TECHNISCHE UNIVERSITÄT MÜNCHEN

Ingenieurfakultät Bau Geo Umwelt

Professur für Siedlungsstruktur und Verkehrsplanung

Consequences of Sharp Increases in Mobility Costs on Accessibility

Suggestions for individual and public development strategies

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Vollständiger Abdruck der von der Ingenieurfakultät Bau Geo Umwelt der Technischen Universität München zur Erlangung des akademischen Grades eines

Doktor-Ingenieurs (Dr.-Ing.)

genehmigten Dissertation.

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Die Dissertation wurde am 12.09.2016 bei der Technischen Universität München eingereicht und durch die Ingenieurfakultät Bau Geo Umwelt am 21.11.2016 angenommen.

Danksagung

Die vorliegende Dissertation entstand während meiner Tätigkeit als Wissenschaftlicher Mitarbeiter im Rahmen von den Forschungsprojekten „Stress-Tests for a sustainable mobility“ und „MOR€CO“ an der Professur für Siedlungsstruktur und Verkehrsplanung der TU München.

Für die kontinuierliche Unterstützung mit hilfreichen Ratschlägen sowie zahlreichen konstruktiven Diskussionen bedanke ich mich ganz herzlich bei meinem Doktorvater Herrn Prof. Gebhard Wulfhorst. Es ist viel wert zu wissen, dass Ihre Tür mir jederzeit offensteht.

Zudem bedanke ich mich sehr für die bereichernde Übernahme des Koreferats bei Herrn Prof. Yves Crozet und Herrn Prof. Michael Wegener. Der Blick von außen und die treffenden Anmerkungen und Ratschläge haben mir sehr geholfen, diese Arbeit zu vervollständigen.

Für die zahlreichen wertvollen Diskussionen und Anregungen danke ich all meinen Kollegen an der Professur für Siedlungsstruktur und Verkehrsplanung, den Kollegiaten des Promotionskollegs mobil.LAB der TU München sowie den Projektpartnern. Für die konstruktive Zusammenarbeit und Unterstützung möchte ich meinen studentischen Mitarbeitern danken.

Besonderer Dank geht an meine Familie und meine Freundin, die mir den Rücken kontinuierlich freigehalten haben und hierdurch auch einen zentralen Baustein zu dieser Arbeit geleistet haben.

Die vorliegende Dissertation ist meinem Vater gewidmet. Ich vermisse Dich.

Benjamin Büttner

München, August 2016

Abstract

The growing region of Munich is experiencing an increased pressure on its housing market and citizens' mobility. Rising land and rent prices are resulting in large scale development of residential sites in peripheral locations and dispersed transport links on the regional level. This situation highlights an urgent need for coordinated control by decision makers on different scales in the Munich region.

Along with the potential of rising mobility costs, the Munich region faces a significant risk of housing misallocation in relatively inaccessible locations. The potential negative impact of these developments is exacerbated by shortages in fossil fuel supplies, political instability in oil-producing countries, and energy price increases.

In line with the complexities of individuals' mobility behaviour, a set of diverse approaches has been applied to examine the impact of increased transport costs on the mobility decisions of various user groups. To cope with the consequences of rising mobility costs, the three steps 'Scan-Explore-Prepare' methodology was developed:

As part of the Scan-step an oil vulnerability assessment aims to scan and subsequently highlight which regions in Munich are at greatest risk due to increasing fuel costs.

As part of the Explore-step an exploration of individual households is undertaken to develop a range of different storylines that portray real-life reactions to mobility cost shocks. These storylines form the basis for a common language between planners, decision makers, and households.

As part of the Prepare-step local stakeholders and decision makers are then given sustainable accessibility recommendations so that they can be better prepared to make key decisions at the regional level.

Based on the findings obtained from the analysis, public decision makers and actors at the local and regional levels are expected to make sustainable provisions for the future, taking increasing mobility costs into account when dealing with real estate and transport development issues. To do this, they need an appropriate and accessible tool that can help them assess the possible effects of changes in mobility costs within their region.

Through this study, the vulnerability assessment has proven to be a very capable platform for identifying areas that are susceptible to severe oil price hikes. Recognizing the vulnerability of these municipalities in terms of exposure, sensitivity, and resilience, has allowed for improved identification of long-term planning opportunities that can better prepare municipalities in the face of increasing mobility costs.

Every day's mobility behaviour of households has been simulated and evaluated for shock scenarios taking into account increases in mobility costs on the household budget. By doing so, individual strategies for coping with these circumstances were formulated for different household and urban structures. Along with the activities and strategies from the stakeholders' workshop, recommendations have been formulated for public decision-makers and actors to respond to increasing mobility costs in the Munich region. Each of the development strategies provide detailed measures for different spatial scales and indicates the responsible actors involved.

Combining this analysis with existing municipal policies, allows for a municipality to directly address mobility cost in its policies, and build upon its efforts to increase sustainability of land-use and transportation activities, while improving the quality of life for its citizens. The fundamental goal of raising awareness about the risks of increasing mobility costs as a result of increasing fuel prices by pointing out how different future scenarios affect accessibility in various regions has been achieved through this thesis.

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PART I

Consequences of Sharp Increases in Mobility Costs on Accessibility:

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1. Introduction

The following cumulative dissertation is based upon three papers that examine the effects of sharp increases in mobility costs on accessibility.

Part I of this dissertation collective summarises the three papers. Additionally, it introduces the background and problem statement and describes the research hypotheses and purpose of this study. The following chapters then present the research methodology, a summary of the scientific findings, conclusions from the results, and a final overarching discussion.

Part II consists of the papers that underlie this dissertation, presented chronologically by publishing date. Taken together, these three papers present a methodology to 1) Scan regions to identify households most vulnerable to mobility cost increases, 2) Explore how these households are impacted by these increases, and 3) Prepare governments with tools to analyse and develop strategies to mitigate these impacts.

Over the course of the French-German cooperation research project “Stress Tests for a sustainable mobility: an accessibility approach” (see Mercier et al. 2012, Büttner et al. 2013, Mercier et al. 2013) as well as the Alpine Space project “MOR€CO: mobility and residential costs” (see Büttner and Wulfhorst 2012, Büttner et al. 2014, Büttner et al. 2016, Büttner 2016) the author was able to generate many scientific findings, which are presented as a whole in the following.

1.1 Background and problem statement

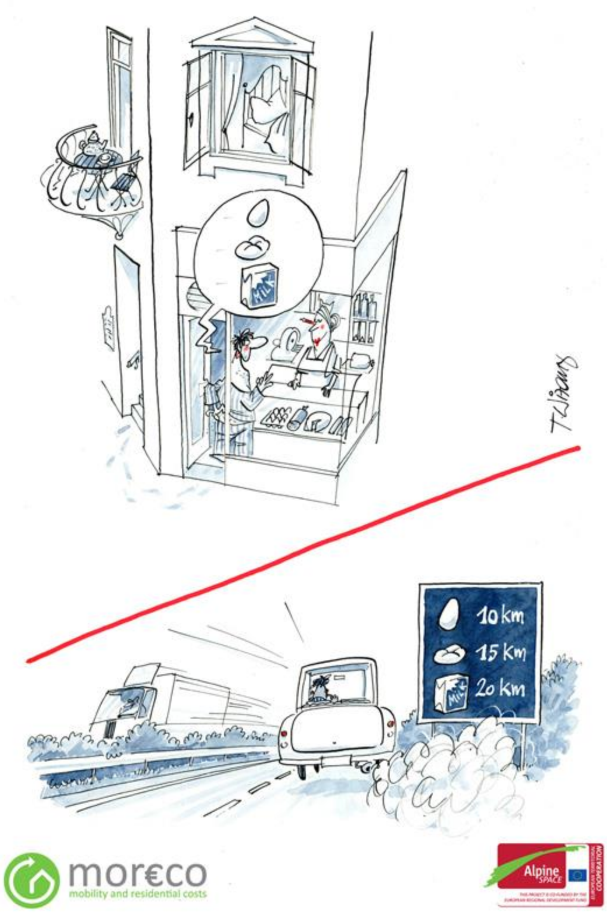

Figure 1: Impacts of affordable and remote housing (Source: moreco-project.eu 2014)

In contrast to many other regions in Germany, Munich's population is continuously growing, in large part because it increasingly attracts new residents from all over the world. The city is expecting a population increase to 1.65 million inhabitants by 2030, which is a 14.9% rise from 2011 (LHM 2012a). This increase in the number of people moving into Munich is straining the housing market, and it is clear that the costs of both renting and owning a home are escalating.

