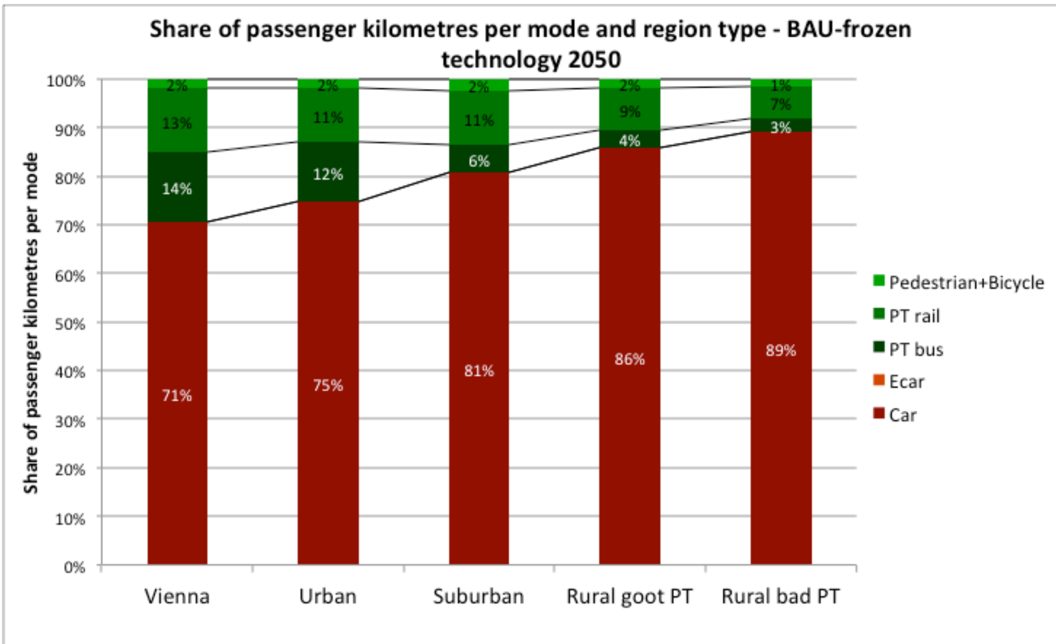

Figure 113 Share of passenger kilometres per mode and region type in 2050 for the scenario BAU-frozen technology

Table 32 presents changes in passenger kilometres per mode and region type between 2010 and 2050. As can be seen, the share of car is increasing in all regions, while the share of the other modes is decreasing in all regions (except for Vienna).

No transport and land-use policies combined with increasing levels of motorization are leading to increases in passenger kilometres for PMT in all region types, while for the other modes the shares are decreasing.

Mode/ region type	Vienna	Urban	Suburban	Rural good PT	Rural bad PT
Ped. + Bike	≈	↓	↓	↓	↓
PT rail	↓	↓	↓	↓	↓
PT bus	↓	↓	↓	↓	↓
PMT	↑	↑	↑	↑	↑

Table 32 Change in passenger kilometres per mode and region type between 2010 and 2050 for the scenario BAU-frozen technology

Figure 114 presents the vehicle kilometres per vehicle for the BAU-frozen technology scenario. Similar to the BAU scenario the vehicle kilometres decrease until 2050.

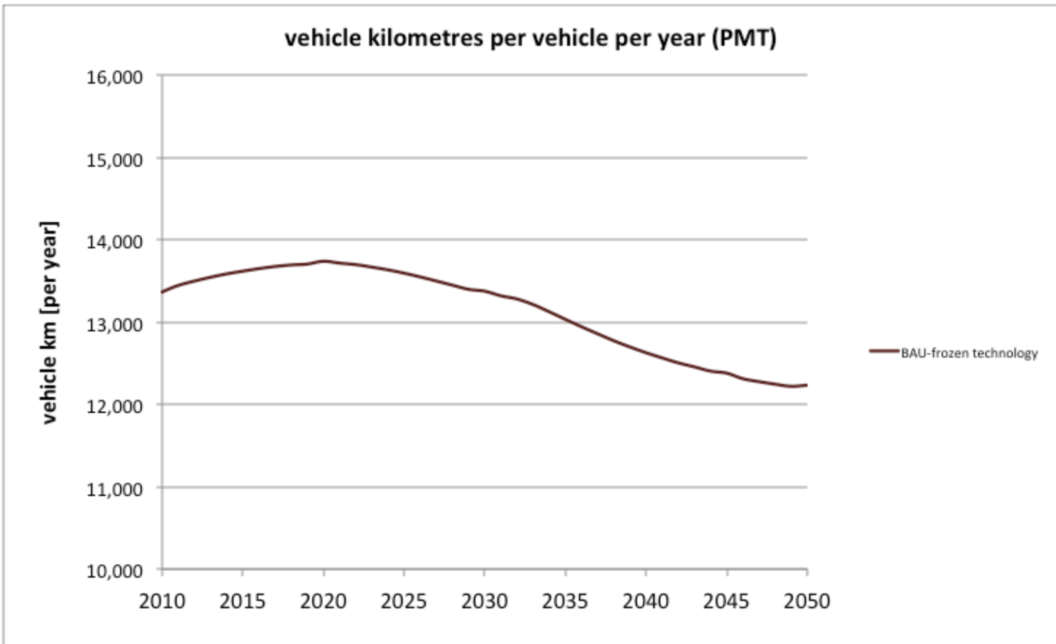

Figure 114 Vehicle kilometres per year for the scenario BAU-frozen technology

Figure 115 shows the average trip length per mode for the BAU-frozen technology scenario. There is a steep decrease in the average tip length for the mode public transport rail of 7 kilometres until 2050, as a consequence of the loss of share in the modal split. The average trip lengths for the public transport mode bus are also decreasing for the same reason.

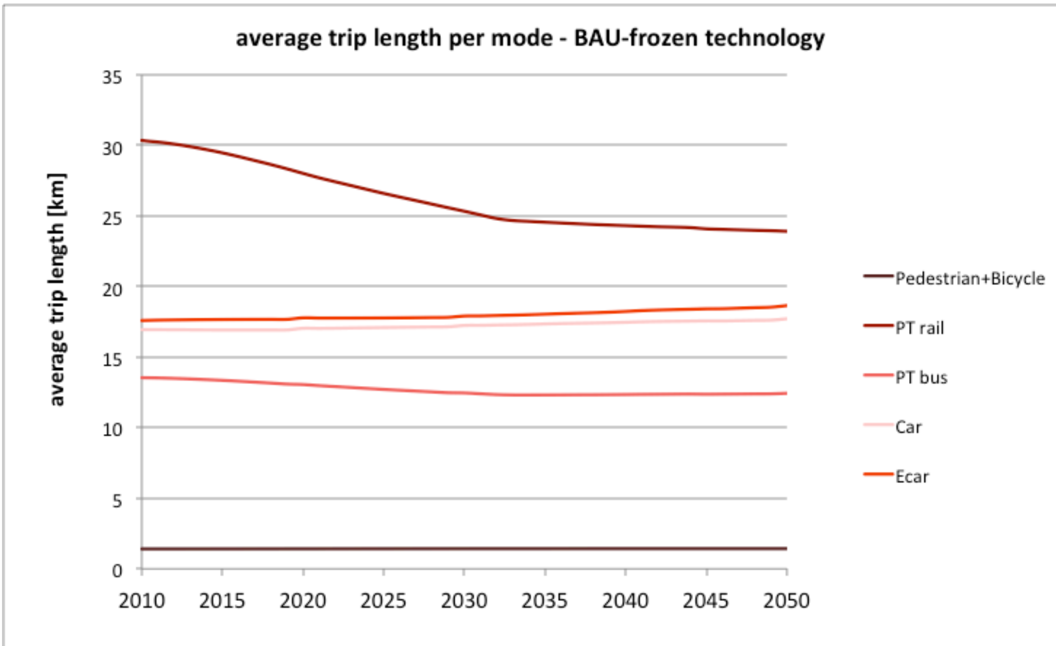

Figure 115 Average trip length in kilometres per mode for the BAU-frozen technology scenario

8.8 TPO (transport policy only)

8.8.1 CO_2 – TPO

Figure 116 shows the CO_2 emissions per year for the TPO scenario. The emissions rise until 2015 to decrease again until 2050, resulting in 8,205,319 tonnes per year in 2050. The reduction from 2015 to 2050 is the result of efficiency gains for petrol and diesel cars, resulting in fewer CO_2 emissions per kilometre and the modal shift, which takes place especially after 2030.

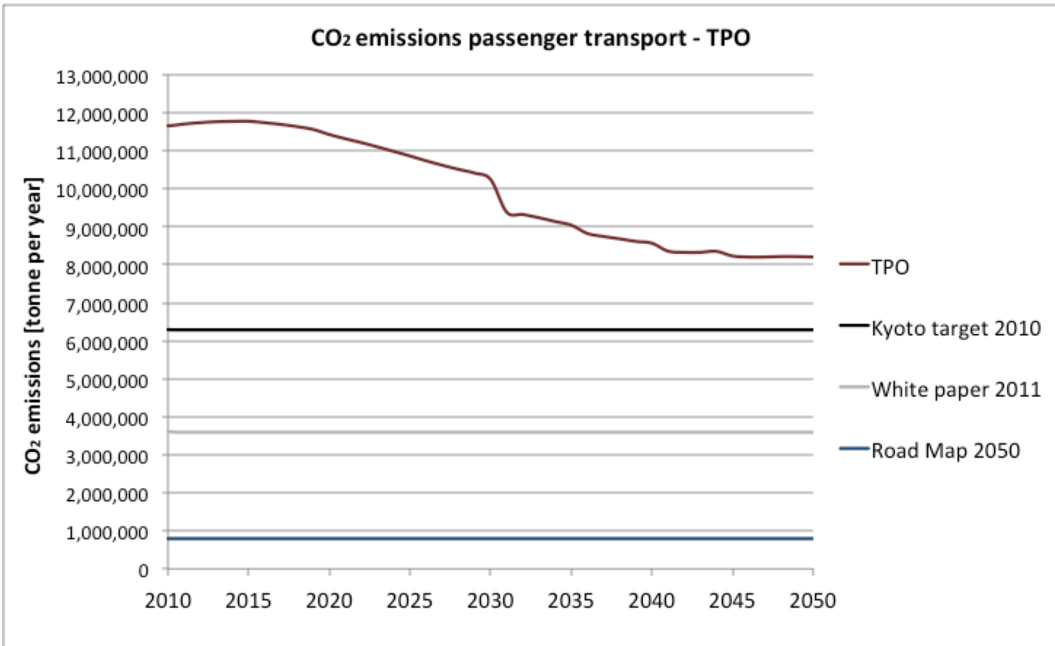

Figure 116 CO_2 emissions per year – TPO

8.8.2 Modal split – TPO

In Figure 117 the development of the modal split for commuting is depicted for the scenario TPO. Over time the share of eco modes is increasing while the share cars of is decreasing. Pedestrians and bicycles gain two percentage points, while public transport rail gains one percentage point and the public transport bus share remains constant.

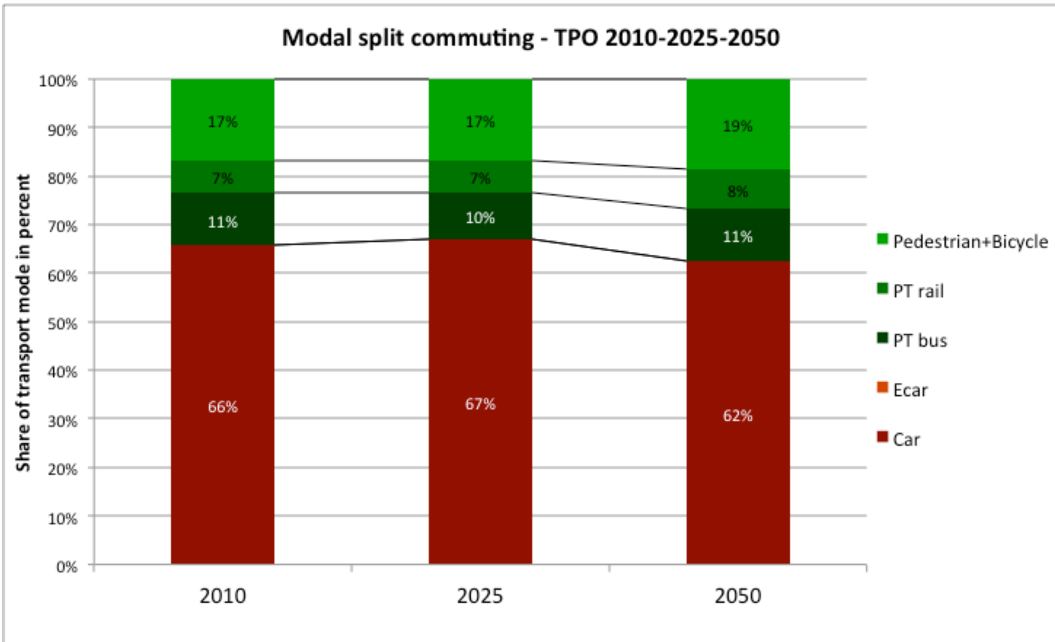

Figure 117 Modal split trip purpose commuting for the scenario TPO, years 2010, 2025 and 2050

For all other trip purposes there is a substantial shift from the mode car to the eco modes. Especially pedestrians and bicycles gain six percentage points until 2050, the public transport modes both two percentage points.

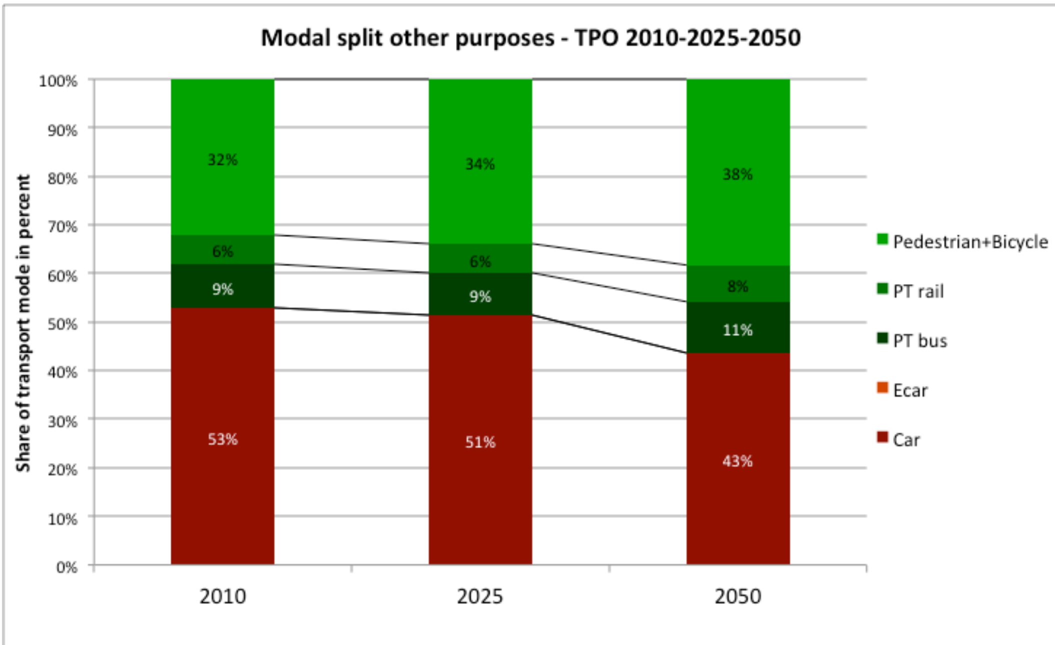

Figure 118 Modal split all other trip purposes for the scenario TPO, years 2010, 2025 and 2050

In total the share of car is decreasing to 50% in 2050, while the shares of all other modes are increasing. In 2050, 50% of all trips are either public transport or pedestrian and bicycle trips.

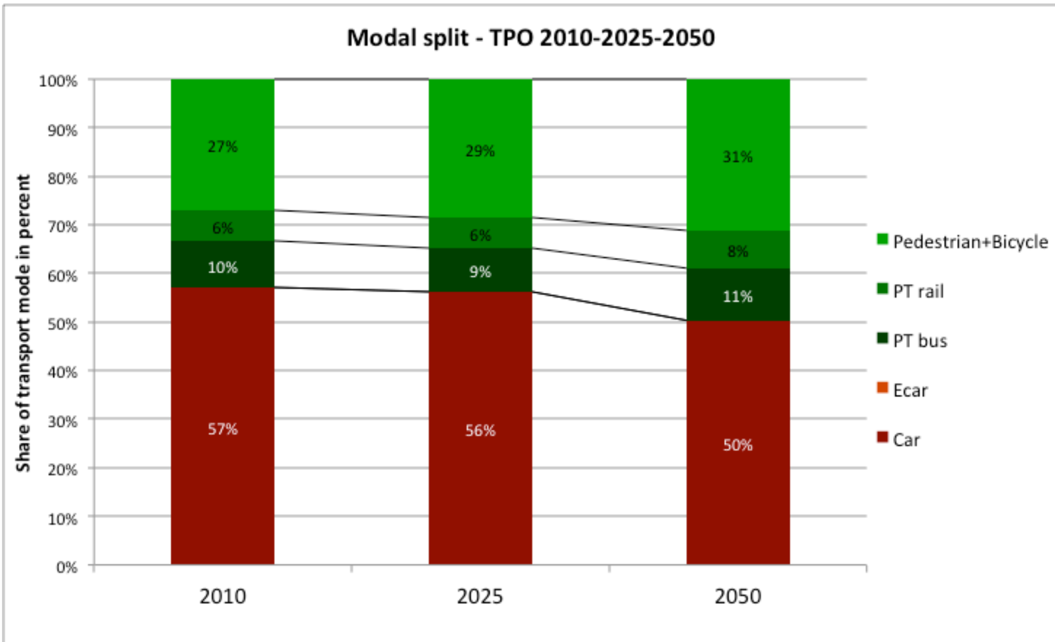

Figure 119 Modal split in total for the scenario TPO, years 2010, 2025 and 2050

8.8.3 Passenger/vehicle kilometres and average trip length – TPO

Figure 120 depicts the passenger kilometres per mode for the scenario TPO. In accordance with the modal split development the passenger kilometres for the mode car are decreasing over time, while the passenger kilometres for the other modes are slightly increasing. The influence of the policy measures is clearly visible through the steep reductions in passenger kilometres.

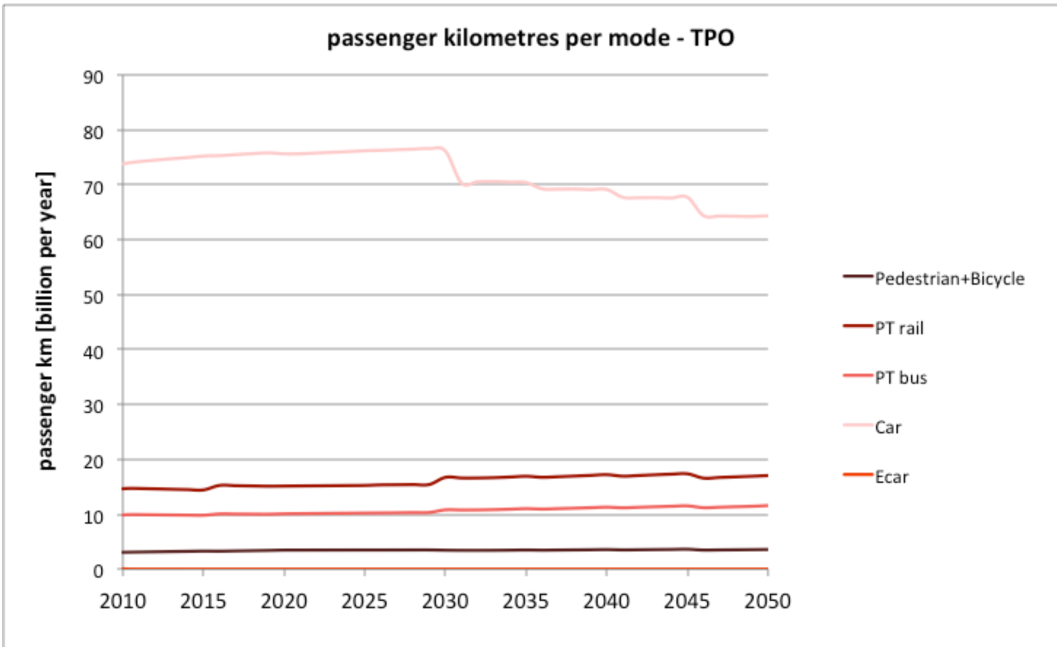

Figure 120 Passenger kilometres for the scenario TPO

The development of the total passenger kilometres is depicted in Figure 121. The development maps the influence of the transport policies. It can be seen that the influence of the policies decreasing the passenger kilometres for PMT are bigger that the policies increasing the passenger kilometres for al other modes. In total the passenger kilometres decrease to 97 billion, corresponding to a decrease of -5%.

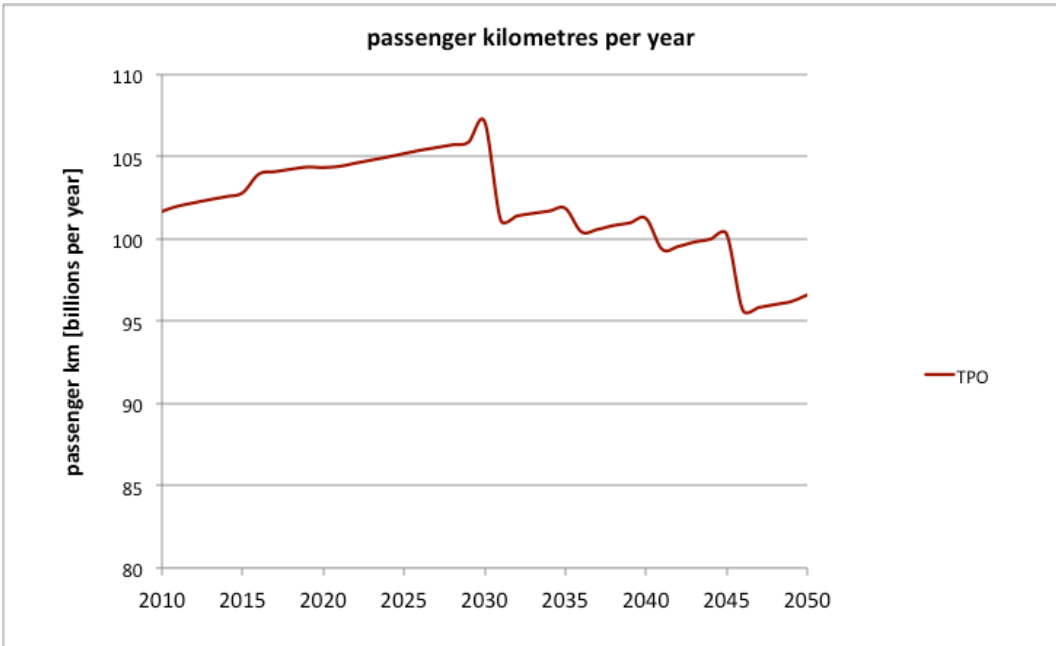

Figure 121 Passenger kilometres in total TPO

Figure 122 show the share of passenger kilometres for trips with destinations in the different region types for the year 2050.

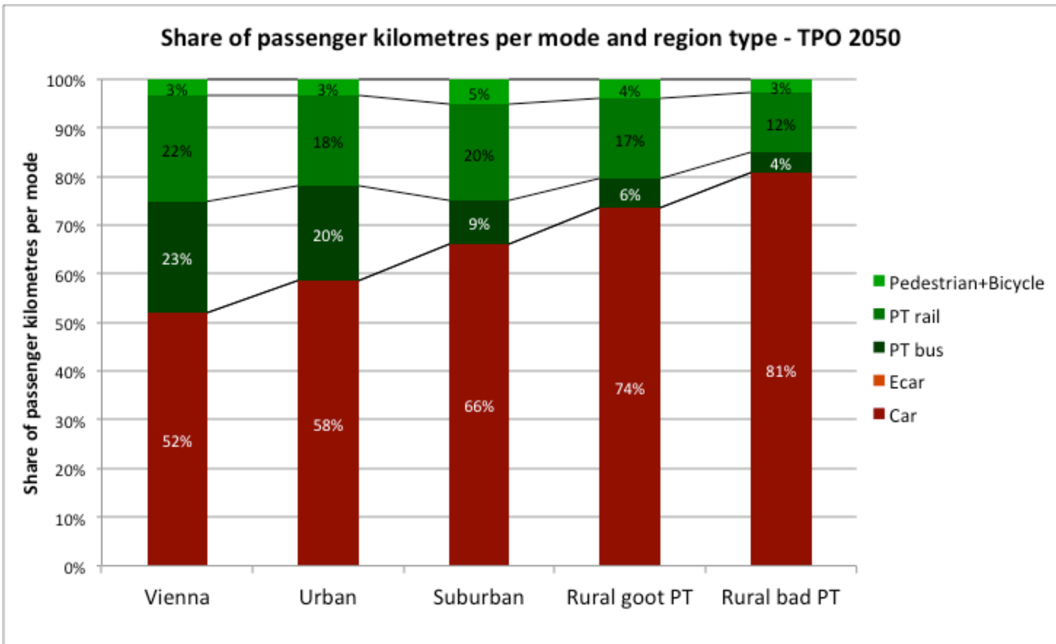

Figure 122 Share of passenger kilometres per mode and region type in 2050 for the scenario TPO

Table 33 presents changes in passenger kilometres per mode and region type between 2010 and 2050. As can be seen the share of car is decreasing in all region types. The public transport modes gain in shares in each of the region types, except for the rural regions with less favourable conditions for public transport, where the share of bus remains constant. The passenger kilometres of pedestrians and cyclists increase in Vienna, the suburban regions and rural regions with favourable conditions for public transport, but remain constant in urban regions and regions with less favourable conditions for public transport.

Mode/ region type	Vienna	Urban	Suburban	Rural good PT	Rural bad PT
Ped. + Bike	↑	≈	↑	↑	≈
PT rail	↑	↑	↑	↑	↑
PT bus	↑	↑	↑	↑	≈
PMT	↓	↓	↓	↓	↓

Table 33 Change in passenger kilometres per mode and region type between 2010 and 2050 for the scenario TPO

The vehicle kilometres per vehicle decrease over time, showing the strong influence of the transport policies. In 2050 the vehicle kilometres per year and vehicle are 11,902.

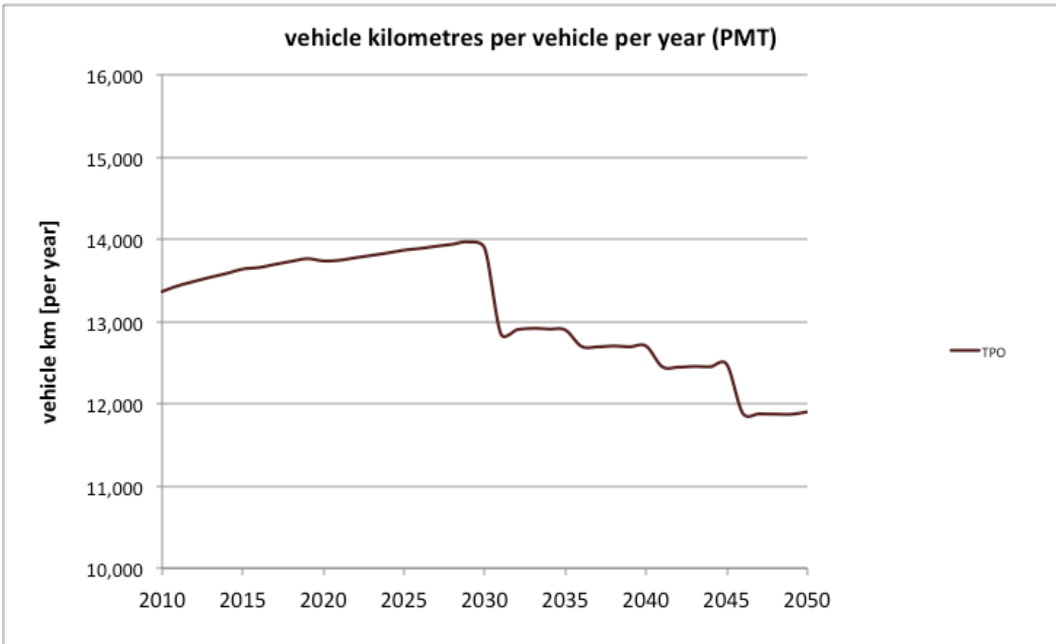

Figure 123 Vehicle kilometres per year for the scenario TPO

Figure 124 depicts the average trip lengths per mode and year. The average trip length of the mode public transport rail is decreasing over time, while the other modes remain relatively constant (the share of the mode E-car is very small in this scenario).

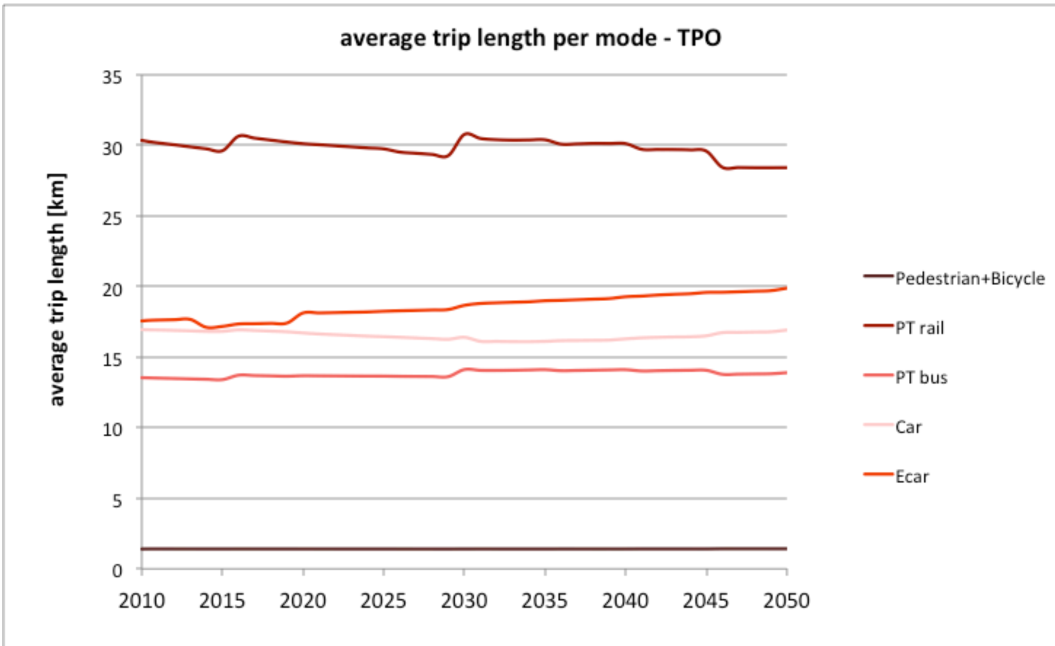

Figure 124 Average trip length per mode in kilometres for the TPO

8.9 LPO (land-use policy only)

8.9.1 CO_2 – LPO

In Figure 125 the CO_2 emissions per year are presented for the LPO scenario. The emissions rise until 2014 to decrease again until 2050, resulting in 9,420,045 tonnes per year in 2050.

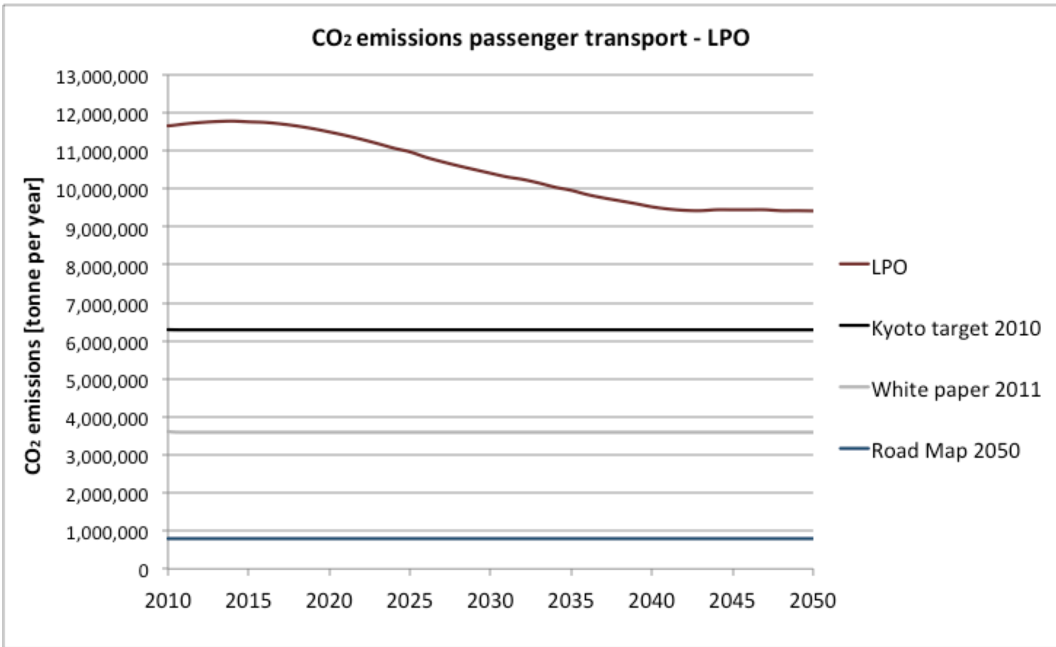

Figure 125 CO_2 emissions per year – LPO

8.9.2 Modal split – LPO

Figure 126 depicts the development of the modal split for commuting for the scenario LPO. The car share in 2050 is 67%, which is a reduction of two percentage points compared to the BAU-frozen technology scenario. The pedestrian and bicycle share is decreased by four percentage points, public transport bus loses one percentage point, while the public transport rail share remains constant.

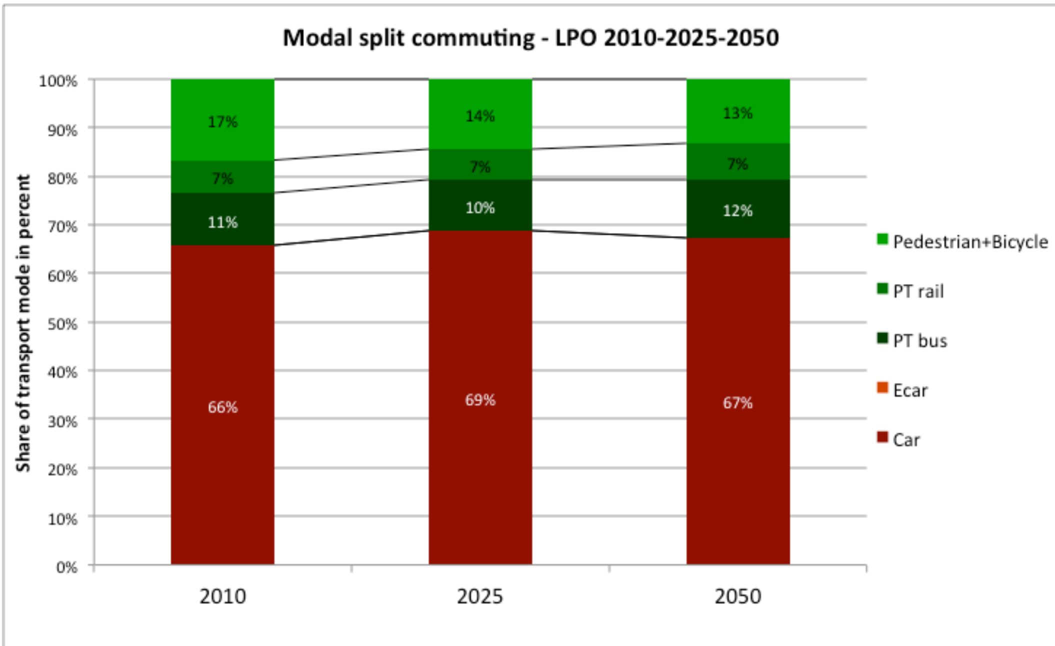

Figure 126 Modal split trip purpose commuting for the scenario LPO, years 2010, 2025 and 2050

For all other trip purposes the modal split of car is decreased by two percentage points until 2050. The biggest winner in off-peak time is the mode public transport bus gaining three percentage points.