Not surprisingly, those choosing to relocate to the Munich region are facing the most expensive housing market in Germany. Munich is undergoing a housing crisis where supply is barely meeting the demand. For this reason, immigrants as well as locals are forced to weigh the costs of living closer to the city centre versus locating themselves in the outer suburbs. Currently, with the relatively affordable fuel prices, households choose to locate themselves in more remote areas with a more affordable housing cost (LHM 2012b).

Settling in or relocating to the outskirts of town is increasingly popular amongst those moving in and around Munich.[1] This is due to households focusing entirely on residential costs and failing to realize their increase in mobility spending. It is clear that the monthly rent or mortgage cost is the dominant figure when making decisions to relocate (Haller et al. 2012). This behaviour causes an immense problem as it creates a major disconnection between residential areas and required activities.

Figure 2: “I used to be a Munich resident” advertisement by the regional economic developer of Mühldorf (Source: MIMMO e.V. 2013)

The situation is worsened by other, more remote and usually car-dependent municipalities capitalizing on the strained housing market by promoting themselves as more affordable. This strategy has been used by regional economic developers in areas such as in Mühldorf am Inn, as seen in Figure 2. An emphasis is made by using the line “’Ich war ein Münchner! (I used to be a Münchner!)” and arguing that the area will provide double the quality of life for half the price, “Doppelte Lebensqualität zum halben Preis.” The advertisement suggests that living in Mühldorf is a promising solution to the current housing crisis in Munich, and especially attractive to younger families, the elderly and the relocating households (MIMMO e.V. 2013).

[1] Besides, the TUM research study „WAM: Wohnen Arbeiten Mobilität“ achieved pointing out numerous motives concerning household relocation (Thierstein et al. 2016).

Such strategies are promoting the relocation of those needing more affordable housing to remote locations where access to amenities and activities is more difficult. Sprawling housing leads to increased distances to work and forces people to travel farther for basic amenities and desired activities. Additionally, the denser an urban area is structured, the more attractive public transport, walking and cycling are. Conversely, the more an urban area is spread out, the more private vehicles are favoured (Scheiner 2006, Cervero and Guerra 2011). This change in mode share has been analysed in the Munich region by the Institute of Media Research and Urbanism (IMU 2002), which found that non-motorised transport decreased from 12% to 6% and public transport usage decreased from 31% to 15% when households moved from the centre to the outskirts of Munich.

In addition to creating communities with distant activities, urban sprawl also increases a region’s vulnerability to potential future increases in mobility costs. With the political instability in many oil producing countries, an increase in fuel demand may encounter a volatile fuel supply. Therefore, future mobility costs are expected to increase in a sharp and unpredictable nature (Wegener 2009). This phenomenon was observed in the years from 2002 to 2008 when the average price of petrol in Germany petrol station more than doubled from $US1.03/L to $US2.48/L as shown in Figure 3 (EIA 2015). During the same period, there had only been a minor increase in household income (Brenke 2009). Given the increased distances to activities, households had to spend a larger portion of their household budget to maintain the same level of mobility (Büttner et al. 2013). In contrast to the extreme volatility of the past decade, fuel prices are expected to remain relatively stable for the next decade (EIA 2016). According to fuel price statistics from the federal market transparency authority for fuels “Markttransparenzstelle für Kraftstoffe (MTS-K)”, the average German price for petrol in the first half of 2016 has remained well below 1.50€/L (MTS-K 2016). However, these seemingly affordable fuel prices might prove temporary and foster unsustainable settlement structures due to short-sighted location choices (housing allocation in affordable, but remote areas). More information about trends in oil and fuel prices will be discussed in chapter 2.2.2.

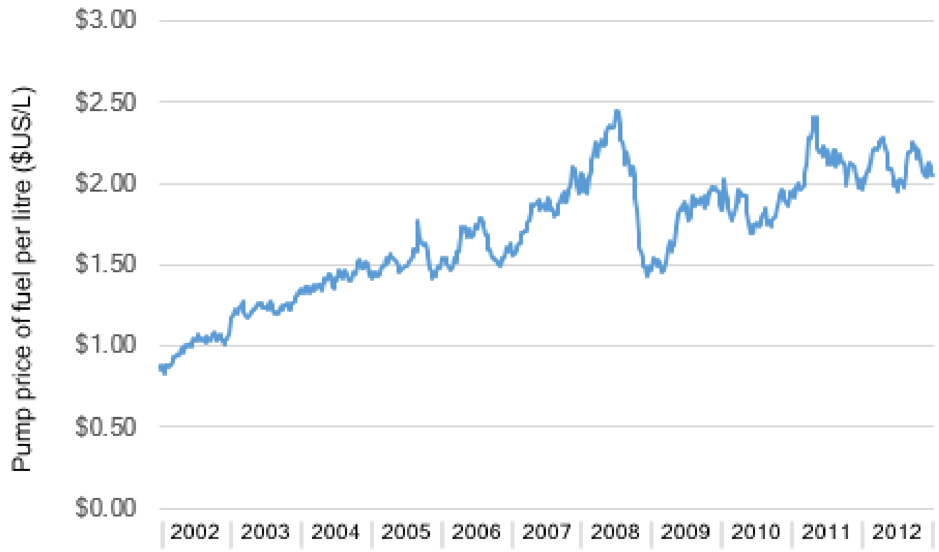

Figure 3: Price of fuel in Germany from 2002 to 2012 (EIA 2015)

Unaware of potential mobility constraints in the future, the world continues to rely on fossil fuels for daily activities (EPA 2015). The majority of the world is heavily dependent on private vehicles for everyday use (Kahn Ribeiro et al. 2007). With the combination of fossil fuel reliance, the increasing number of distant activities, and rising mobility costs, life in an ‘affordable’ remote location may become extremely expensive and is already an environmentally harmful lifestyle. In this context, it is vital to find sustainable mobility solutions and strategies so that the effect of an increase in mobility costs can be minimized for all households involved.

1.2 Hypotheses and research objectives

Given the complexities involved with individual mobility behaviour, a set of diverse hypotheses is examined which focuses on increases in mobility costs and their effects on accessibility and the mobility options of different user groups/stakeholders.

- If mobility costs are increasing, then certain regions will reveal their vulnerability:

To begin, it is of high importance to **scan** and subsequently highlight which **regions** are in danger of increasing mobility costs. For this reason, a vulnerability assessment is performed with a combination of indicators including exposure (e.g. fossil fuel consumption), sensitivity (income) and resilience (accessibility to jobs by public transport) within the Munich region. Following the assessment, three municipalities representing different settlement structures (urban, sub-urban and rural) are selected in order to better understand and characterize localized differences in vulnerability. A full description about scanning regions using a vulnerability assessment is presented in part II in the paper "**The impact of sharp increases in mobility costs analysed by means of the vulnerability assessment"** (Part II: Büttner et al. 2013).

- If mobility costs are increasing, households will have different options to cope with these circumstances depending on their social status and location:

After having determined the characteristics of each region, an exploration of the mobility behaviors of individual households is undertaken to develop a range of different storylines which portray real-life reactions to mobility price shocks. By doing so, the second approach studies the initial vulnerability assessment by analysing how different changes in mobility constraints can impact daily activity schedules, mobility behaviour, and residential and activity locations. The research **explores** and evaluates the resilience of three **households** by applying potential shocks to mobility costs (i.e. severe mobility price increases). With studies on the Munich region indicating that the mobility share of the household budget is increasing (Büttner et al. 2013), understanding how these price shocks influence household mobility is becoming more crucial. A detailed exploration of how these price shocks affect individual households is presented in part II in the paper "**Ensuring accessibility to daily activities for different population segments with respect to sharp increases in mobility costs"** (Part II: Büttner et al. 2016).