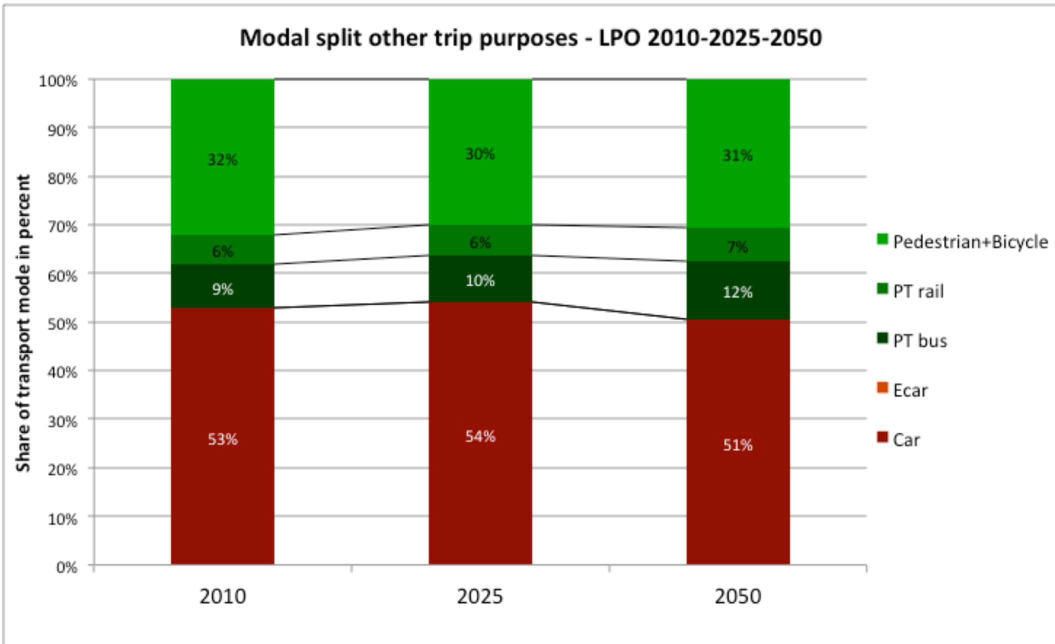

Figure 127 Modal split all other trip purposes for the scenario LPO, years 2010, 2025 and 2050

In total the share of car is decreasing to 56% in 2050, whereas the shares of all other modes are increasing. The share of pedestrians and bicycles and public transport bus is each increased by two percentage points. Public transport rail gains one percentage point.

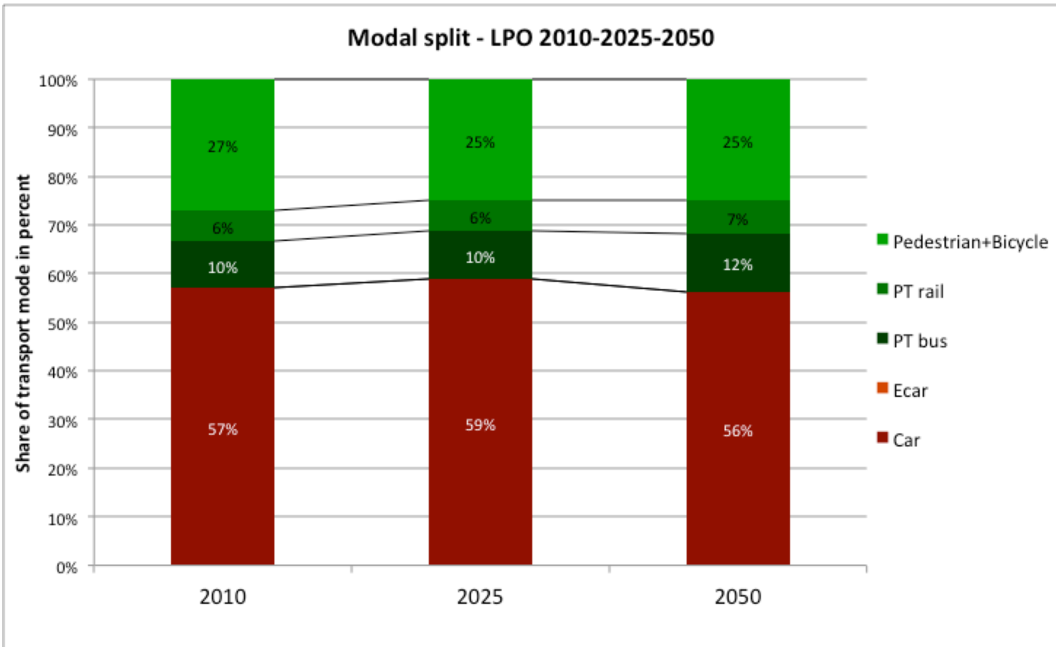

Figure 128 Modal split in total for the scenario LPO, years 2010, 2025 and 2050

8.9.3 Passenger/vehicle kilometres and average trip length – LPO

Figure 129 depicts the passenger kilometres per mode for the scenario LPO. The land-use policy does not seem to have a significant influence on the passenger kilometres per year and mode.

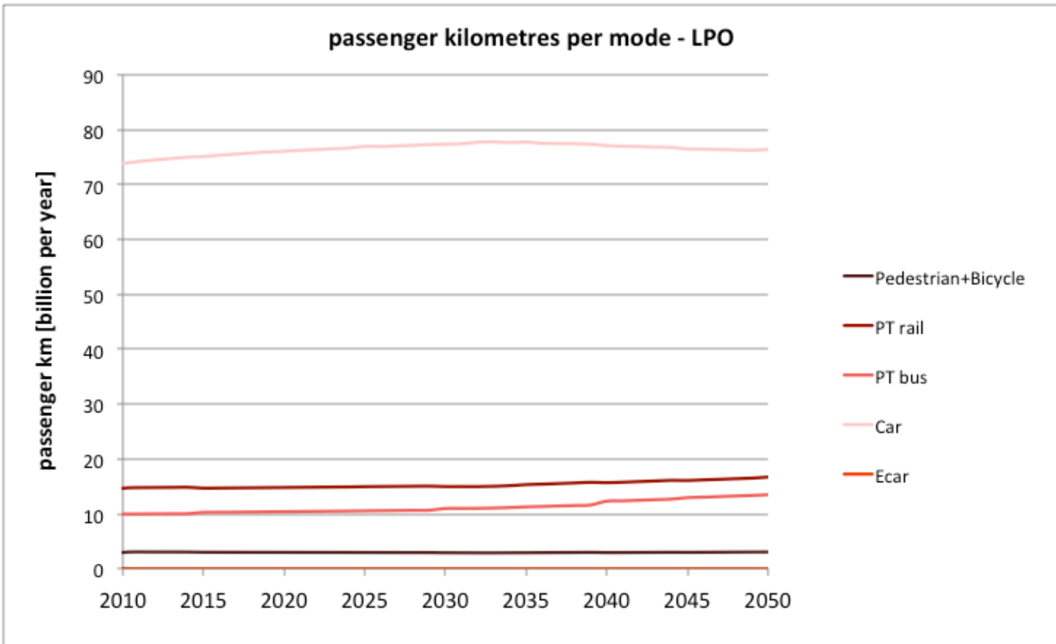

Figure 129 Passenger kilometres for the scenario LPO

In total the passenger kilometres rise to 110 billion in 2050, corresponding to an increase of 8%.

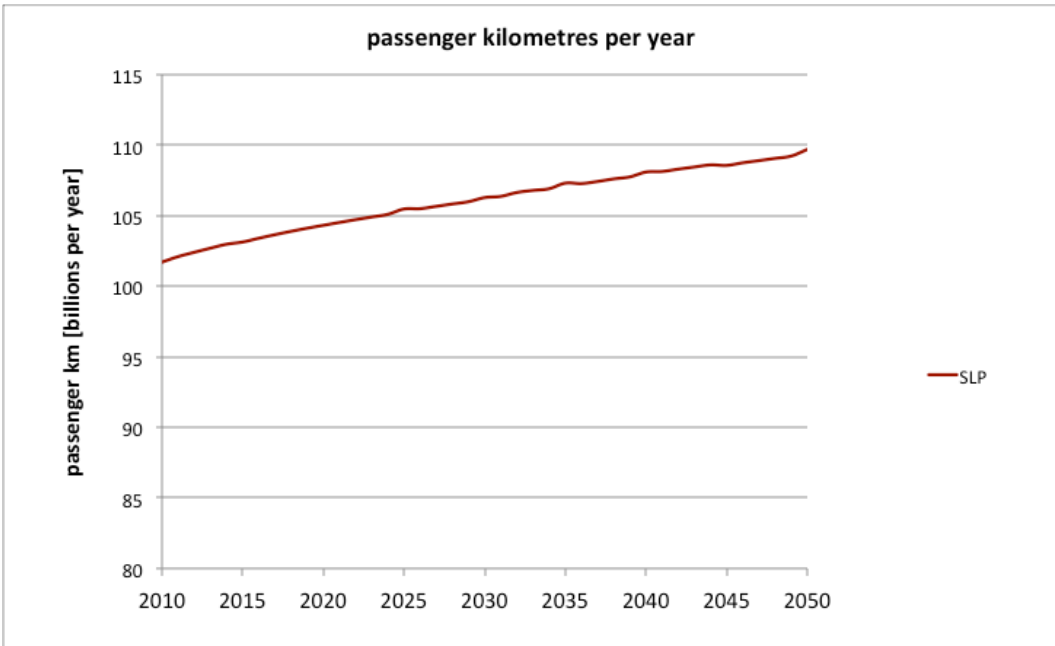

Figure 130 Passenger kilometres in total LPO

Figure 131 shows the share of passenger kilometres for trips with a destination in the different region types for the year 2050.

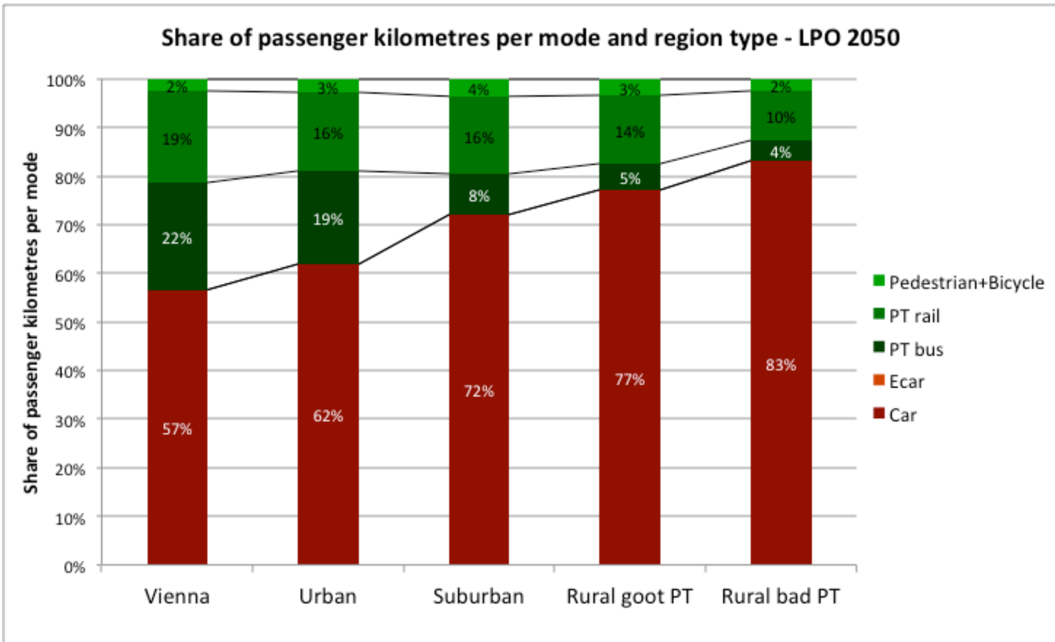

Figure 131 Share of passenger kilometres per mode and region type in 2050 for the scenario LPO

Table 34 presents changes in passenger kilometres per mode and region type between 2010 and 2050. The land-use policy has the biggest influence on Vienna and the urban regions, leading to a decrease in passenger kilometres for the mode car, while the share of the public transport modes increases (except for public transport rail in urban regions).

Mode/ region type	Vienna	Urban	Suburban	Rural good PT	Rural bad PT
Ped. + Bike	≈	≈	≈	≈	↓
PT rail	↑	≈	≈	≈	↓
PT bus	↑	↑	≈	≈	≈
PMT	↓	↓	≈	↓	↑

Table 34 Change in passenger kilometres per mode and region type between 2010 and 2050 for the scenario LPO

The vehicle kilometres per vehicle increase over time. In 2050, 14,085 kilometres per year and vehicle are driven.

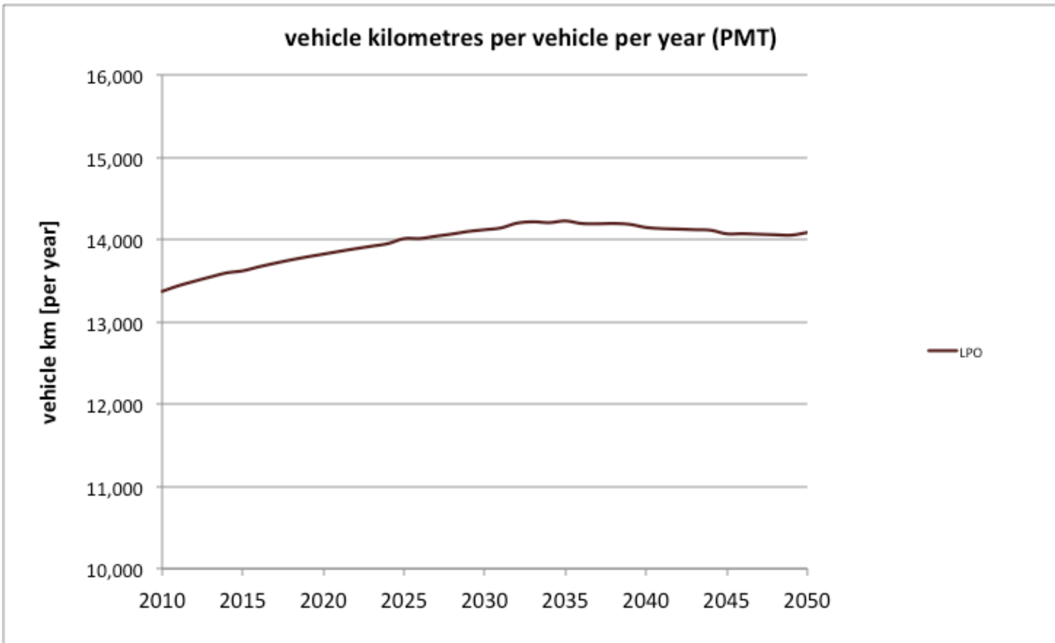

Figure 132 Vehicle kilometres per year for the scenario LPO

Figure 133 depicts the average trip lengths per mode and year. The average trip length of the mode public transport rail is decreasing over time, while the car trip length is increasing.

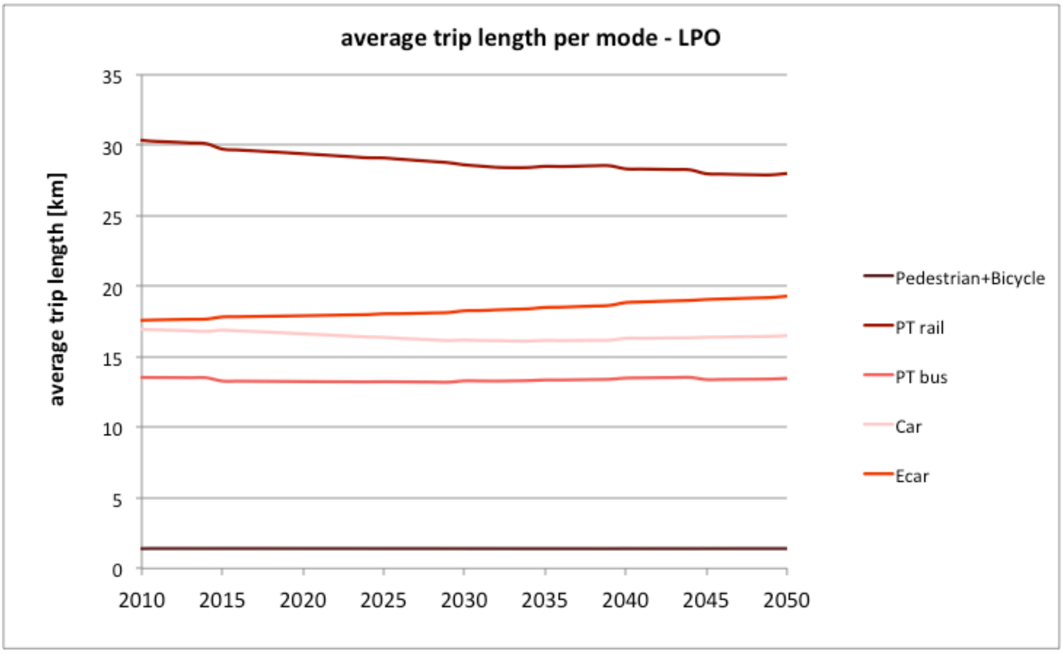

Figure 133 Average trip length per mode in kilometres for the LPO

9 COMPARISON OF THE RESULTS AND ANSWERS TO THE MAIN RESEARCH QUESTIONS

In this chapter the results of the scenarios (policy scenarios and frozen-technology scenarios) are compared and the answers to the main research questions and sub-questions are given. As a reminder the two main research questions of this thesis are:

"What are the overall effects of different transport and land-use policy scenarios and different development paths of electric mobility on the transport behaviour and on CO_2 emissions on a national scale?" "Which policy combinations enable to reach the Kyoto- White Paper- and Roadmap-targets?"

The sub-research questions that were to be answered (see section 1.3) are:

1. How can transport and land-use policies be modelled within the MARS model?
2. Which policy combinations are most effective in reducing CO_2 emissions on a national scale, and are therefore recommendable for the purpose of reaching national and international targets?
3. What is the impact of different diffusion scenarios of E-cars CO2 emissions?
4. Are technological measures alone sufficient for reaching long-term climate targets?
5. Which policy combinations are most influential in changing transport behaviour?
6. Are stand-alone land-use policies or stand-alone transport policies more effective? Where do combinations of the two lead us?

So far **sub-research question one** was already answered in chapter 6, where the implementation of the policies (transport and land-use) into MARS is described in detail.

9.1 CO_2 reduction potential

9.1.1 Policy scenarios

Looking at the potential to reduce the CO_2 emissions in the transport sector, it is not surprising that the 450 ppm scenario is the most effective one (**sub-research question two**), for the simple reason that it contains the “strongest” policy measures for both the transport and the land-use sector. Additionally, the underlying fleet development assumes a strong shift towards E-cars and an energy mix shifting quickly towards renewables, reaching a 100% renewable energy mix at the end of the simulation period. The big influence of the fleet development on CO_2 emissions can especially be observed when the 450 ppm scenario is compared to the tech. scenario, where the difference in emissions in 2050 is negligible. The difference is, that the policy measures decrease the emissions compared to the tech. scenario at earlier time steps during the simulation period.

These two scenarios are the only ones reaching all three described CO_2 emissions targets. This development also answers the **sub-research questions three and four** listed above, whether technological measures alone would be sufficient to reach long-term climate targets and which impact is to be expected from different diffusion paths of electric mobility. As can be seen, the assumption that the energy consumed by electric cars is produced from renewables allows the climate targets to be reached even without implementation of policies. But the dependency on the assumption of a 100% renewable energy production might be also crucial. Nevertheless with the assumptions made here, the climate targets are reached.

Figure 134 presents the CO_2 emissions per year until 2050 for the different policy scenarios. Clearly the influence of the fleet is visible in all depicted scenarios, because compared to the frozen-technology scenarios (see Figure 137) the curves are all declining rather sharply.

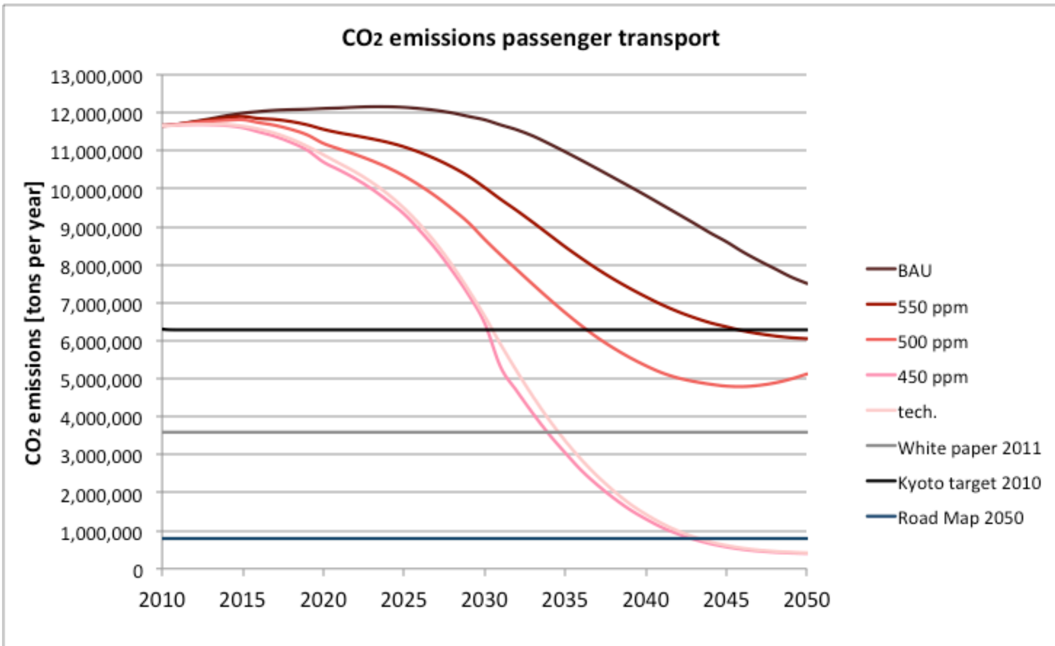

Figure 134 CO_2 emissions per year – policy scenarios

Figure 135 gives an overview of the accumulated CO_2 emissions from 2010 to 2050 per policy scenario. It can be seen that the accumulated CO_2 emission from the 450 ppm and the tech. scenario differ only slightly.

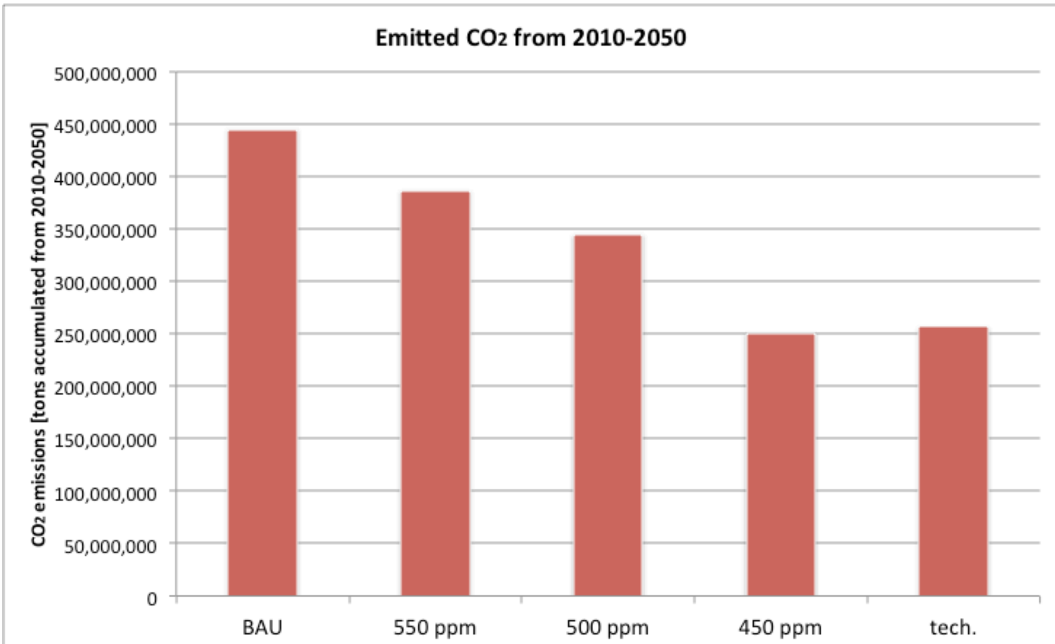

Figure 135 Accumulated CO_2 emissions for the policy scenarios 2010 until 2050

Figure 136 depicts the CO_2 emissions resulting from E-cars. The shift in energy production towards renewable energy sources is illustrated by the sloping curves depicting the CO_2 emissions. Following the assumed developments, the 450- and

500 ppm and the tech. scenarios are the ones producing the lowest CO_2 emissions from E-cars.

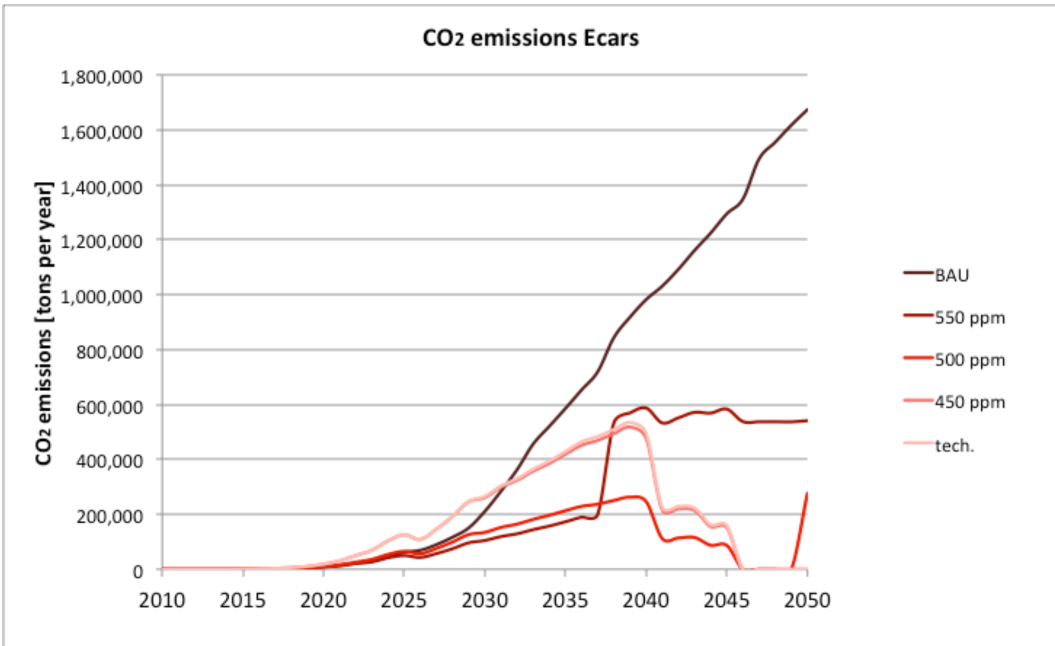

Figure 136 CO_2 emissions from E-cars – policy scenarios

9.1.2 Reduction potential without technological shift (frozen-technology scenarios)

Figure 137 presents the CO_2 emissions for the frozen technology scenarios. The influence of the transport policies becomes visible after 2030. The TPO scenario has a reduction potential of roughly 3.4 billion tonnes of CO_2 until 2050 compared with the 2010 values (-30%). This would reduce the CO_2 emissions to a value equivalent to the value of 1985.

The land-use policies scenario (LPO) has a reduction potential of 2.2 billion tonnes (-19%). The resulting CO_2 emissions roughly match the 1991 value.

However, the behavioural change initiated by the policies alone would not be sufficient to reach the CO_2 reduction targets.

The curves of the TPO and LPO scenario are almost the same at the beginning of the simulation period. In 2020 the TPO curve is slightly below the LPO curve, because the first policy measures have started. In 2030 the transport policies change their magnitude respectively new policies are implemented (see section

7.7.2) resulting in the sharp decline at that point in time. Because the assumptions for the fleet and the energy prices are the same the curves are almost parallel, differing only in the influence of the transport respectively land-use policies. The BAU-frozen technology curve looks different from the beginning, because there are no policies implemented and the energy price assumptions are following the BAU scenario development. From 2010 to 2020 the different development is a consequence of the different energy prices between the TPO/LPO and the BAU-frozen technology scenario.

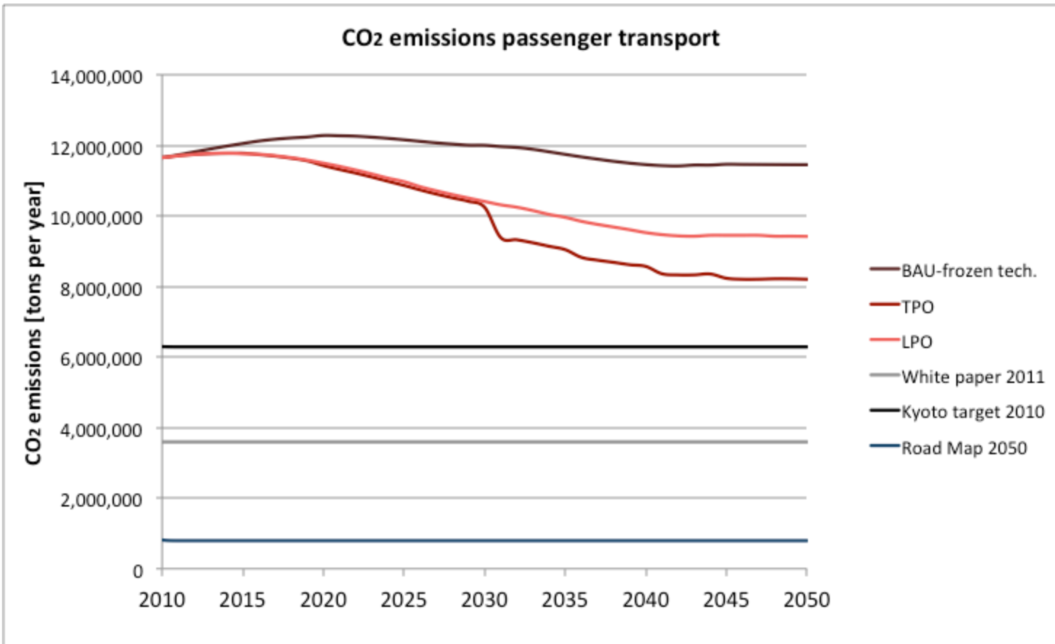

Figure 137 CO_2 emissions per year – frozen technology scenarios

Regarding the accumulated CO_2 emissions it can be seen that the level of TPO and LPO emissions is similar to the 550 ppm scenario (see Figure 135), where a technological shift towards electric vehicles of 44% and 36% of hybrid cars in 2050 is already assumed and combined with modest transport policies. Concerning the reduction potential of CO_2 emissions the very ambitious transport policies without technological shift and the very ambitious land-use policies can almost offset the technological change of the 550 ppm scenario in combination with modest transport policies.

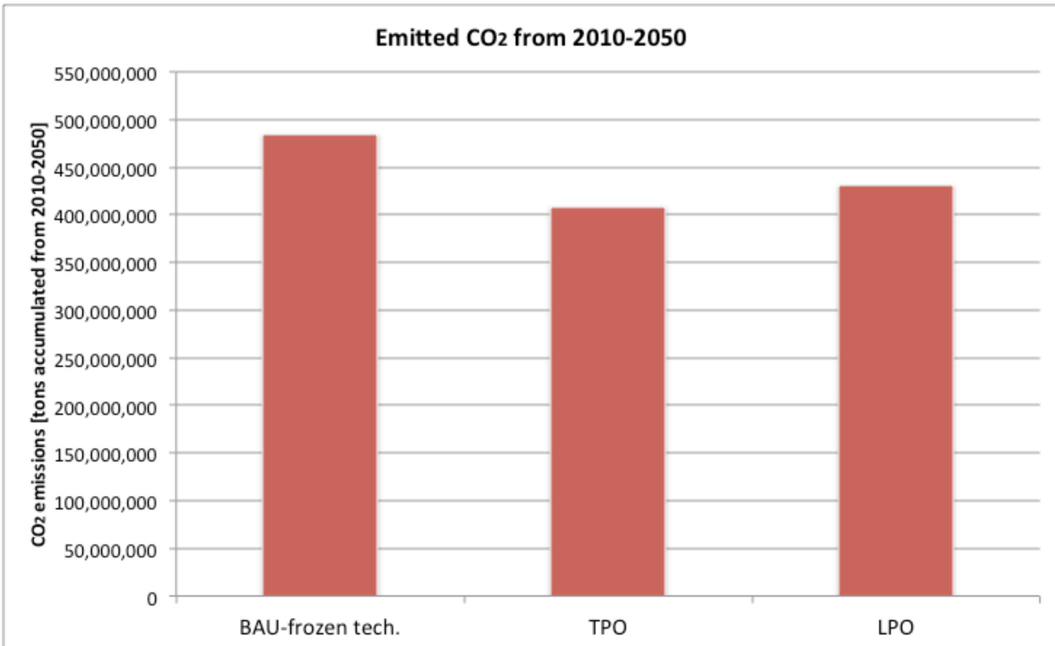

Figure 138 Accumulated CO_2 emissions for the frozen technology scenarios 2010 until 2050

9.1.3 CO_2 emission comparison of all scenarios

Figure 139 puts all emission curves for all scenarios together. It is interesting to see that as long as the technological shift is progressing slowly (till 2030 for the scenarios BAU and 550 ppm) the frozen-technology scenarios are in the same range. Especially the TPO and 500 ppm scenario curves are similar till 2030, where the TPO scenario is even producing less CO_2 that the 550 ppm scenario. As the technological shift is accelerating the frozen-technology scenarios stay behind concerning the reduction potential of the CO_2 emissions.

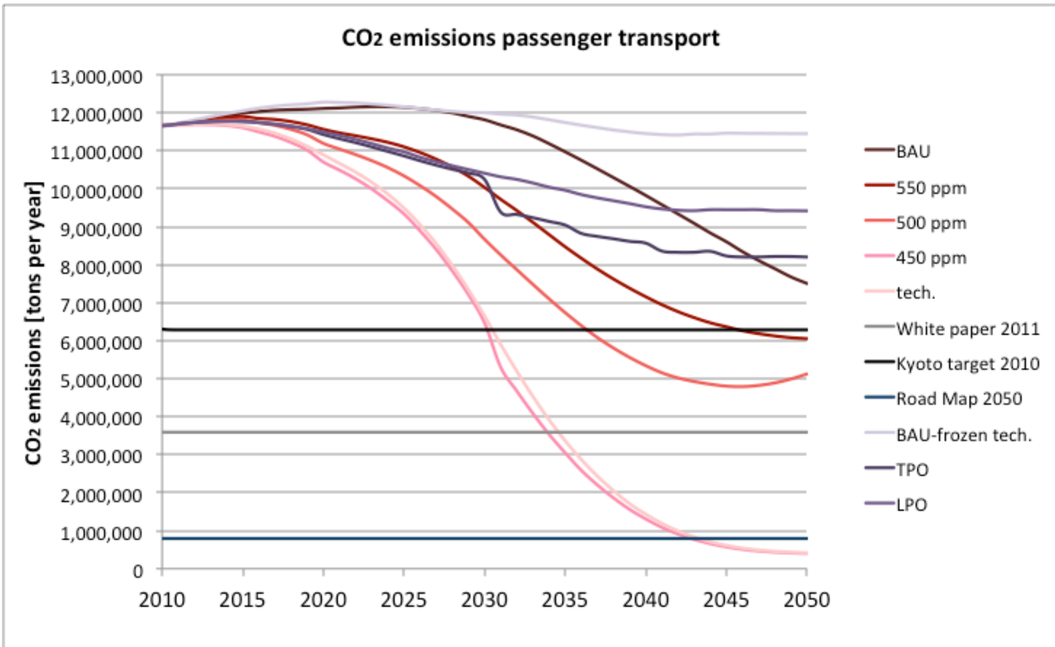

Figure 139 CO_2 emissions per year – all scenarios

9.2 Changes in transport behaviour

9.2.1 Modal split development of the policy scenarios

In this section the influence of the policies on transport behaviour are examined. Figure 140 presents the modal split for the trip purpose commuting for the policy scenarios in 2050.

Looking at the modal split for the trip purpose commuting in 2050, the scenario where the PMT share decreased the most is the 450 ppm scenario, almost reaching the values of 1995 (see section 5.4.2.1). Moreover, the 450 ppm scenario is the most influential one concerning the modal split for the public transport modes, increasing the shares of bus and rail.