- If decisionmakers are aware of the risks of increasing mobility costs, land-use and transport planning can help to create more resilient communities:

In most cases, vulnerable households are only able to change their mobility behaviour once they are offered more viable mobility options. Helping governments recognize the interdependencies between land-use and transport can help vulnerable **communities** better **prepare** for and adapt to potential increases in mobility costs. Recommendations to public stakeholders and decision makers must be based on detailed regional-level analyses that take into account the development of future residential and mobility costs. In order to foster such sustainable spatial development, policies, intervention strategies, and recommendations should be discussed which concern dense and mixed-use development patterns alongside the accessibility of jobs and daily activities (Hull et al. 2012). This is reinforced by Geurs et al. (2012) who state the importance of testing the current accessibility analysis in practice. A strong collaboration between researchers and planning practitioners is needed to implement this accessibility planning. More about how decision-makers can prepare households by providing sustainable mobility is presented in part II in the paper

“**Sharp increases in mobility costs as a trigger for sustainable mobility in the metropolitan region of Munich”** (Part II: Büttner 2016).

The fundamental purpose of this work is to **raise awareness about the risks of increasing mobility costs** as a result of increasing fuel prices by pointing out how different future scenarios impact access to amenities for various users and regions. This work also gives a stimulus how to plan for more resilient communities on a local and regional scale.

2. Scientific findings regarding the consequences of sharp increases in mobility costs on accessibility

2.1 Accessibility

2.1.1 Understanding accessibility and mobility behaviour

„Accessibility is a slippery notion… one of those common terms that everyone uses until faced with the problem of defining and measuring it." (Gould 1969, 64)

When sharp increases in mobility costs occur, accessibility plays an important role. For example, the affordability of accessing daily activities by car or public transport, as well as the opportunity to cycle or walk to work and shopping facilities, are crucial variables when discussing accessibility and sharp increases in mobility costs. Yet despite its importance, accessibility is a vague term that must be clearly defined for this research. Hansen stated back in 1959 that accessibility can be understood as *"a measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome spatial separation*" (Hansen 1959, 73).

The following widely shared assumptions regarding human (mobility) behaviour are needed to reach a sound definition of accessibility (e.g. Hägerstrand 1970, Zahavi 1974, Bertolini et al. 2005):

- People need to travel in order to participate in spatially disjointed activities (e.g. living, working, shopping, visiting)
- People want to be able to access a large number of diverse activities
- The freedom to perform these activities is not predominantly limited by the travel distance, but rather by the required mobility costs and travel time

Taking into account these assumptions, Zahavi et al. (1981) were able to come up with some interesting observations. The Unified Mechanism of Travel (UMOT) project conducted by them proved that despite increasing travel speeds, the total time spent traveling was not reduced. Instead the number of accessible activities increased which led to increasing travel distances. Additionally, studies of several cities in different countries found that time and money budgets for daily transport differ due to age, income and housing location. Despite differences between these cities the average person's time and money budgets were found to be relatively constant. Hence, with higher travel speeds and constant budgets, the additional time and money is used for increasing distances in order to maximize the access to activities. The stable nature of time and money budgets can be further explained by considering the decreases in inflation-adjusted fuel prices until the 1990s (see EIA 2015). This decline did not reduce total mobility costs, but rather led to a significant increase in car travel (Zahavi et al. 1981). According to Zahavi's theory, changes in travel speeds and costs influence spatial planning.

Crozet and Wulfhorst (2010) ask themselves if higher travel speeds are the main reason for urban sprawl and unsustainable regions, is there an opportunity to turn around by regulating low speeds in cities with the aim of promoting higher densities and enabling a non-motorized environment. They conclude that it is unrewarding to just focus on travel speeds and transportation issues themselves. It is necessary to tackle these issues by looking at interactions of land-use and transport. The accessibility concept successfully incorporates both these dimensions, which makes it very suitable concept for strategic planning (Crozet and Wulfhorst 2010).

Accordingly, the accessibility formula stated below takes into account both the land-use by the activity destinations at point j (Dj) as well as the transportation infrastructure, which determines the generalised costs of the trip between points i and j (cij).

$$A_i = \sum_j D_j \; f(c_{ij})$$

Ai = Accessibility to destinations D from point i

Dj = Activity destinations at point j

cij = Generalised costs (time, price/costs, comfort) of the trip between points i and j

This formula shows the effects of increasing mobility costs on accessibility, which is in line with the theme of this research study. With an increase of mobility costs, the number of potentially accessible activity destinations will decrease if we assume the same monetary budget. The land-use, and hence the activities, have to be rearranged and densified in order to maintain the same level of accessibility with higher mobility costs. This can create urban qualities and will reduce distances, while enabling neighbourhood mobility.

In line with this, Mumford (1956) stated the importance of proper land-use planning by bringing origins and destinations closer together to mitigate the need for car usage. Such theories regarding the densification of activities demonstrate that shrinking trip distances will result in increased non-motorized mobility like walking and cycling. For instance, several researchers have suggested increasing shopping accessibility by planning local stores within residential areas (Robinson and Vickerman 1976; Handy and Clifton 2001). However, a resident's potential to visit a shop is dependent on that resident's knowledge of its existence. This is particularly true for walking, where it is very important to distinguish between perceived and actual accessibility, specifically the gap between the two for each type of activity (e.g. shops, bakeries, pharmacies, banks and schools) (Krizek et al. 2012).

Methods for further understanding mobility behaviour have been developed by Kutter (1972) using the concept of behaviourally homogenous groups. Classified by social attributes like income, age, gender and car availability, populations can be divided into homogenous behavioural groups that are linked to a particular type of travel behaviour. By relying on the assumption that certain demographics exhibit specific behaviour – for example, employees go to work and students go to places of education – the activities of behaviourally homogenous groups can be eventually localized to places of opportunities. Accordingly, the activities and attributes of homogenous behavioural groups have the ability to define trip patterns (Kutter 1972).

Aside from the classification of behaviourally homogenous groups, Geurs and van Wee (2004) attempted to further understand mobility behaviour by highlighting the interactions between the various components of accessibility (see Figure 4). The land-use component of accessibility reflects the spatial distribution and characteristics of both demand and opportunities. On the other hand, the transport component describes the transport system with regard to infrastructure, and hence the disutility for an individual to cover a certain travel distance, be that freight or passenger travel. The latter two components of accessibility, namely the temporal and the individual component, recognize respectively the time-based constraints (e.g. opening hours for a store) and the distinct needs, abilities and opportunities of individuals.