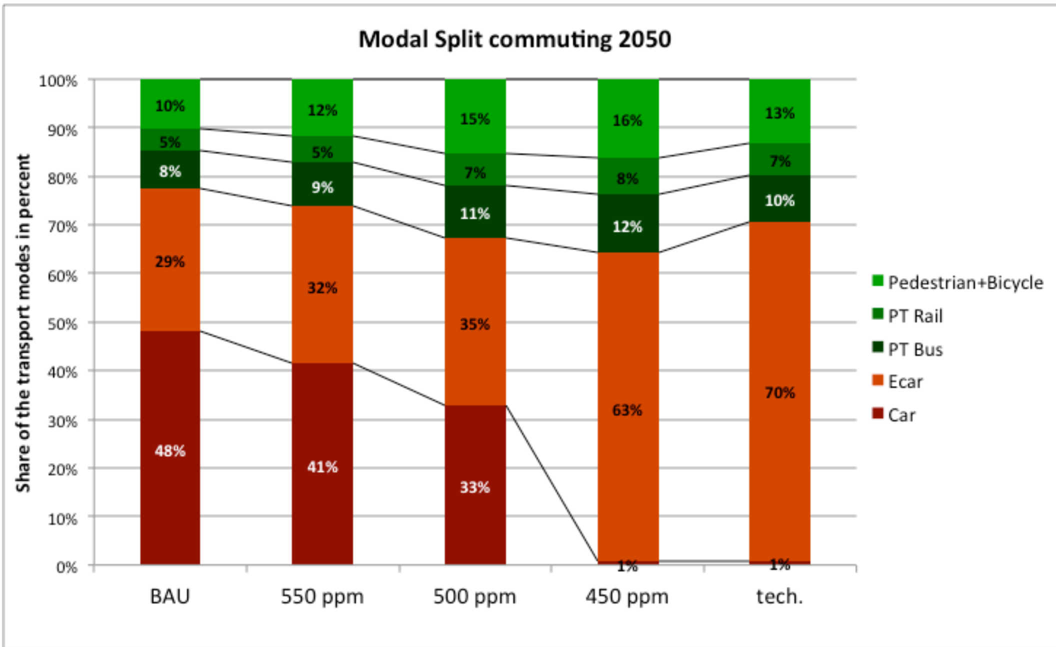

Figure 140 Modal spit trip purpose commuting, all policy scenarios 2050

The rather modest decrease of the PMT of 2 percentage points over 40 years in the 450 ppm scenario can be argued as follows:

1. The workplace location choice model predicts losses of workplaces in nearly all model zones belonging to region type 4 (rural with less favourable conditions for public transport), extrapolating the development performed between 1991 and 2001 into the future (see section 5.4.2.2).
2. The external predefined residential development (land-use policy) predicts either small losses or gains for the same region type model zones.
3. This development shifts the number of workplaces to model zones of region type 0,1,2,3 (Vienna, urban, suburban, rural with favourable conditions for public transport).
4. This results in more commuting trips from rural zones with less favourable conditions for public transport to all other zones by PMT. Commuting trips from rural zones with less favourable conditions for public transport account for roughly 22 % of all commuting trips.
5. To sum up, due to the predictions from the workplace location choice sub-model, the transport policies are less influential.

The difference is that the residential development is mapping implemented densification processes, including the strengthening of town centres also in shrinking municipalities (region type 4), while the workplace location choice model is (as described above) not.

The reason for the higher PMT share in the tech. scenario compared to the 500 ppm scenario lies in the implemented higher level of motorization in the 550 ppm scenario compared to the tech. scenario (which follows the 450 ppm development). This results in a PMT share of 73%, while in the tech. scenario the PMT share is 71%.

It should be noted that E-car costs (development of electricity price until 2050) may be estimated too modestly for all modelled scenarios, resulting in smaller friction factors for all origin destination pairs, and therefore putting into perspective the effectiveness of the policies (see section 9.2.2). This effect is made clear by the frozen-technology runs, where the net effects of transport and land-use policies are visible but without a fleet based on E-cars.

Figure 141 presents the modal split for all other trip purposes for the policy scenarios in 2050.

For the trip purpose commuting, as well as for all other purposes, the 450 ppm scenario is the one with the biggest modal shift from PMT to the eco modes. For the development of the modal split in the tech. scenario again the influence on transport behaviour of the level of motorization can be seen, resulting in smaller PMT shares that compared to the 550 ppm scenario. For all other trip purposes the public transport modes gain one respectively two percentage points in the 450 ppm scenario until 2050.

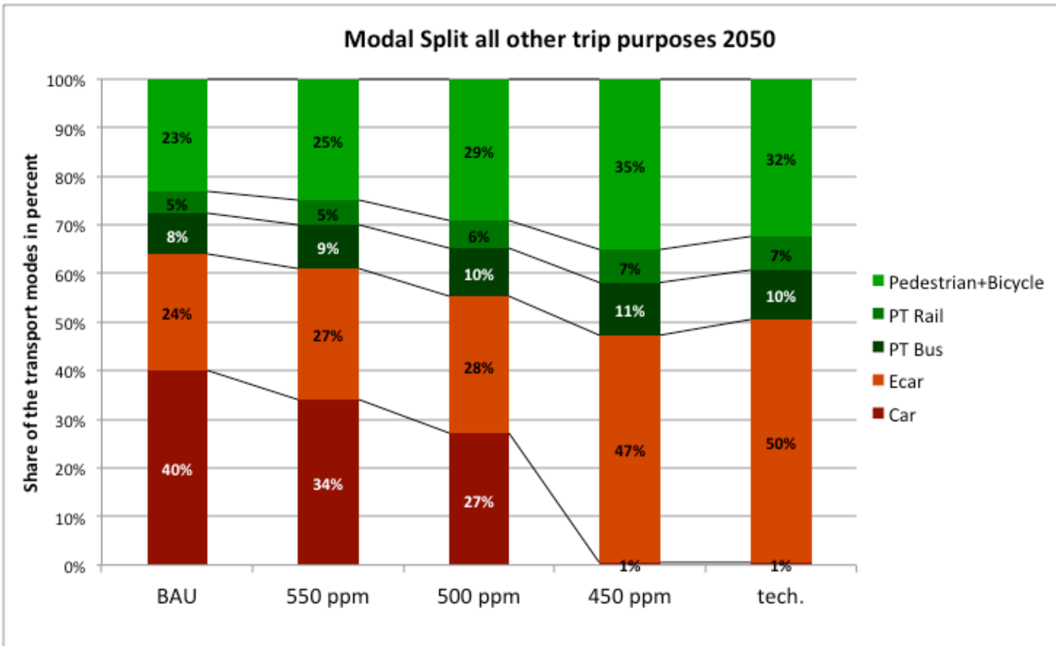

Figure 141 Modal split all other trip purposes, all policy scenarios

Figure 142 shows the overall modal split development for the policy scenarios. The total modal split follows the development of the commuting trips as well as all other trip purposes. The 450 ppm scenario is the most effective one, increasing the eco modes and decreasing the PMT share. In 2050, 53% of all trips are PMT trips. Compared to the value of the BAU scenario in 2050, this in a decrease of 12 percentage points, and compared to the value of 2010 it is a decrease of 7 percentage points.

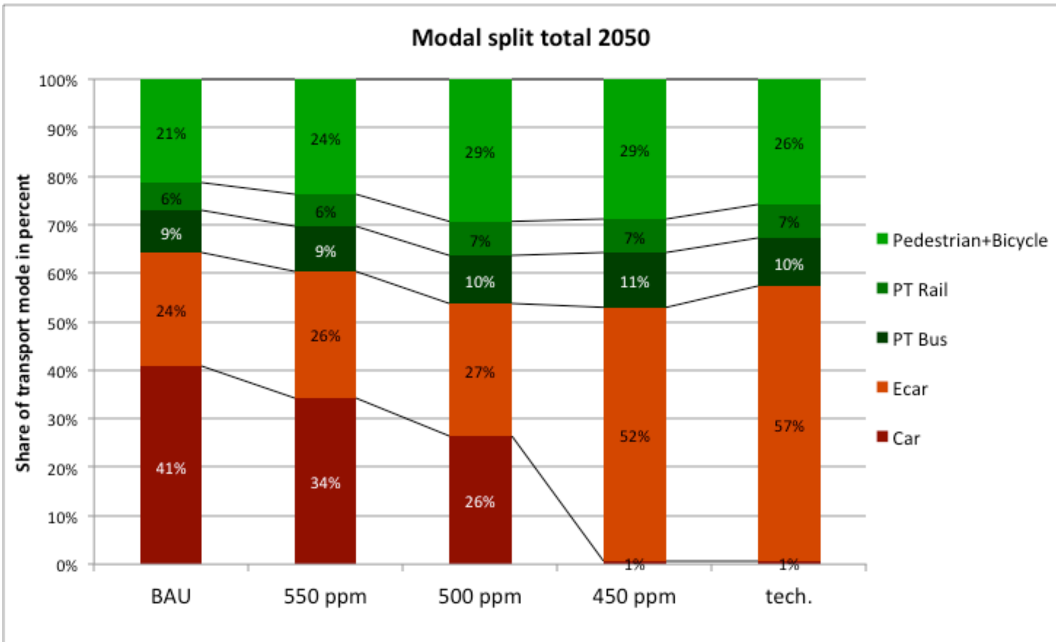

Figure 142 Modal split in total, all policy scenarios

9.2.2 Digression on the composition of the friction factors (generalized cost)

The policy scenarios modelled are composed of transport and land-use policies both affecting either the travel time or the travel cost. The friction factors formulated as generalized cost are also composed of a time and cost share. Because of the implemented theory of Walther (see section 4.4.2.1) the cost and time shares of the public transport modes are not equal. For the mode car the shares are almost equal, while for the mode E-car the time share is bigger (because of the mentioned moderate development of the electricity price).

The following figures present the time and cost shares of the generalized cost per mode for trips from zone 908 (8th district Vienna) to all other zones.

For the public transport modes the region type relations are clearly visible, the cost share for trips to urban zones is higher than the time share, because the connection to these destinations is assumed to be much better (reducing the time part of the friction factor). It is vice versa for trips from zone 908 to rural regions with less favourable conditions for public transport supply.

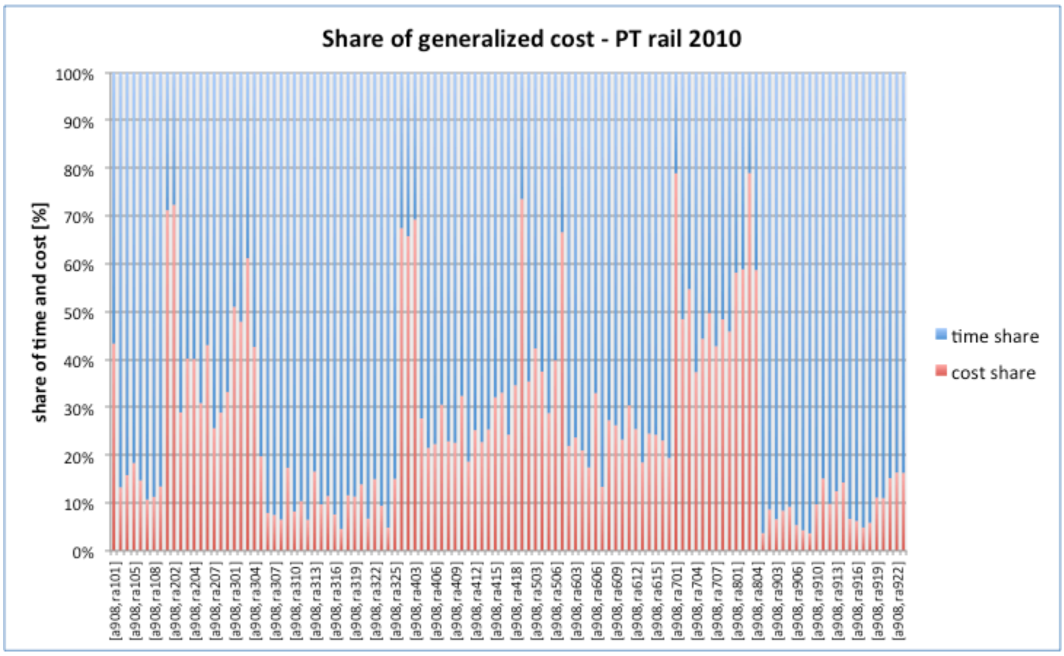

Figure 143 Share of time and cost of the generalized cost of the mode PT rail in 2010

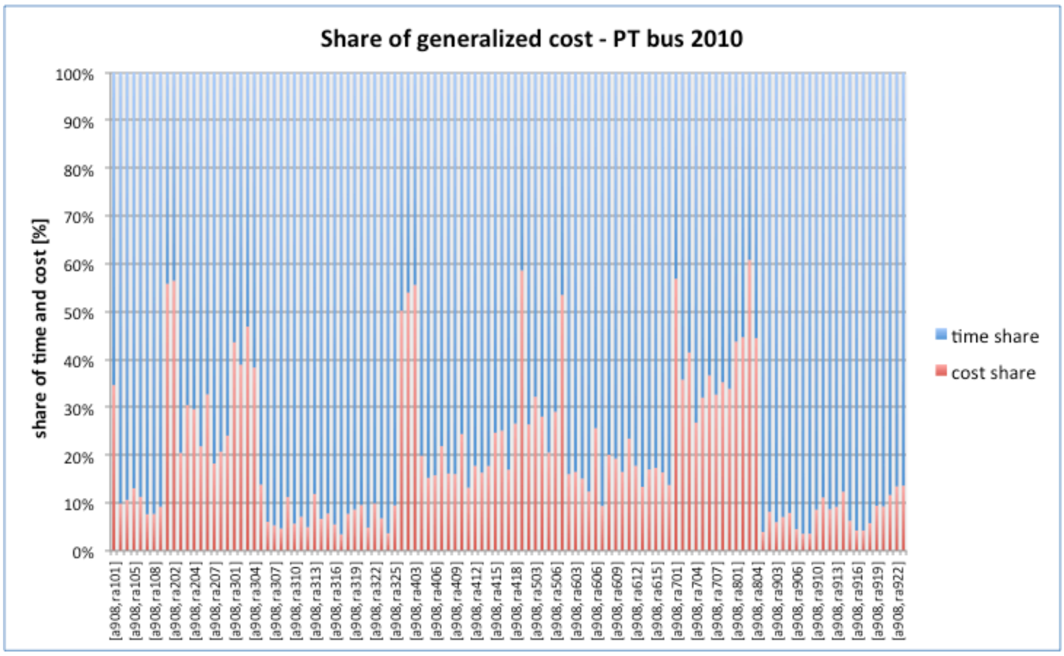

Figure 144 Share of time and cost of the generalized cost of the mode PT bus in 2010

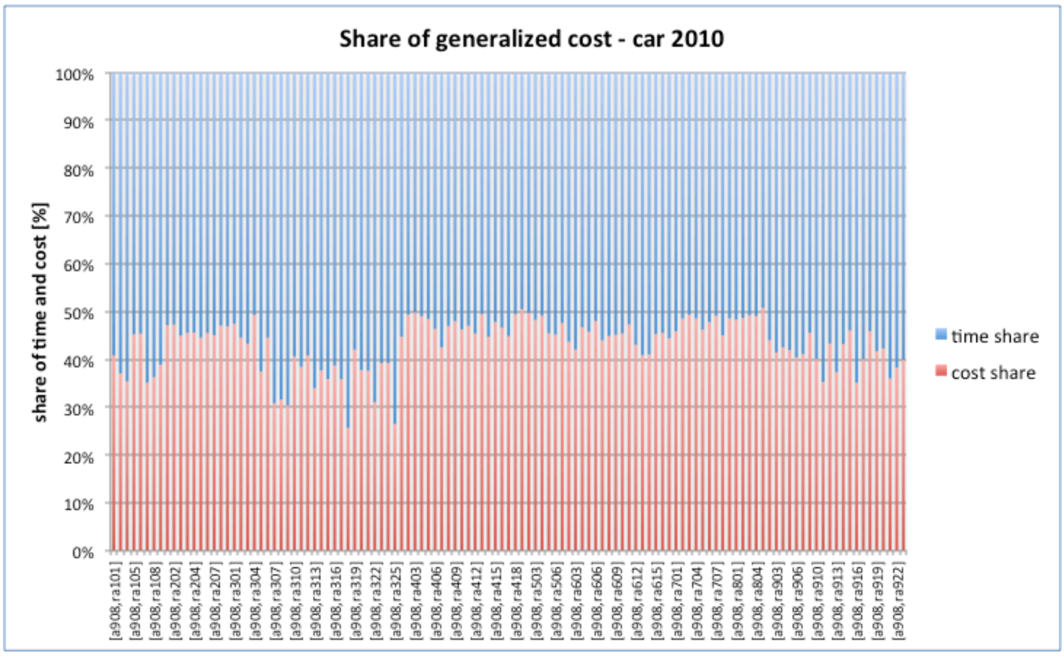

Figure 145 Share of time and cost of the generalized cost of the mode car in 2010

The assumed electricity prices lead to smaller shares of the cost part of the friction factor for E-cars than for cars. Therefore policies affecting the cost part of the PMT are more influential concerning cars than E-cars.

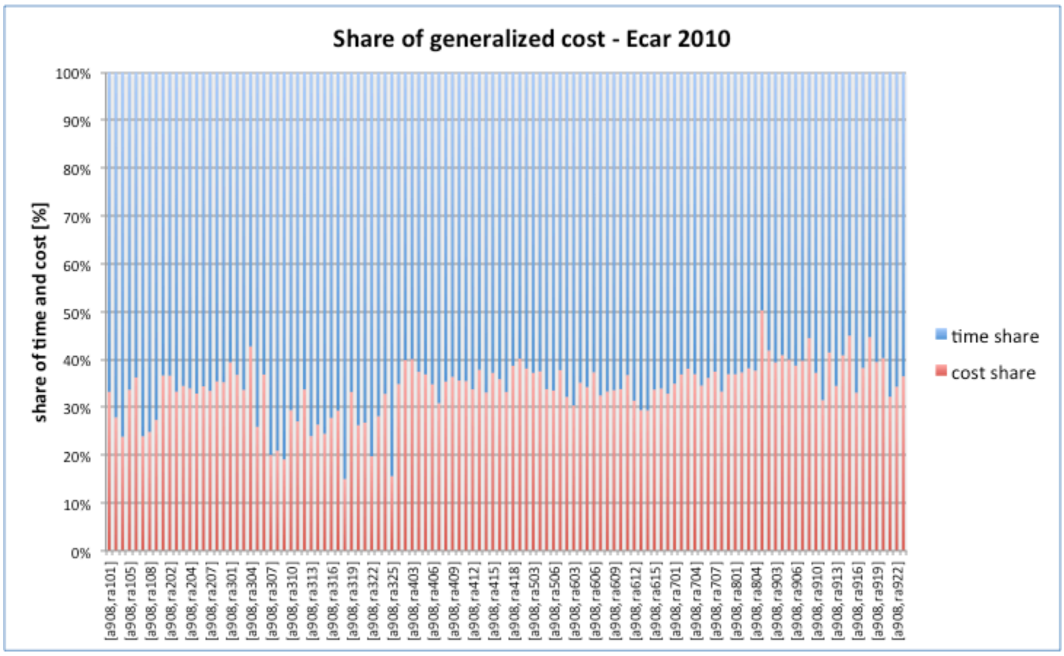

Figure 146 Share of time and cost of the generalized cost of the mode E-car in 2010

9.2.3 Modal split development of the frozen-technology scenarios

Figure 147 presents the modal split for the trip purpose commuting for the frozen technology scenarios in 2050.