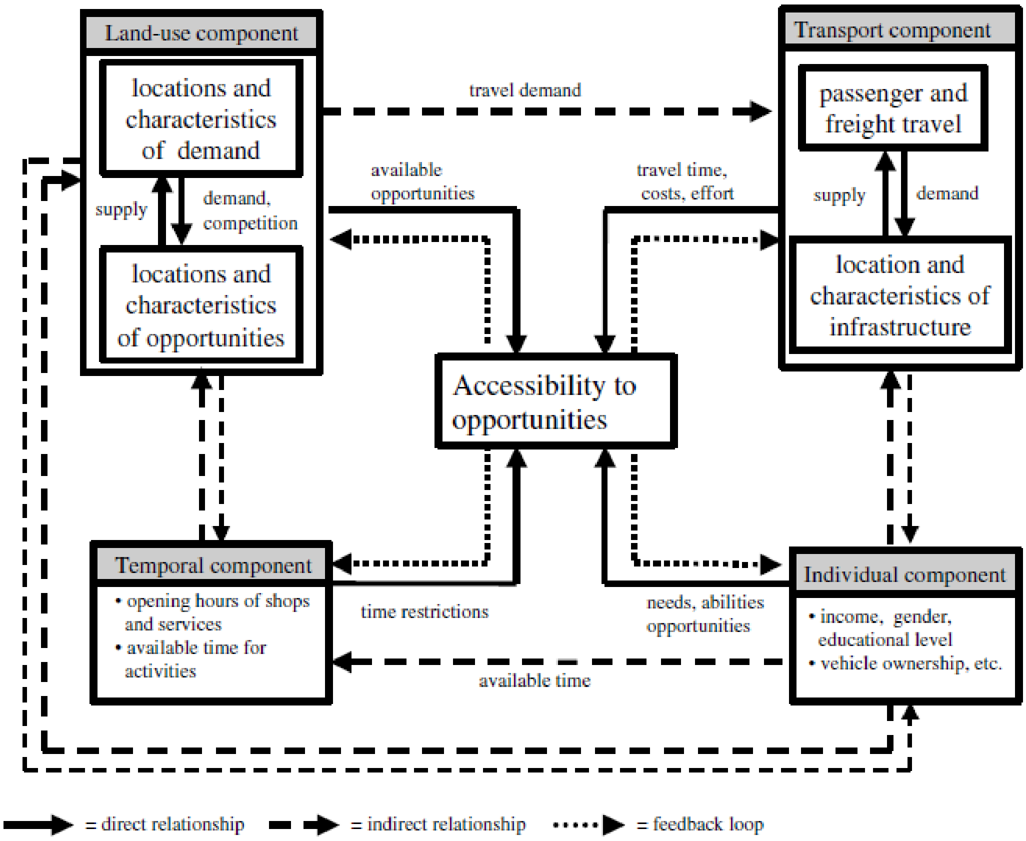

Figure 4: Interactions between components of accessibility (Geurs and van Wee 2004)

2.1.2 How accessibility planning enables sustainable mobility behaviour

The main purpose of transport systems is to link places where a combination of activities are carried out – for example, private activities, within the meaning of basic functions (e.g. living, working/education, shopping, leisure, etc.), act as triggers for passenger or commercial activities, which then subsequently generate goods and commercial traffic. By linking places, the transport system ensures connections and the development of specific locations. Together with the spatial distribution of opportunities, the transport system ensures accessibility and participation, as well as social and economic exchange. Therefore, it is clear that transport planning should not focus specifically on transport, but rather on the daily lives of people (Bracher et al. 1992). Thus, transport planning is less about the velocity of transport systems and more about the accessibility of activities (Handy 2005). Hence, transport related issues cannot be solved by transport measures and projects alone.

With this interpretation, the accessibility concept can be seen as a suitable framework with respect to sustainable mobility and spatial development while integrating land-use and transport planning. According to Bertolini et al. (2005), accessibility has to be adequately defined, considering the characteristics of both the transport system (e.g. travel speed) and the land use (e.g. density and mixed use). By doing so, economic goals (e.g. access to employees, customers, suppliers), social goals (e.g. access to jobs, goods and services) and environmental goals (resource-efficiency, mobility patterns) can be addressed more effectively.

In the same way, a paradigm shift from providing mobility to providing accessibility can promote more sustainable travel options (e.g. non-motorized and public transport, reduced distances by car) when combined with certain land-use attributes (e.g. high densities, well-balanced mixed functions) (Bertolini and le Clercq 2003). For example, Curtis (2008) highlights the need to reorient existing urban structures towards the development of high accessibility places, which support efficient and sustainable modes of transport within the transport system (e.g. non-motorized and public transport).

With the concept of accessibility seen as a new measure of sustainable mobility and spatial development, Banister (2008) maintains that a degree of flexibility regarding future development is required for sustainable mobility to become a reality.

"Accessibility planning as a concept of strategic planning should therefore aim towards ensuring and improving mobility options that, from a collective point of view, enable economic development and social exchange, while at the same time reducing the negative effects of transport." (Crozet and Wulfhorst 2010)

As seen in Figure 5, Wulfhorst (2008) highlights the potential of accessibility planning as a strategy for sustainable transport development by the interaction of transport supply, spatial structure as well as transportation demand management.. In other words, sustainable mobility behaviour should not be a given, but instead a target which can be achieved by the land-use and the transport supply. However, sustainable development, facilitated by the means of transportation demand management, can only be achieved if there is political and societal acceptance (Wulfhorst 2010). This acceptance is fostered by raising awareness of future issues and challenges (e.g. increasing mobility costs, traffic jams, pollution, and noise).

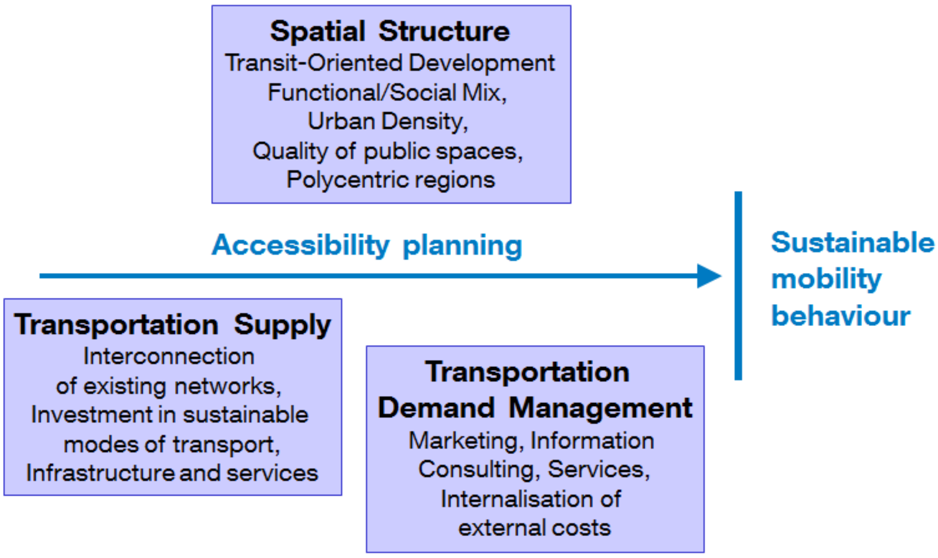

Figure 5: Accessibility planning enables sustainable mobility behaviour (cf. Wulfhorst 2008, Wulfhorst 2010, Crozet and Wulfhorst 2010)

Banister (2008) argued that sustainable mobility can be achieved by existing policy measures. However, there must be a focus on actively promoting suitable projects and innovative strategies, and by gaining public interest on accessibility through participation.

2.1.3 Accessibility as a key for good governance and policy making processes

Accessibility is a powerful concept when it comes to policy making. However, in many cases accessibility is not only misunderstood, but also ill-defined, poorly measured and miscalculated. As a result, the concept often remains fuzzy and relatively unclear (Geurs and van Wee 2004). Consequently in policy making, there is a trade-off between complex, obscure accessibility computations (e.g. gravity-based/distance decay) and simple, transparent accessibility indicators (e.g. travel times, speed) (see chapter 3.3 and 5).

Similarly, Bertolini et al. (2005) stressed the need for the accessibility measures to be both empirically sound and sufficiently plain when it comes to strategic spatial planning. Many authors also reach similar conclusions about these measures with respect to planning processes (e.g. Geurs and Ritsema van Eck 2001, Halden 2002, Geurs and van Wee 2004, te Brömmelstroet and Bertolini 2008, Büttner and Wulfhorst 2016).

To summarize, better governance requires that transport planning should focus first on the daily routine of people before considering the provision, design, and specifications of the transportation supply. Furthermore, the impact on everyday life should be measured by the accessibility of (daily) activities rather than the velocity of the transport infrastructure (Bracher et al. 1992, Holz-Rau 2012). In this way, transport planning is not about 'planning transport' in terms of infrastructure and other transport supply, just as spatial planning is not about ‘planning spaces’. Both transport and spatial planning are built to fulfil a basic social need to access different activities. From a spatial planning perspective, this need is reflected in the physical transport or telecommunication links between these activities and land-use configurations. The task in this context is to ensure access to activities and develop this access in a socially, economically and ecologically sustainable way, from the local to regional and individual to collective level (Holz-Rau 2009).

2.2 Interdependencies of mobility costs and residential costs

Residential costs and mobility costs are closely linked to accessibility. Since German households spending approximately half of their available income on these costs (Statistisches Bundesamt 2010), they should both be examined in detail. Therefore, the following will highlight the interdependency of location choice (accessibility) and housing costs.

The interactions between mobility behaviour and destination choice is displayed in the land-use and transport feedback cycle in Figure 6 (Wegener 2009).

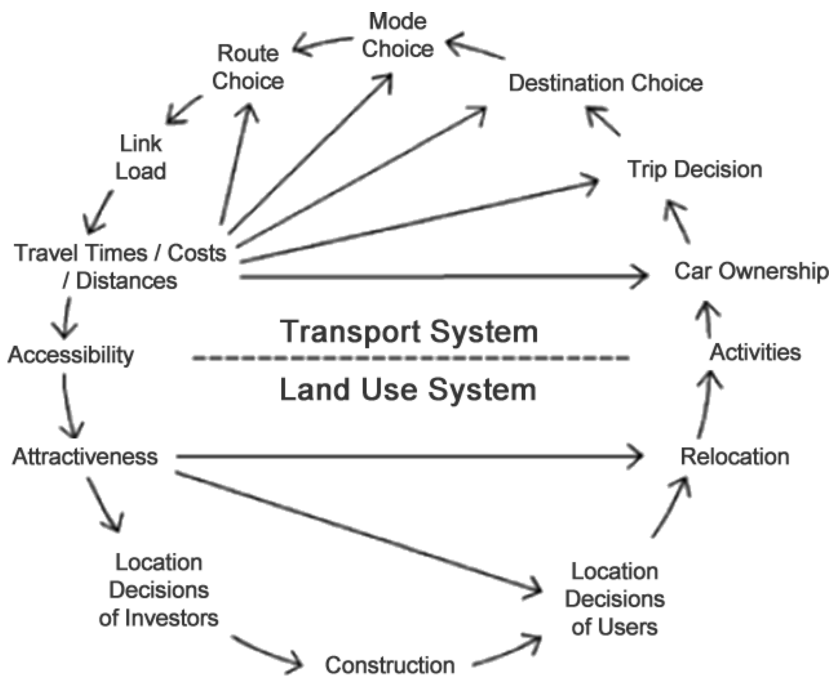

Figure 6: Interactions between transport and land use (Wegener 2009)

Wegener (2009) highlighted the most important relationships in the following:

- The distribution of land-uses strongly influences residential as well as commercial site locations and respectively dictates the daily acitivities.
- The spatial distribution of these activities requires a change of location.
- The change of location is accomplished by the transport system. The specific mobility behaviour is influenced by the availability of a certain transport mode, the number of trips made and the available destination options. Based on these factors, the mode of transport and a suitable route are chosen. This determines the traffic flows as well as distances, travel time and mobility costs.
- Travel time, distances and mobility costs determine the effort needed for changing locations, hence the accessibility. Accessible locations become more attractive to investors, which results in investment and the creation of new activities (Wegener 2009).

Addtionally, Wegener (2004) points out the varying temporal dimensions in the urban transition processes. Transport networks and land use are *“the most permanent elements of the physical structure of cities”* and consequently change very slowly. In comparison, workplaces and housing change slowly, while employment and population can change rather quickly and freight and passenger transport can change immediately (Wegener 2004).

For private household decisions, the cost of housing is the strongest factor in residential location choice. Low rent and real estate prices are mainly found in rural regions, however these regions are also characterized by high car dependency due to the lack of alternative transport modes (Albrecht et al. 2008). Hence, there is a trade-off for households which are unwilling, or unable, to pay the higher costs of living in accessible places surrounded by different amenities.

Studies in the Hamburg (Gertz Gutsche Rümenapp and UBA 2006) and Munich regions (Gertz Gutsche Rümenapp 2008) have shown that in peripheral areas, the additional mobility costs approximately cancel out the cheaper residential costs. The key findings of both studies are that the total costs of living in the cities, suburbs, suburban centres, smaller rural municipalities, and municipalities with and without rail access, are approximately equal due to the high mobility costs of the more peripheral locations and their attributes (Gutsche 2008). These evened out total costs in the Hamburg region is exemplarily displayed in Figure 7.

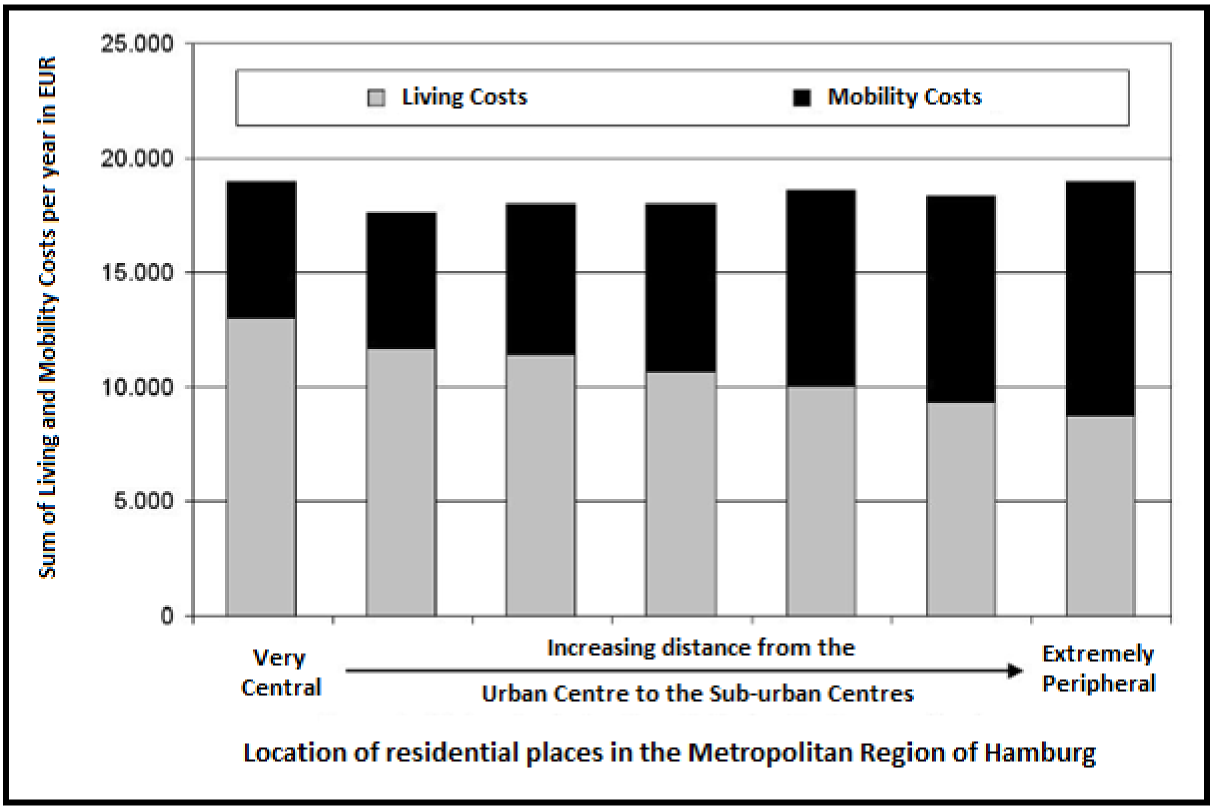

Figure 7: Balancing of residential and mobility costs for very central to very peripheral areas in the Hamburg region (translated after Gertz Gutsche Rümenapp and UBA 2006)

Density plays an important role in implementing efficient public transport infrastructure and encouraging non-motorized trips (e.g. increasing the walkability), which leads to low mobility expenditures according to Newman and Kenworthy (1989). Figure 8 shows the exponential increase in gasoline consumption as urban density decreases for 31 cities in the developed world in 1980. European and Asian cities with a dense settlement structure and an efficient public transport network show low per capita fuel consumption, while sprawling US cities, which have long invested primarily in car infrastructure, show high per capita fuel consumption.