Compared to the modal split in 2010, the car share is decreased by four percentage points in the TPO scenario. In the LPO scenario the public transport bus share is increased by one percentage point, like the car share, which is also increased by one percentage point. But for the reasons mentioned in section 9.2.1, the influence of the LPO policies on the trip purpose commuting is smaller than for all other trip purposes (lack of mapping the densification processes, including the strengthening of town centres also in shrinking municipalities (region type 4) for the workplace location choice model).

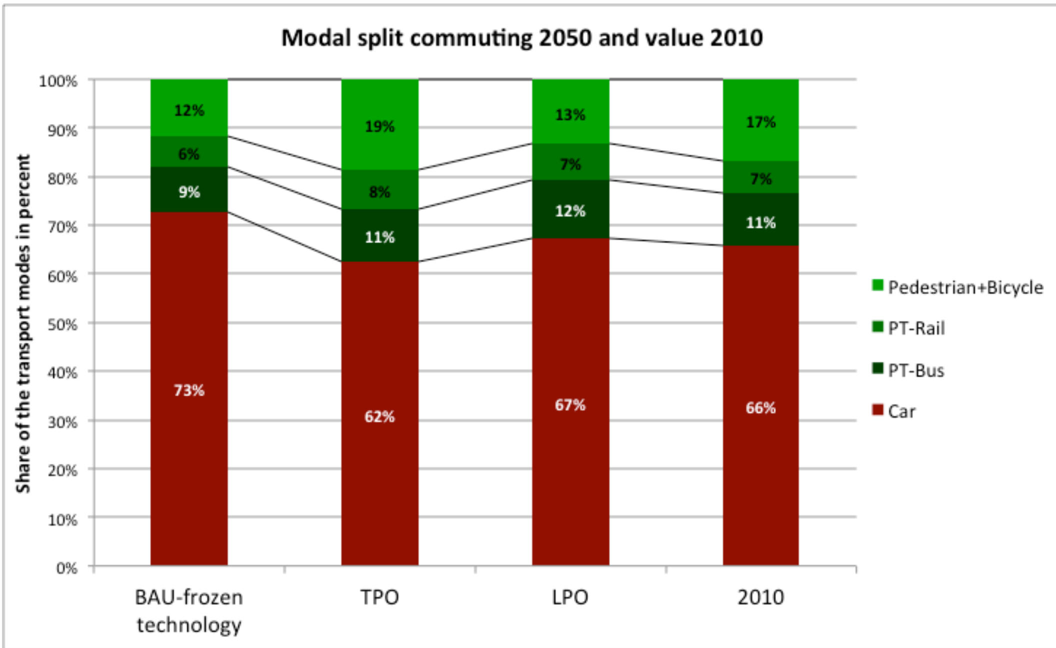

Figure 147 Modal split trip purpose commuting, frozen technology scenarios 2050

Figure 148 shows the modal split for all other trip purposes for the frozen technology scenario is 2050.

It can be seen that especially the TPO scenario is very effective, reducing the modal split of the car mode by 10 percentage points compared to 2010. The shares of both public transport modes are increased by two percentage points, while the share of pedestrians and bicycles increases by six percentage points.

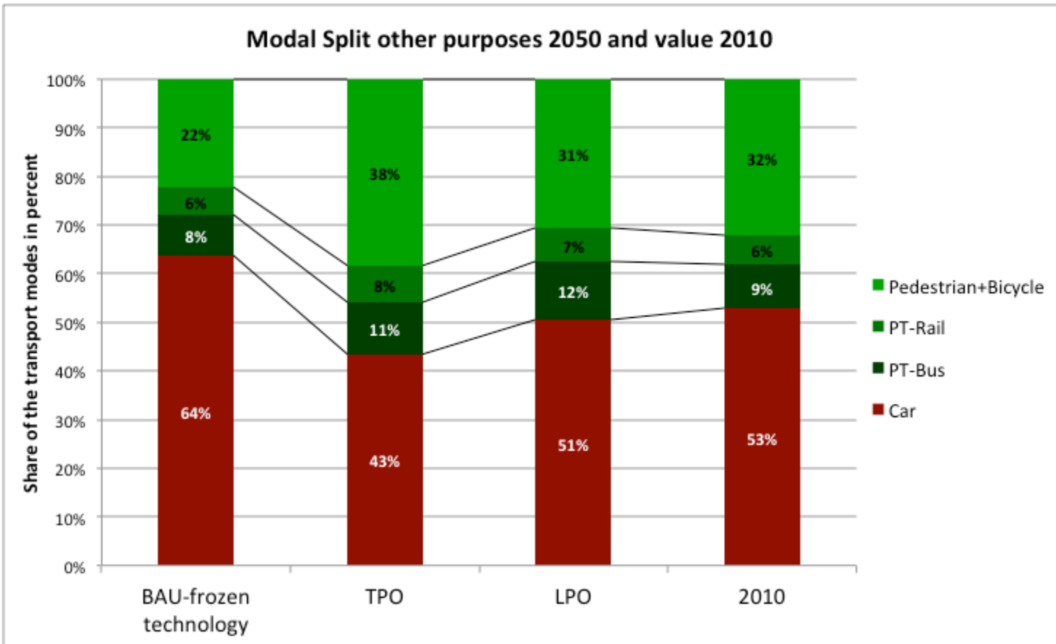

Figure 148 Modal split all other trip purposes, frozen technology scenarios

Figure 149 shows the total modal split development for the frozen-technology runs.

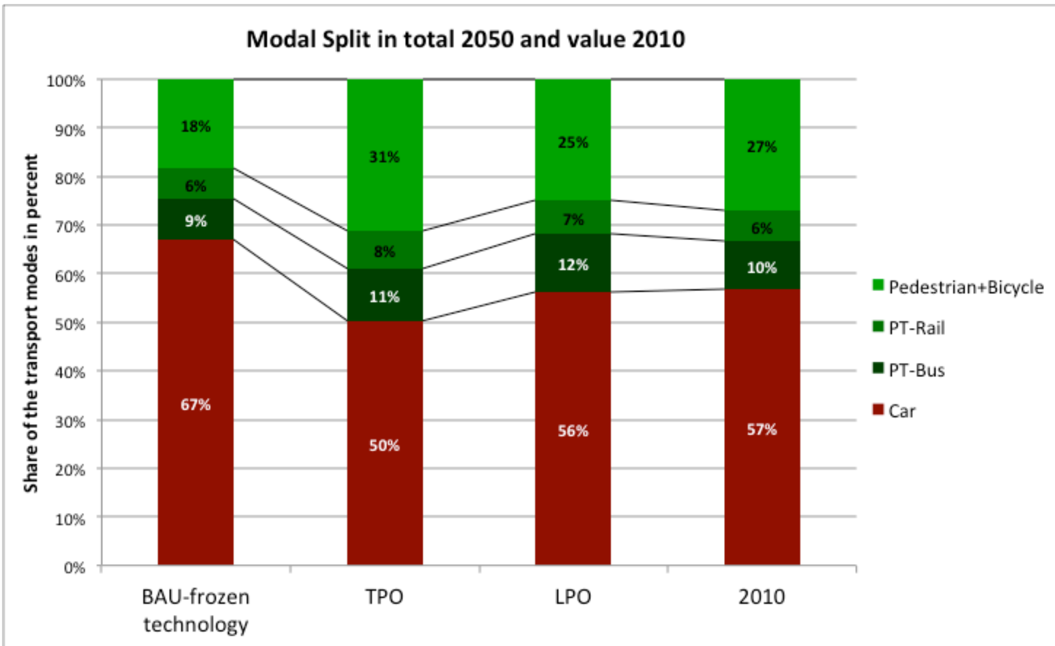

Figure 149 Modal split in total, frozen technology scenarios

9.2.4 Passenger kilometres for the policy scenarios

Figure 150 shows the development of the passenger kilometres for the policy scenarios over time.

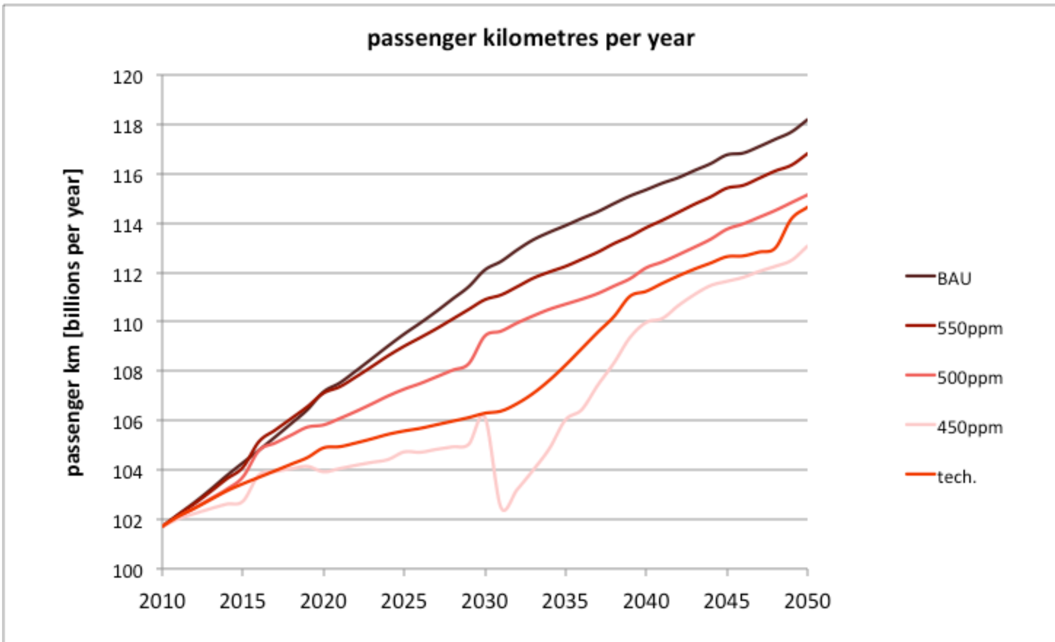

Figure 150 Development of the total passenger kilometres for the policy scenarios

All scenarios show an increase in total passenger kilometres. From 2010 to 2050, the population in Austria increases by 13%. The increase in total passenger kilometres for the policy scenarios is presented in the following table:

Scenario	Increase of passenger kilometres from 2010 to 20150 [%]
BAU	+16%
550 ppm	+15%
500 ppm	+13%
450 ppm	+11%
Tech.	+13%

Table 35 Increase of total passenger kilometres from 2010 to 2050 for the policy scenarios

As a result the passenger kilometres per year and person remain constant in the 500 ppm and tech. scenario and decrease in the 450 ppm scenario.

9.2.5 Passenger kilometres frozen technology scenarios

Figure 151 presents the development of the total passenger kilometres for the frozen technology scenarios.

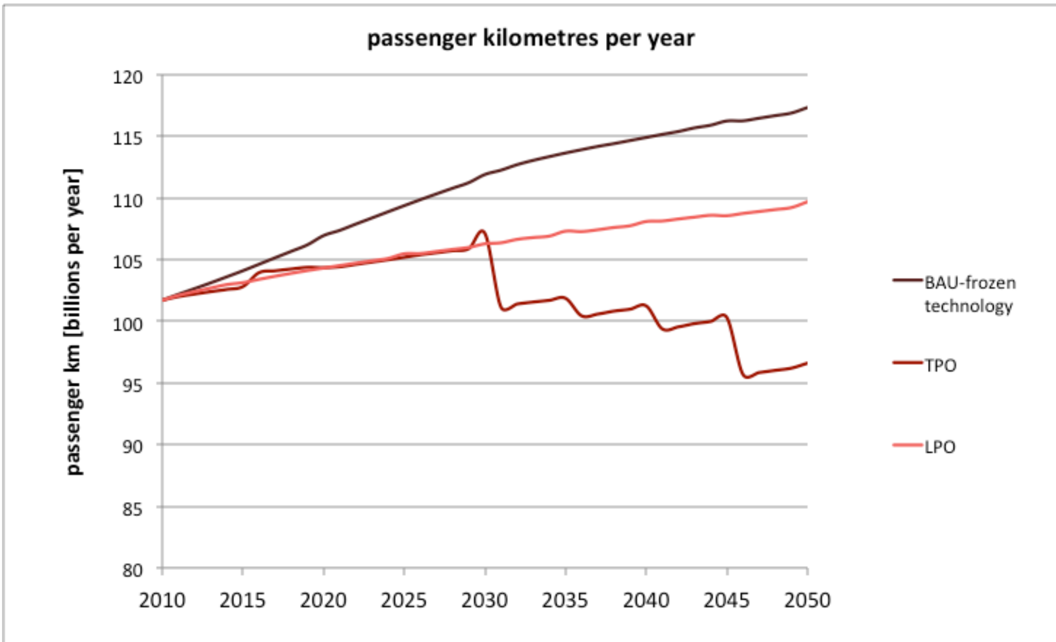

Figure 151 Development of the total passenger kilometres for the frozen technology scenarios

In the TPO scenario the total passenger kilometres are reduced by -5% until 2050, reaching in absolute numbers the values of 2005. In the LPO scenario the passenger kilometres per person are reduced, resulting in an absolute increase by 8%.

Scenario	Increase of passenger kilometres from 2010 to 20150 [%]
BAU-frozen tech.	+15%
TPO	-5%
LPO	+8%

Table 36 Increase of total passenger kilometres from 2010 to 2050 for the frozen technology scenarios

As a result the passenger kilometres per year and person increase by 2% for the BAU-frozen technology scenario, decrease by -16% for the TPO scenario and -5% for the LPO scenario.

It seems that the answer to **sub-research question five,** which policy combinations are most influential in changing transport behaviour is also depending on whether E-cars will be strongly established or not. The implemented transport policies are more effective in the TPO frozen technology run than in the 450 ppm scenario. As presented in section 9.2.2 the cost share of the friction factor part for the mode car is higher than for the mode E-car. Policies influencing this part have more impact on cars than on E-cars. Therefore the TPO scenario is the one with the biggest shift in modal split from PMT to the eco modes.

Figure 152 presents the changes in passenger kilometres per mode and region type for the scenarios 450 ppm, TPO and LPO.

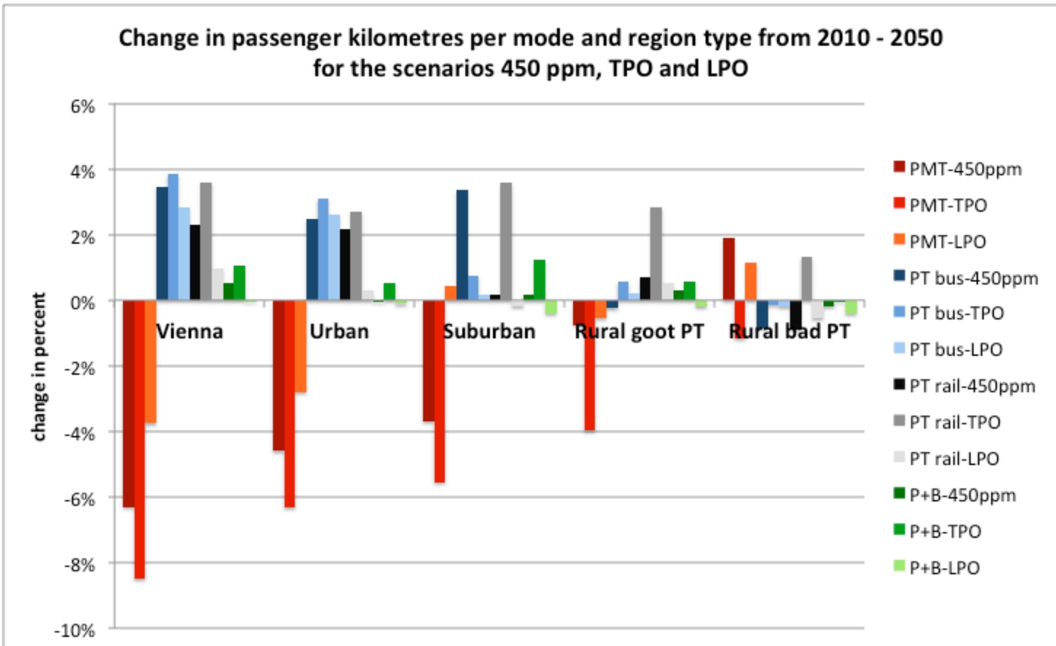

Figure 152 Change in passenger kilometres per mode and region type for the scenarios 450 ppm, TPO and LPO[44]

It can be seen that in all scenarios the PMT share in passenger kilometres is decreasing for the region types Vienna, urban, suburban and rural favourable conditions for public transport. Just in one scenario, which is the TPO scenario, the passenger kilometres for PMT also decrease in rural regions with less favourable conditions for public transport. This is the only scenario where the policies affecting the mode car (price increases and reduction of speed) plus the policies affecting rail (reduction of changing times and speed increases), make the mode rail relatively more attractive.

This leads to the general conclusion that the policies implemented are most influential in the urban and suburban regions.

Figure 153 is the same graph but for the tech. scenario. Without policy measures the PMT share is increasing in all region types except for Vienna. This is true also for the BAU and the BAU-frozen technology scenario (see section 8.2.3 and 8.7.3).

[44] P+B stands for pedestrian and bicycle.