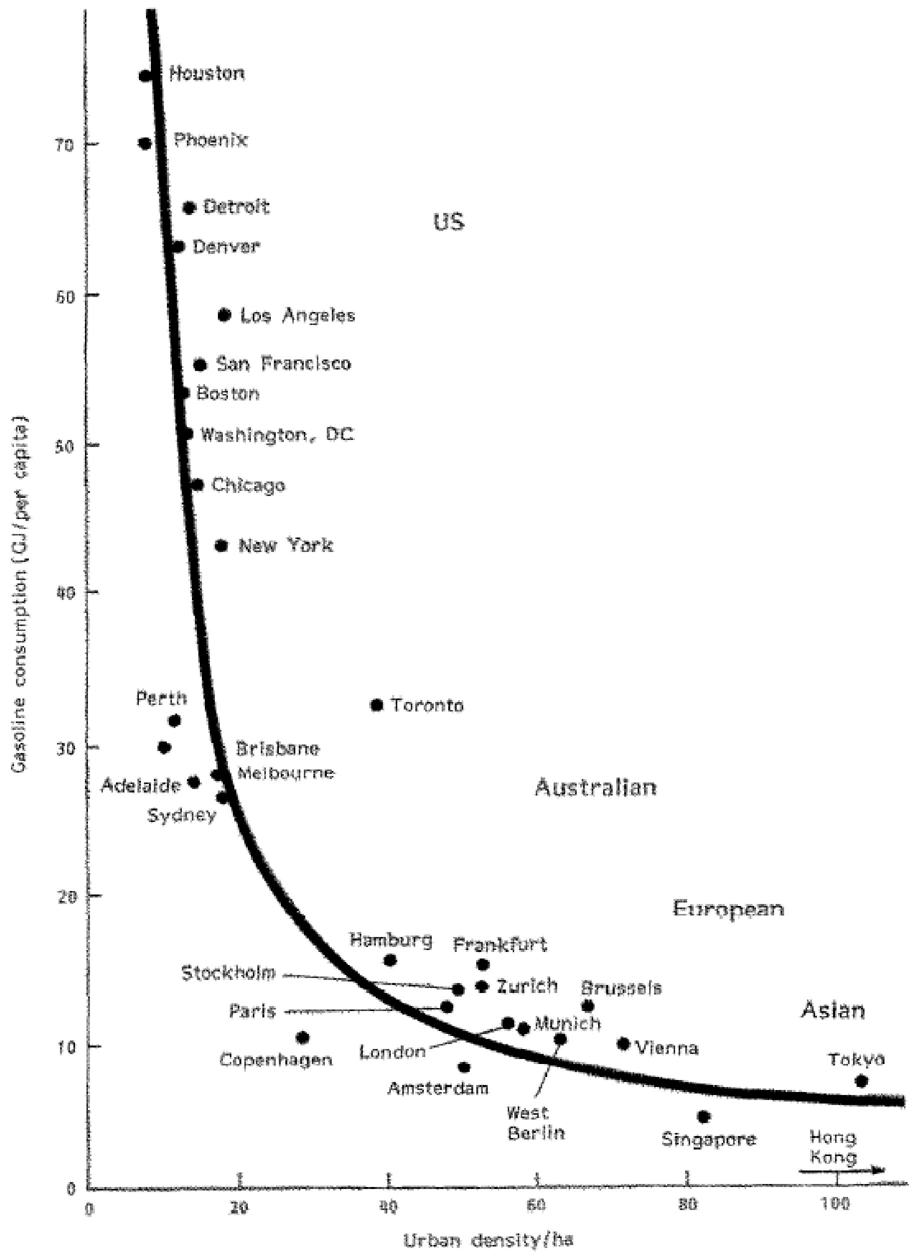

Figure 8 : Fuel consumption and urban density in 1980 (Newman and Kenworthy 1989)

Density surely is not the only determining factor when it comes to transport energy consumption. Diversity of land-use and its proximity is enabling non-motorized trips.

As a result of an extensive state of the art literature review on land-use and transport interactions Wegener and Fürst (1999) came to the following conclusion in respect to the interdependencies between transport energy consumption and urban density:

"In summary, one might hypothesise that urban density is only an intermediate variable and that the real cause behind a high level of mobility, trips lengths and transport energy consumption is the availability of cheap transport energy." (Wegener and Fürst 1999, p. 32)

2.2.1 Development of residential costs

The most influential elements in the development of residential costs are spatial development, which describes the evolution of the land use system, and the individual choice of residential location and its resulting monetary impact. These will be highlighted in sections 2.2.1.1 and 2.2.1.2 respectively.

2.2.1.1 Spatial Development

First and foremost, the decentralization of employment is the driving force behind the rise of the multifaceted urban forms of the polycentric city and the polycentric metropolitan region. At the same time however, it is often assumed that the decentralization process improves job access for average and highly skilled workers, allowing them to reduce their residential costs by moving to peripheral residential locations and hence triggering a new round of urban sprawl (Ham 2002). Many researchers believe these theories can effectively mitigate transport related problems, especially by reducing high levels of commuting traffic and inefficient commuting mode choices (Levinson 1998, Messenger and Ewing 1996).

Despite such advocacy, there is still significant debate whether decentralized spatial development can really contribute to efficient commuting and reduced residential costs. (Wachs et al. 1993, Peng 1997). For example, Miller and Ibrahim (1998) hold that location has a larger impact on commuting behaviour than the job-housing balance, which describes the even distribution of population and work-places in one area. Furthermore, considering the economies of agglomeration the job-housing balance within a small municipality is not realistic or achievable. This renders the separation of residence and workplace as an unavoidable product of urban economic development. To remedy this, spatial planning solutions should be pursued that either provide transport infrastructure to connect centres of employment and housing, or provide new housing areas along the public transport corridor connecting to job centres (Zheng and Sun 2011).

Best summarized by Holden (2007), it is well accepted that the built environment (i.e. land use planning) has specific consequences for individuals' transport patterns and demands.

In one way, proper land-use planning, in terms of decentralized yet compact land-use, can facilitate the development of improved public transport systems. On the other hand, however, land use planning can also reduce transport demand by facilitating the uptake of more active non-motorized modes, which can also increase the attractiveness of an area and hence increase residential costs.

2.2.1.2 Residential site location

Aside from spatial development, the choice of residential location also has an effect on residential costs and commuting decisions. Romani et al. (2003) state that commuting patterns are an explicative variable in the residence change equation. Moreover, travel decisions may even precede residential relocation and hence changes in residential costs since 98% of households already own one or more cars before moving to the suburbs. Although travel decisions may possibly precede residential relocation, residential costs can usually be estimated in advance in an accurate and simple manner. However, the resulting mobility costs and the duration required for travel are often underestimated, if they are even considered (Haller et al. 2012).

Employed people that have recently moved out of the inner urban area are likely to misjudge mobility costs, especially those that continue to work in the city centre. People’s transport modes also change after relocating, which is problematic since inner urban districts are better suited for public transport and non-motorized transport while suburban neighbourhoods favour car use (Scheiner 2006, Thierstein et al. 2016). When relocation patterns favour the periphery of cities, where less public transport exists, higher rates of car dependency will be found. As mentioned previously, non-motorized transport decreased from 12% to 6% and public transport decreased from 31% to 15% when residents moved from the centre of Munich to the outskirts (IMU, 2002).

To control and reduce both residential and mobility costs, the findings of previous studies need to be incorporated into practice. For example, Shi et al. (2013) highlight the close correlation between residential and workplace decisions made by employed persons; while Korsu (2012) demonstrates that previous policies underestimate a household’s ability to mitigate long-distance commuting by locating their residence near their workplace. As can be seen, there exists a conditional interdependency on commuting cost between residential and workplace mobility (van Ommeren et al. 1999). Theoretical and empirical findings (Merriman and Hellerstein 1994, Rouwendal 1998, Clark et al. 2003) reveal that distance and time have a strong influence in the joint location choice of residence and workplace, and hence residential costs.

Aside from changes to workplace locations, households are tempted to change their residential location for other reasons, for instance to have additional transport options. In the case study by Geurs et al. (2006) of regional rail in the Netherlands, it was found that residents’ willingness to pay for an additional transport option, in terms of their residential costs, exceeds the expected benefit. This willingness to pay was observed when the public transport option was used frequently, infrequently, and even not at all.

Another common reason to relocate is to have more indoor and outdoor green space. Munich residents want to live in close proximity to green spaces (LHM 2012) but also have sufficient living space, and this has dramatically increased housing costs. A report from the city's government found that the average household moving to Munich experiences a 39% increase in rent and a 27% decrease in living space area. On the other hand, the average move out of Munich results in an 51% increase of living space and a 25% decrease in rent (LHM 2012). Due to the pressure on the housing market within the Munich region, the majority cannot afford an optimal location. However, moving to the periphery of the city, or even further, rarely results in an overall cost savings. Residential costs may decrease outside of cities, but mobility costs will rise in response (Haller et al. 2012).

In the United States of America, urban growth over the last few decades has been driven by a mentality described as "Drive till you qualify". In this mind-set, people seeking desirable homes look out past the cities and suburbs to the exurbs, where new, beautiful homes were surprisingly affordable (Cornwell 2013). The term "exurb" originated in the 1950s to describe semi-rural communities of wealthy estates, but now encompasses urban fringe communities that serve as "affordable housing havens for middle-class families" (Berube et al. 2006). A similar trend was found by Thierstein et al. (2016) when households which have moved within the last three years were asked concerning their preferred residential site location within the metropolitan region of Munich. 27% of the households have stated that the reason was to live more "comfortable" by expanding the housing space. For most, this was only achievable by moving further out than originally planned (Thierstein et al. 2016). Naturally, this meant long commutes and high mobility costs for those working in cities. However, these high costs were largely neglected, especially when oil was relatively cheap. Leigh Gallagher (2014), author of "The End of the Suburbs", states that *"Most people think about their housing costs without factoring in transportation…plus it's the people who can least afford it who buy at the costliest distances."*

Indeed, studies have found that mortgage default rates during the latest housing crisis were highest in exurbs. In response, the U.S. Departments of Transportation and Housing & Urban Development recently partnered to create the Location Affordability Portal, where users can calculate their combined housing and mobility costs and locate more affordable places to live. An analysis of housing affordability in the Washington D.C. metropolitan area by the Center for Neighborhood Technology shows the importance of considering transportation costs. The analysis showed that a surprisingly large region (the red area shown below in Figure 9) becomes unaffordable when transportation costs are considered. The red areas that become unaffordable had housing costs below 30 percent of median household income, but the costs jumped above 45 percent when bundled with transportation costs (Snyder 2011).

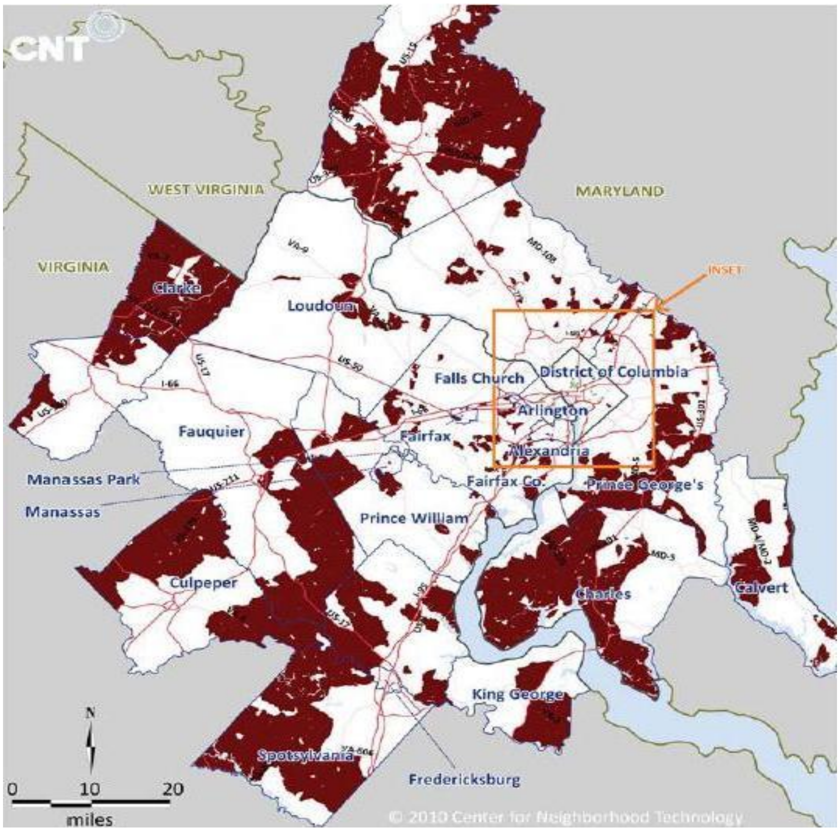

Figure 9: Housing locations (red) in the Washington DC metropolitan area that become unaffordable when considering mobility costs. (Center for Neighborhood Technology 2010)

However, the trends of the last few years show a change from this “drive till you qualify” practice, especially among millennials (those born in the 1980s and 1990s). According to the U.S. Census Bureau (2015), only one of the 50 largest U.S. cities grew faster than its metropolitan area between 2000 and 2010. However, at least 14 of the 50 largest U.S. cities grew faster than their metro area between 2013 and 2014. There is also a notable shift from single-family homes to multifamily housing. Nationwide, multifamily housing accounted for 33% of all new housing in 2013, the highest portion since 1973. Indeed, a recent survey found 62% of millennials preferred to live in mixed-use communities in urban centres.

Despite this trend, the recent relative stability of low oil prices is keeping fuel prices down and could renew the appeal of the exurbs. However, these newly attracted exurbanites would be vulnerable to increased mobility costs and reduced accessibility when oil prices rise again.

2.2.2 Development of mobility costs

2.2.2.1 Mobility behaviour

The theory of travel behaviour states that humans tend to minimize travel time or mobility costs needed to participate in activities while considering their daily mobility decisions. Instead Zahavi (1974, 1979, Zahavi et al. 1981) demonstrated that individuals maximize the number of activities or opportunities that can be accessed within their travel time and monetary budgets (see chapter 2.1.1).

In line with such thinking, those who are able to pay for a high level of mobility via a private car can realistically maximize daily activities while also reducing travel times (assuming free flow conditions), relative to other modes. On the other hand, those without the ability to access a car, whether it be at a certain time or at all, will spend a significant proportion of their time on daily travelling, or as a second option confine their activities to parts of the urban area accessible by public transport and active modes (Næss 2006).

In Germany, for example, the share of adults without a car available in the household is approximately 13%. In municipalities with less than 5,000 inhabitants the share is 7%, while in cities with upwards of 500,000 inhabitants this share lies at 28%. At the same time, however, the average distance from home to the next public transport station is less than one kilometre for households in cities with more than 500,000 inhabitants (MiD 2008). The proximity of the population to public transport stations also allows for an amount of flexibility within an individual's mobility behaviour and hence their mobility costs.

2.2.2.2 Mobility costs

Energy prices having a significant effect on land use and mobility, influencing many aspects of society including the location choice of households and firms, mobility behaviour, living and construction costs as well as municipal revenue and expenditure. The manifestation of these costs in society, however, paints a different picture. Within the context of demographic change, especially in relation to rural areas, sharp rises in energy prices will continue to affect societies in ways stronger than everyday fluctuations (Bohnet et al. 2012). These sharp increases are especially serious given that today's transport systems are heavily dependent on non-renewable energy sources (Schindler and Held 2009).

Underpinned by the history of non-renewable energy sources, the evolution of infrastructure to the specific settlement structures of the 20th century was made possible by inexpensive crude oil. As a result, the vast majority of transport is reliant on fossil fuels. The aftermath of such dependence is reflected through increasing tensions in many oil-exporting countries, alongside sharply rising oil prices and volatile price fluctuations since 2004 (Schindler and Held 2009). To change a society so dependent on non-renewable fuels requires more than a sustained increase in fuel efficiency and a slow substitution of oil with renewable energy. It also requires insights into the upcoming fundamental structural break and an understanding of the need for technical and infrastructural changes (Schindler and Held 2009). Two research studies have helped provide this insight by examining the outcomes of various degrees of energy price increases against a variety of policy responses.

The first of these studies is the Scenarios for the Transport System and Energy Supply and their Potential Effects (STEPs) Project, published in 2006, which was envisioned to "develop, compare, and assess" the effects of future energy supply security on the interactions of transport and land-use. Particularly of interest, STEPs compares a variety of models that pair various degrees of fuel price increases against various degrees of policy responses and measures the resulting transport demand. To model what the future fuel prices will be like, STEPs combines the POLES model to determine the effect of oil prices and the ASTRA model to determine the effect and feedback loop of transport demand. It then studies the effects of the resulting energy scarcity with a variety of models, such as the SASI and IRPUD models, which study the interactions between transport, land use, socioeconomics, and the environment. These models were applied in five cities that represent four of the five various planning cultures within Europe: Brussels, Dortmund, Edinburgh, Helsinki, and South Tyrol (Monzón and Nuijten 2006).