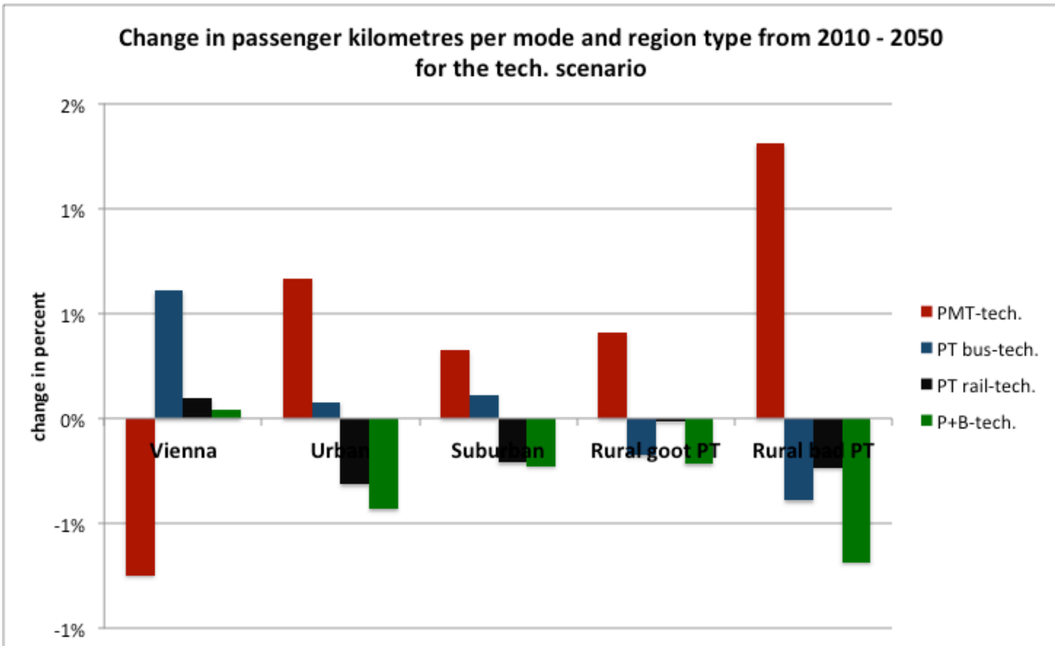

Figure 153 Change in passenger kilometres per mode and region type for the tech. scenario

With the implementation of land-use policies chosen in this thesis it can be said that stand-alone transport policies seem to be more influential than stand-alone land-use policies (**sub-research question six**). But for the afore-mentioned reasons (see section 9.2.1), the land-use policies could not exploit their full potential.

9.2.6 Vehicle kilometres per vehicle policy scenarios

Unlike the passenger kilometres per person the vehicle kilometres per vehicle are increasing in the 450 ppm and the tech. scenario, due to the reduction in level of motorization and the relatively low energy prices effecting E-car use. In the other scenarios the level of motorization either continues to increase or remains constant but the number of kilometres per vehicle decreases.

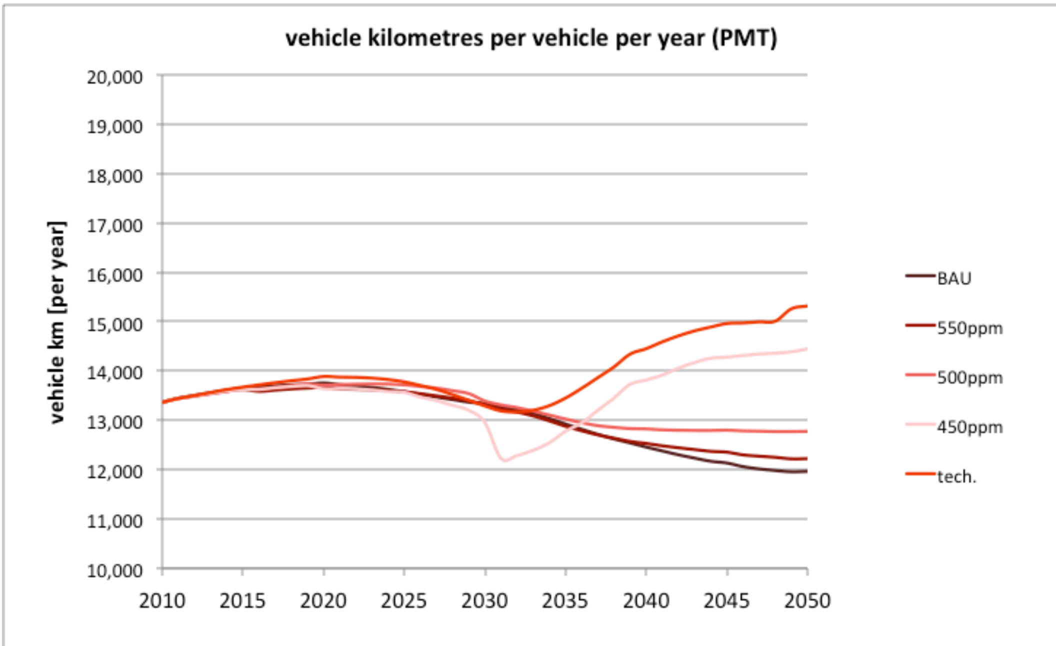

Figure 154 Vehicle kilometres per vehicle for the policy scenarios

9.2.7 Vehicle kilometres per vehicle frozen technology scenarios

Figure 155 shows the development of the vehicle kilometres per vehicle for the frozen technology scenarios. In the BAU-frozen technology and the TPO scenarios the vehicle kilometres are decreasing. The BAU-frozen technology scenario almost follows the BAU development. In the TPO scenario the energy prices for cars are relatively high compared to the ones in the 450 ppm scenario and in addition the policies in the TPO scenario are leading to a reduction in vehicle kilometres.

In the LPO scenario the vehicle kilometres are increasing as a result of the increasing level of motorization. Further the land-use policies are influencing mainly the urban and suburban region types, but not affecting the car trips taking place in rural regions with less favourable conditions for public transport.

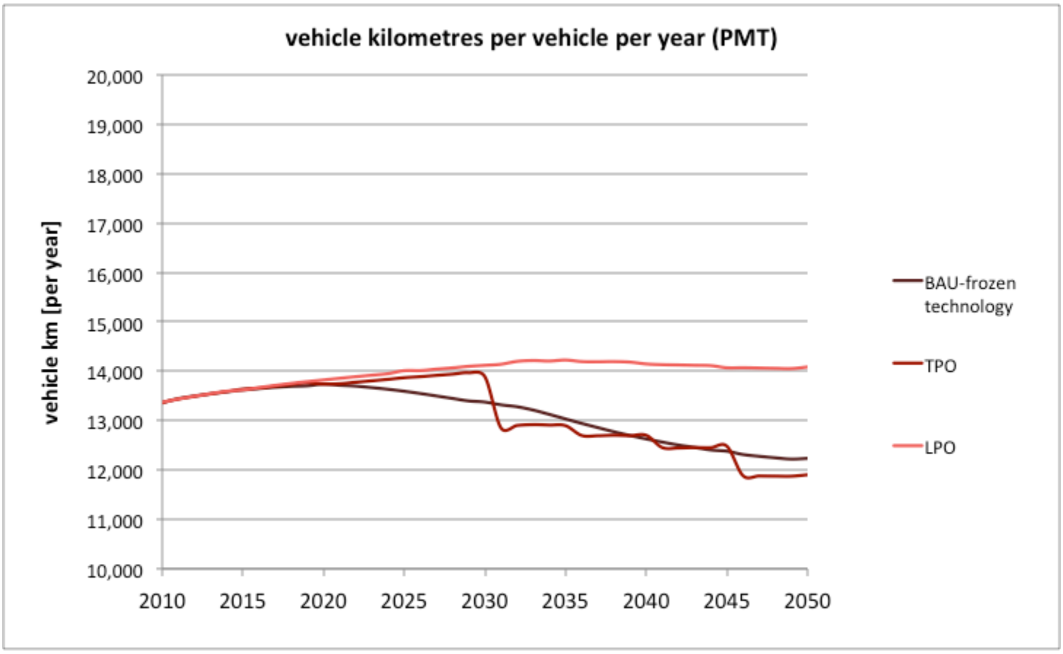

Figure 155 Vehicle kilometres per vehicle for the frozen technology scenarios

9.3 Summary of the results

Unsurprisingly the biggest CO_2 reduction potential results from a combination of a strong shift towards E-cars (combined with an energy mix shifting quickly towards renewables) as well as the most ambitious policy measures both for the transport and the land-use sector, which is the 450 ppm scenario. This scenario is also reaching the climate targets of the "Kyoto Protocol", the "White Paper 2011" and the "Roadmap 2050".

However the influence of the technological shift in the fleet development is astonishing. The climate targets can be met even without the implementation of a single transport and/or land-use policy measure. This is proved by the development of the CO_2 emissions in the tech. scenario.

As a reminder, this result is totally dependent on the assumptions made concerning the energy mix for the production of energy consumed by electric cars and the magnitude of change of the share of E-cars in the fleet.

The investigation of the stand-alone policy scenarios (TPO and LPO) revealed that the single transport policy measures implemented were more effective in reducing CO_2 emissions that the stand-alone land-use policy measures. Both resulted in accumulated emissions similar to the 500 ppm scenario (technological shift towards 44% electric cars and 36% hybrid cars in 2050 combined with modest transport policies) and therefore compensate the technological change.

Examining the transport behaviour is more complicated than the CO_2 emission development, because several indicators have to be considered.

Concerning the modal split development the TPO and 450 ppm scenario are clearly the scenarios where the PMT share decreased the most, in favour of the eco modes, as a result of the implemented policies. In the LPO and tech. scenario the modal split in the year 2050 equals almost the modal split at the beginning of the simulation period in 2010 (about 57% of PMT).

Beside the implemented policies the big influence of the level of motorization can be seen through the resulting modal split in the tech. scenario. Even with no policies implemented the modal split for PMT is hardly changing, compared to the 2010 value, as a result of the declining level of motorization following the 450 ppm scenario, which is also assumed in this scenario.

Looking at the development of the total passenger kilometres, there is just one scenario where the total passenger kilometres are declining to a value below the staring value in 2010, which is the TPO scenario. There the total passenger kilometres are reaching the value of 2005 in 2050. The passenger kilometres per year and person remain constant in the 500 ppm and tech. scenario and decrease in the 450 ppm, LPO and TPO scenario.

The biggest influence on the vehicle kilometres travelled seems to be the level of motorization, the energy prices and the policies implemented. While the transport policies in combination with a decreasing level of motorization led to a reduction in vehicle kilometres in the TPO scenario, the same policies in combination with the same assumption about the level of motorization, led to a increase in the 450 ppm scenario. The difference lies in the assumption about the energy prices, which are relatively smaller in the 450 ppm scenario that in the TPO scenario.

9.4 Comparing the MARS AUSTRIA 2010 scenarios and the passenger transport prognosis 2025+

In this section the main differences of the two model approaches will be shown and there will be a comparison of the results.

The first main difference concerns the assumptions about the levels of motorization. As described in section 3.1.2.1, the Austrian transport prognosis assumes rising levels of motorization for all 14 district-groups till 2050. In the base year of MARS Austria 2010, the overall level of motorization is assumed to be 515 vehicles per 1,000 inhabitants. In 2010, 11 of the 14 district groups from the transport prognosis already have higher levels of motorization than the MARS Austria level. In 2050 all district groups except for the first district in Vienna have higher levels of motorization in the transport prognosis than in the BAU scenario in MARS Austria 2010 (642 vehicles per 1,000 inhabitants), which is the scenario with the highest level of motorization implemented. The assumed developments in the transport prognosis 2025+ seem rather questionable looking at the recent developments of levels of motorization in the Austrian provincial capitals (see Figure 4), were the levels of motorization declined in Vienna and Graz between 2004 and 2012.

The second major difference is that implemented rises in energy prices in the MARS Austria 2010 scenarios are much higher than in the transport prognosis. As mentioned in section 3.1.2.2, for the scenario 1 the price increases are compensated through efficiency gains, keeping the prices constant, while in scenario 2 there is an assumed oil price increase by 30% until 2025. In the MARS Austria 2010 scenarios this assumption is met in the 550 ppm scenario, while in the 500 and 450 ppm respectively TPO and LPO scenarios the rises are even higher.

The third difference concerns the prices for public transport. While in the MARS 2010 scenarios, except for the BAU scenario, decreases in public transport fees are implemented. The price for public transport rises by 40% in the scenario 2 of the transport prognosis (see section 3.1.3.1).

The fourth difference is that the MARS Austria 2010 scenarios consider different development paths of electric vehicles, while in the transport prognosis the technological shift is not considered at all.

Fifthly, the transport prognosis models also contain a network model with an integrated net graph covering the transport infrastructure road, rail and public transport supply in the form of timetables, while the MARS Austria 2010 model does not contain a network model in the sense of physical road and rail infrastructure.

The sixth difference concerns the calculation of the friction factors for the different modes. In the transport prognosis these are also calculated, but as opposed to MARS Austria 2010 model, the time parts of the friction factor for public transport are weighted with constant values (for the MARS Austria calculation see section 4.4.2.1). For the transport prognosis model it makes no difference whether the next public transport stop is five or ten minutes away, in the friction factor calculation the access/egress time is always weighted with a constant factor of 1.5, for example.

Figure 156 shows the comparison of the total modal split in 2025 from the policy scenarios modelled with MARS Austria 2010 and the two modelled scenarios from the transport prognosis.

At first sight, the outcomes do not seem very different from each other. Interesting to note is that the implemented policies in MARS are leading to higher shares for pedestrian and bicycle, than in the transport prognosis scenarios. On the other hand the public transport modes result in higher shares in the transport prognosis scenarios then in the MARS 2010 scenarios. Concerning the levels of PMT the MARS Austria 2010 BAU scenario is predicting a higher share that the business as usual scenario from the transport prognosis (scenario 1).

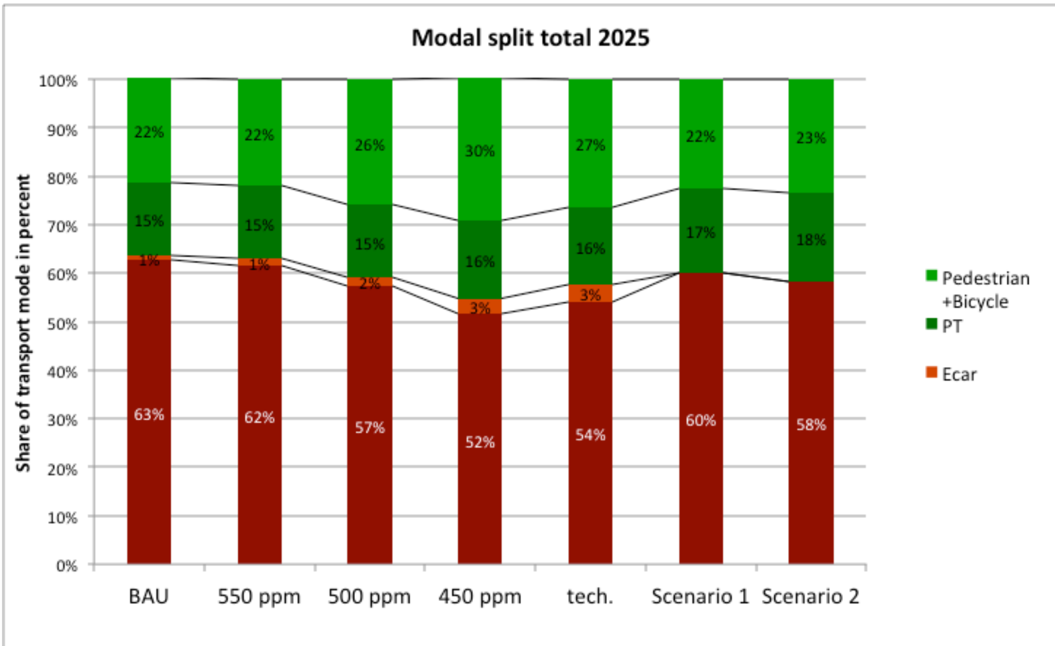

Figure 156 Total modal split in 2025 comparison of the MARS 2010 scenarios and the transport prognosis scenarios. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009), own representation

Comparing the passenger kilometres resulting from the two business as usual scenarios (BAU – MARS Austria 2010 and scenario 1 – transport prognosis) the total passenger kilometres are very similar. Tough in the graph depicting the scenario 1 development the passenger kilometres for pedestrian and bicycle are not contained.

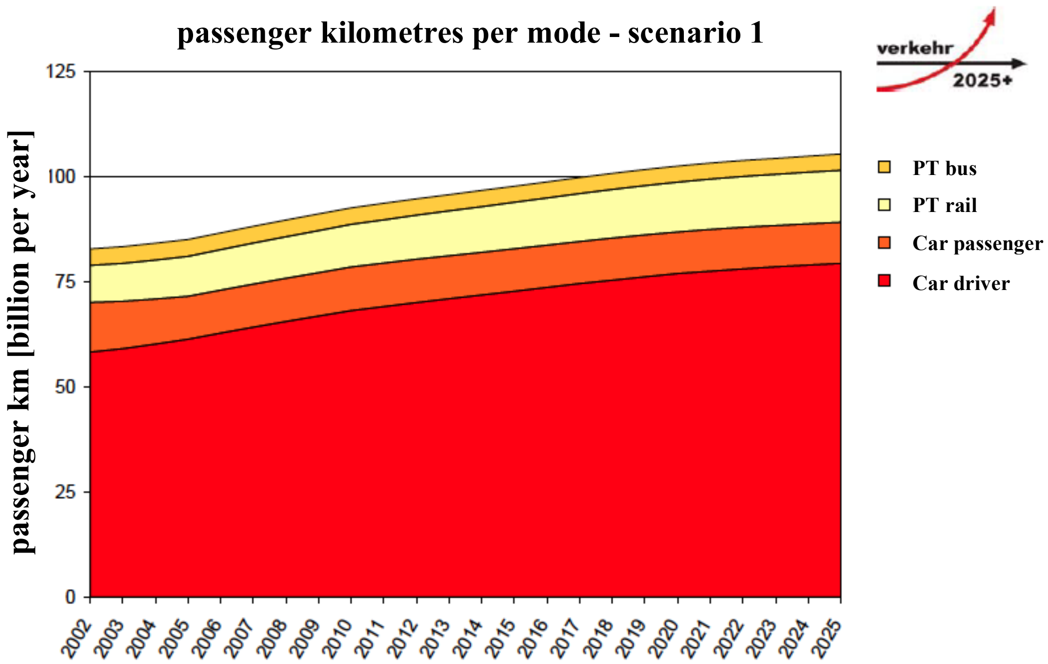

Figure 157 Passenger kilometres - prognosis 2025+ scenario 1. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p.38)

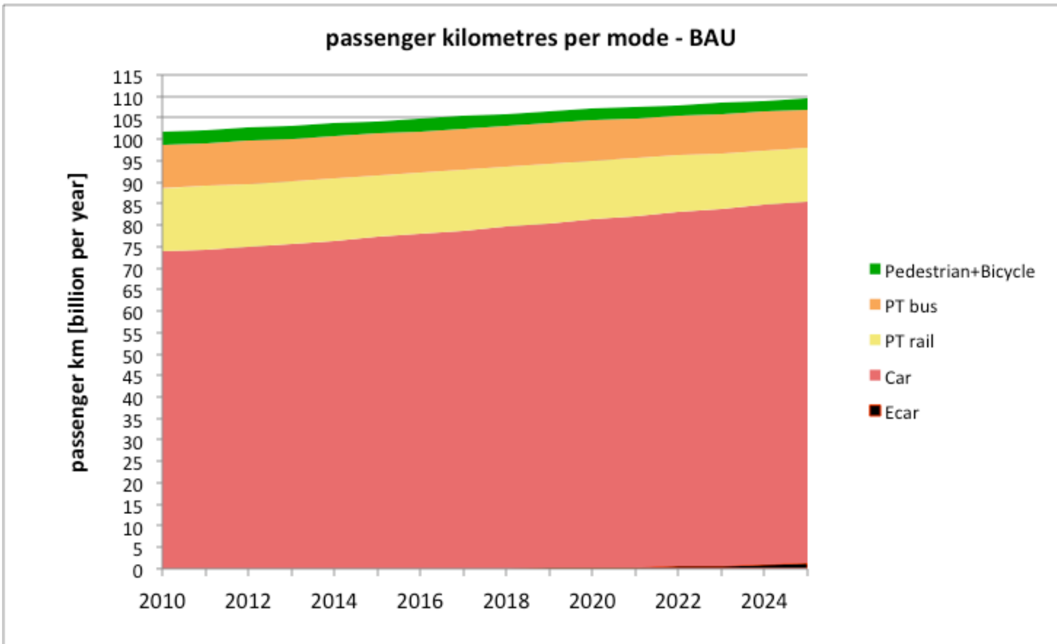

Figure 158 Passenger kilometres in total BAU scenario till 2025.

Looking at the scenario 2 from the transport prognosis and the 450 ppm scenario from the MARS Austria 2010 model, the biggest difference are the total passenger kilometres in 2025. While in the MARS Austria scenario these are higher than 100 billion in the scenario 2 of the transport prognosis the value is clearly below

100 billion. Though again the passenger kilometres for the non-motorized modes walking and cycling are missing.

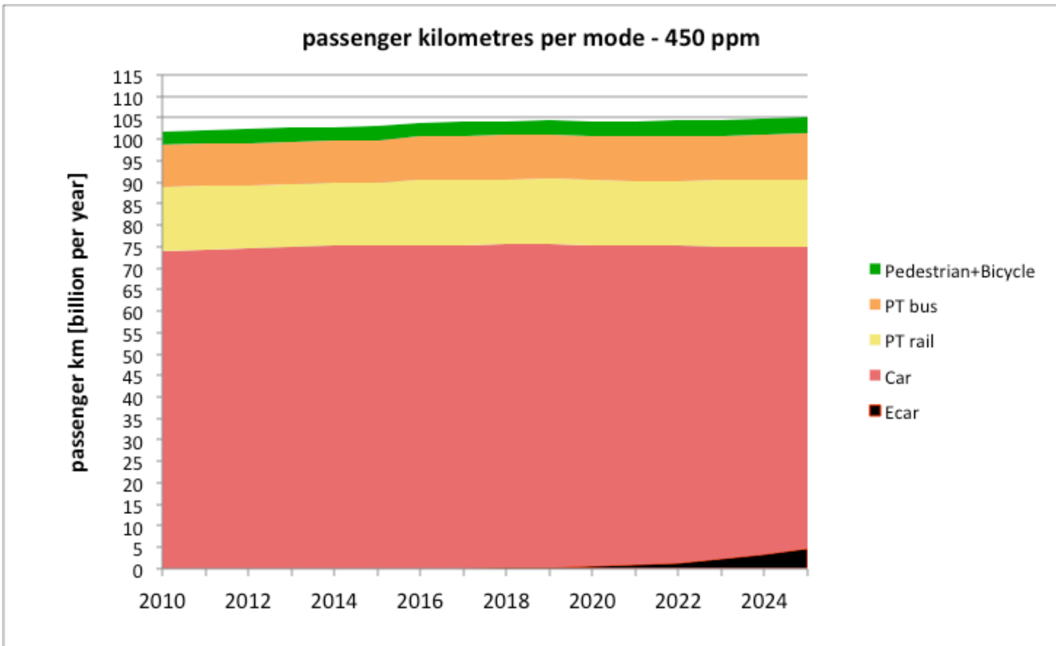

Figure 159 Passenger kilometres in total 450 ppm scenario till 2025.

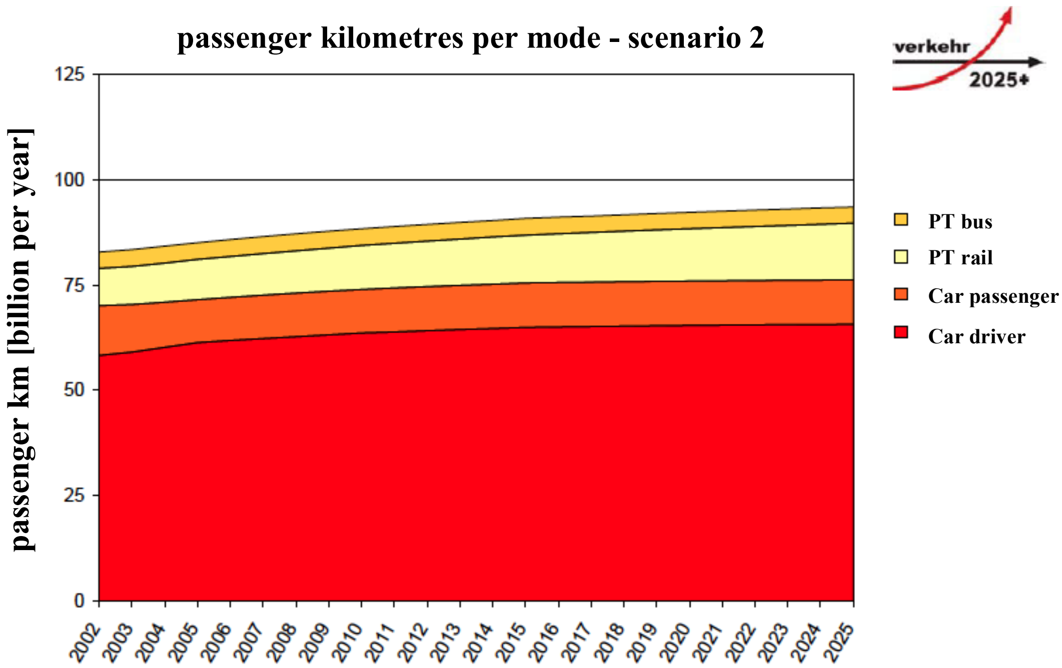

Figure 160 Passenger kilometres - prognosis 2025+ scenario 2. Source: (TRAFICO - Verkehrsplanung Käfer GmbH, Universität Graz - Institut für Volkswirtschaftslehre (IVWL) et al. 2009, p.38)

The last result presented here is the development of CO_2 emissions in the passenger transport sector. The scenario 2 from the transport prognosis is the most effective in reducing the CO_2 emissions per year. Even the 450 ppm policy scenario cannot reach the level of the scenario 2 in 2025. Tough it should be noted that some of the implemented policies in the 450 ppm scenario are starting after 2030.

The main reason for the outcome of roughly 7,8 billion tones of CO_2 in 2025 for the scenario 2 lies in the small emission factor assumed (113.35 g/km) (see section 3.1.5). Even in the most ambitious policy scenario in MARS Austria 2010 (450 ppm) this emission factor value is not reached, it is 145.72 g/km for petrol and 142.26 g/km for diesel.

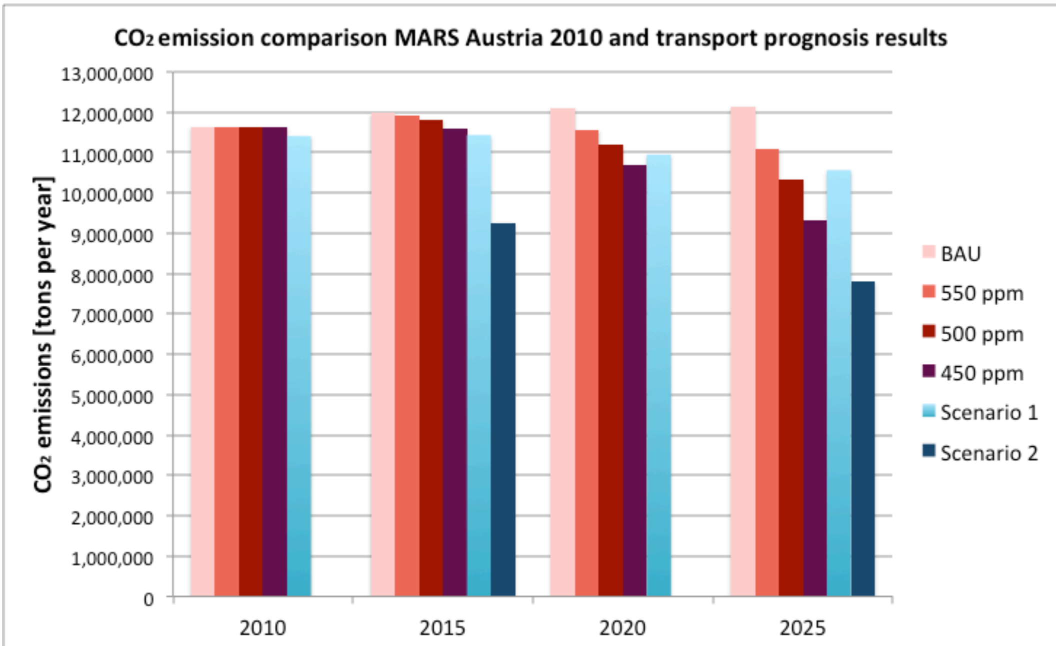

Figure 161 Comparison of the resulting CO_2 emissions from the MARS Austria 2010 scenarios and the transport prognosis scenarios.

10 CONCLUSIONS

Concerns over transport problems have been a constant issue over the past decades and recently deepened in the context of climate change because of the ever-increasing transport related CO_2 emissions. Not only the CO_2 emissions are in a steep rise but the majority of the trips in Austria are car trips and the share of private motorized transport of the total passenger kilometres travelled is increasing since 1990 (Bundesministerium für Verkehr Innovation und Technologie 2012).

To date there is just one modelling approach in Austria to forecast the developments in the passenger transport sector, which is the Austrian transport prognosis 2025+. The necessity of modelling the effects of transport and land-use policy measures for changing the transport behaviour, the assessment of the CO_2 reduction potential and the existence of a single prognosis so far clearly make the case for further research in this area.

Therefore the main target of this thesis was to model transport- and land-use scenarios, in order to test the influence of different policy measures. Two research hypothesis were considered: The “land-use transport interaction” (that there is interaction between transport, the spatial structure of settlements and the economy forming a dynamic self-organising system) - research hypothesis one - was considered by modelling a system covering the transport and the land-use system with a land-use transport interaction type model. It is suitable for the scope of the work, which was to model the interrelationship between transport, land-use and the economy on a strategic level. The focus did not lie in modelling the economy and the spatial distribution of economic activities in detail, as for example the NEG approach or CGE models would allow for. Pure transport models on the other hand typically work with fixed spatial structures, which would not allow any dynamics in land-use, while macro-economic modes neglect the explicit consideration of space. Therefore these were not the right choice at hand. Another important feature of LUTI models lie in their modular structure, which was used in this thesis by replacing a sub-model part with a new structure.

The second research hypothesis addressed was that non-motorized modes are an essential element of the transport system, even at higher spatial levels, and are strongly influenced by settlement patterns. The modelled scenarios in this thesis proved that land-use policy is influencing the development of the non-motorized modes positively. This influence is neglected by most of the common transport models; also the transport prognosis 2025+ is not modelling land-use scenarios and their impact on the non-motorized modes.

The scenario modelling in the field of passenger transport allowed propositions of the development of the CO_2 emissions and the transport behaviour in Austria. The freight transport was excluded in this thesis. The reason was that 68.5 % of the total CO_2 emissions of road transport originate from passenger transport, further freight transport has preconditions and influencing factors very different to passenger transport, which probably would have resulted in a totally different methodological approach. Nevertheless research in this area would be important for the future.

Transport models (and also LUTI models) are widely used in transport planning for forecasting transport developments. Their purpose is to facilitate processes in decision-making. Therefore their influence is quite substantial.

The fundamental idea in formulating a model is to reduce complexity by the attempt to describe and explain reality (Frey 2010). This illustrates that science is not free of individual interpretation and subjective evaluation. Each (modelling) result is based on the decision of calculation method and causalities. Attributes that are considered important are chosen and system boundaries are set, because only partial sections of reality can be represented and these just under certain assumptions. A model is as a matter of fact just a narrow excerpt of a complex system. Therefore models can't be classified as either “right” or “wrong”. The model has only the requirement to refer to one aspect of the modelled empirical phenomena (Bailer-Jones 2002). According to Bailer-Jones models are frequently describing the phenomena inconsistently or the assumptions taken are contradicting common knowledge, or the model in itself is inconsistent.

In the course of this modelling approach certain model limitations and improvement potential were revealed for MARS Austria.

The level of motorization is given for all modelled scenarios. Actually the relationship between land-use and transport policies and the development of the level of motorization is a mutual one. Recent developments of decreasing levels of motorization in the two biggest Austrian cities Vienna and Graz (see Figure 4) make this interrelationship visible. Further the assumption of ever increasing (till 2080, see Figure 14) levels of motorization was a major criticism of the transport prognosis 2025+ (see section 3.1.2.1). A reasonable improvement of the model structure would be to capture this interrelationship and change the influence into a two-way interaction to make it possible to map the influence of policy measures on the level of motorization and the influence of the level of motorization on transport behaviour.

Clearly the strengths of MARS Austria (2001 and 2010) are the capabilities to model passenger transport and residential migration. The workplace location choice model is the weakest model part.

Till now there is little research in the field of location choice of companies. Which results in the fact, that there is no workplace migration flow data (like for the residential migration) and no data about the life cycle of firms, making it impossible to distinguish new firms in a district from already established firms that just moved their location. To close that gap between theory (the influence of the location of workplaces on the transport behaviour) and data needs more research is needed. For the MARS Austria model this lack in data made it difficult to estimate the parameters for the workplace location choice model, which led to a less strong influence of the land-use policy on modal split for the trip purpose commuting than expected (see Figure 140). If new data would be available, an update of the workplace location choice model would be a major improvement for the MARS Austria model.

In this thesis the scenarios modelled covered different policy types ranging from pricing measures (public transport fees, parking fees and infrastructure tolls for the road network) as well as physical measures (building up cycling infrastructure, collective garages policy, regular interval timetable reducing changing times, road capacity reduction and speed limits for road traffic and an increase in rail network).

The results showed that in order to influence the transport behaviour in reality a lot of combined efforts have to be undertaken. This thesis supports the belief that strong policy measures reducing the attractiveness of PMT while enhancing the use of the eco modes are needed. The results indicate that policies focusing just on enhancing the attractiveness of public transport would influence the transport behaviour only to a limited extend.

Further the results showed that the pure shift in technology with a fast change of energy supply towards renewable energy would significantly decrease CO_2 emissions, but would not influence the transport behaviour towards the less energy consuming modes.

From a societal perspective it is questionable whether this path should be followed. At least for cities a pure shift in technology might not be a desired outcome. The increase of population in the urban agglomerations in Austria implies huge challenges for the cities. Most cities have the target of keeping the quality of living at a high level. An important factor for the quality of living is the availability of public space. Changing the amount of parked cars in public space is a great possibility for changing the availability of public scape. A pure substitution of combustion technology, is not changing the space availability of PMT. Therefore policy measures influencing stationary traffic additional from other measures enhancing the use of non-motorized modes and public transport are needed.

For rural regions with less favourable conditions for public transport, electric mobility might be a good alternative for enabling people to fulfil their daily needs. Still, as proven in the scenario that focused on transport policy (TPO scenario), improvements in public transport supply have a potential to positively influence public transport use even in this regions.

The thesis provides added value in the field of national transport/land-use modelling. The developed model is capable of modelling different transport and land-use policies as well as different development paths for electric vehicles for the whole territory of Austria. The research carried out gives insights into the effects of divers transport and land-use policies, on the development of CO_2 emissions and the transport behaviour in Austria.

Science and research are capable of providing a significant contribution for understanding the feedback mechanisms and relationships in the transport system. Despite or even due to the increased usage of transport models for predicting the transport behaviour and the calculation of future scenarios, their limitations need to be considered. Comparing the model results with real human behaviour, gained through surveys or field research, is necessary and reasonable. The application of models is useful if they help us to reach high-level targets defined previously. Despite the advantages which can be generated through model approaches, they still remain incomplete, for the before mentioned reasons. The output is more a product of the perceived subjective reality, rather than the reality. In this context Fasching introduces the term of “objective illusion” (Fasching 2007).

Despite enormous efforts and investments in the transport sector many transport problems could not be solved or just reduced slightly. The question is whether with the prevailing paradigms and societal values, a reversal of the trend towards a more environmentally friendly transport system is possible. The development of the boundary conditions seems to indicate that a “new” resource-protecting transport system is necessary. Part of it is the assessment of the investments regarding their effectiveness in the system – where system dynamic models can play a crucial role – as well as questioning decision processes in transport policy. The awareness for the role of transport as means to an end can be the starting point and precondition for a form of ethics of responsibility, which considers the needs of the following generations.

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