A meta-analysis of each of the STEPs models reveals general agreement in the type of transport responses and observed effects. The results reveal that fuel cost increases do reduce accessibility in all regions, but also increase regional integration. Additionally, the extreme fuel shocks studied in Dortmund indicated notable travel behaviour changes: a shift from car trips to public transport and active modes, as well as individual relocation to higher-density areas close to workplaces (Emmerson and Wegener 2006). Finally, the STEPs study identifies a need for further research on how extreme fuel price increases impacts land use through lifestyle and work pattern changes, a need even more critical after the extreme fuel price volatility observed in 2007-2008 (Monzón and Nuijten 2006).

The second study was the €LAN project, an approach to modelling the rising energy prices on rural and urban structures and also a way to look at stakeholder reactions to these prices variations and the economy. The project combines a LUTI-model from the Hamburg area and uses a "Serious Game" that includes various actors (politicians, federal and state governments, members of local advisory groups, etc.) to generate a scenario where the price of energy increases and the actors react and produce measures in response to these changes in price.

The overall goal is for these stakeholder-made strategies to be fed back into the model so that it generates another scenario based on the given input (Gertz et al. 2015).

The €LAN Project presents a quantitative simulation tool (the model) and combines it with a qualitative one (the Serious Game). The involvement of participants can enhance the realness of the inputs for the model and therefore enhance the reliability of the model outputs. It is important to note that Guimaraes et al. (2014) point out that the data developed through the Serious Game was not tested against an alternative setup as they are unique inputs created by the participants and the Serious Game is not repeatable (compared to that in laboratory conditions). Also, there are risks taken when only basing assertions on a single experiment. In general, the €LAN Project showed that the combination of a Serious Game and a model can produce more innovative solutions by enhancing the quality of decision making with regard to a better understanding of complex issues. Early outcomes of the project suggest that inter-municipal cooperation schemes will increase in importance as the energy prices increase – this deep need for cooperation between urban and rural municipalities was shown to be especially true (Gertz et al. 2015). Therefore, using the €LAN Project as a trans-disciplinary test field should be appreciated as it is a valuable model for creating innovative solutions to potentially devastating problems.

The vulnerability of oil-dependency studied in the STEPs and €LAN projects was shown during the last decade's oil price spike. In the summer of 2008 world oil prices peaked at US$145, but then rapidly dropped to US$35 per barrel following the financial crisis. Such extreme variation makes it relatively difficult to predict the future of fuel prices and the subsequent extents of fuel poverty. In saying this however, the price of household energy has not been affected by reductions in the price of oil, which continues to escalate (Boardman 2010).

In line with fuel price increase, it is certain that changes in these prices have a strong effect on the number of individuals in fuel poverty. For one thing, all consumers of identical utility experience the same price increase on the same day. At the same time, such price increases can be both unexpected and rather large, compared to other expenses of a fixed nature, for example, rent and mobile phone bills. As a response, households would not be able to change their behaviour in the short-term, having insufficient opportunity to offset increases to their mobility budget to maintain the same standard of living as before (Boardman 2010).

Along with the problems created by fuel price increases, there are also other issues concerning non-renewable fuels. Due to the versatility, convenience and affordability of oil, the material became vital to virtually anything that moved (Maass 2009). However, pressing issues like reducing greenhouse gas emissions and climate change act at the forefront when it comes to such non-renewable fuels, with transport accounting for 24 percent of the world's greenhouse gas emissions (Grieco 2012). This issue is worsened with no large discoveries of conventional oil since the 1970s; there have been three to four barrels of oil being consumed for every new one discovered (Grieco and Urry 2012). According to a report by Information Handling Services (IHS), a leading provider of oil industry research, conventional oil discoveries outside North America have declined to the lowest level on record in 2015 (Smith 2016).

In contrast to the poor outlook for conventional oil production, which is extracted from oil wells, unconventional oil production is booming in the United States and Canada from sources such as tight oil (fracking) and oil sands. A 2013 report by the International Energy Agency (IEA) called this boom *""a game changer" that is"…reaching virtually all recesses of the global oil market."* (IEA 2013). Figure 10 below shows how these sources are resulting in historic levels of oil production in the United States of America.

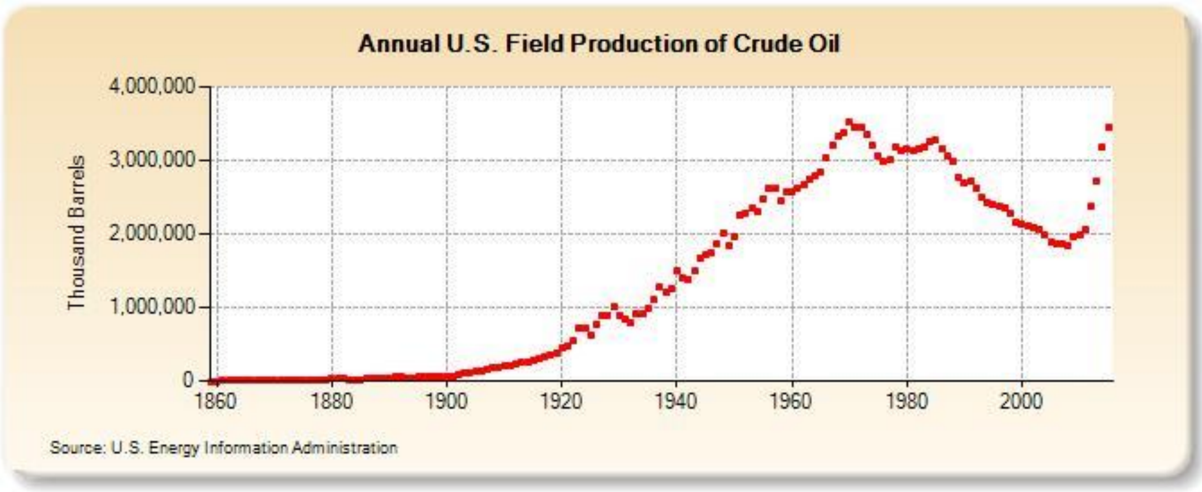

Figure 10: Annual U.S. Field Production of Crude Oil. (U.S. Energy Information Administration 2016)

However, while sources such as tar sands and fracking are providing new life to the oil industry, their increased environmental impacts are also highly controversial and may eventually threaten future production. For example, Canada's Congressional Research Service estimates that oil from oil sands results in 14% more GHG emissions than conventional oil (Biello 2013). Additionally, high risks of groundwater contamination and induced earthquakes from fracking have already led lawmakers to ban the practice in France, Bulgaria, and three U.S. states (McDermott-Levy et al. 2013). As environmental concerns sharpen with each passing decade, the negative impacts of unconventional oil sources could lead to further bans on production.

Two of the largest energy agencies in the world, the U.S. Department of Energy and the International Energy Agency, have suggested that oil demand will increase from 86 million to 125 million barrels a day by 2040. This demand increase will be driven almost exclusively by non-OECD countries and the supply increase will be shared evenly between OPEC (almost exclusively the Middle East) and non-OPEC countries. In terms of supply, it was stated that prices are expected to stay under $100 USD per barrel for the next decade, as OPEC countries seek to increase exports to maintain market share over North America and other non-OPEC countries rather than cut production (EIA 2016).

The latest short-term energy outlook from the EIA (2016) shows the development of the real and nominal oil price from 1974 to the present. Together, fossil fuel scarcity and the uncertainty of peak oil, as well as political instability in oil producing states will eventuate in higher mobility costs in the near future. During the 2000s energy crisis, oil prices rose suddenly from US$40 per barrel in 2004 to more than US$100 per barrel four years later in 2008. Prices have been highly volatile since then, having spiked again and most recently dropping by 75% in just 18 months.

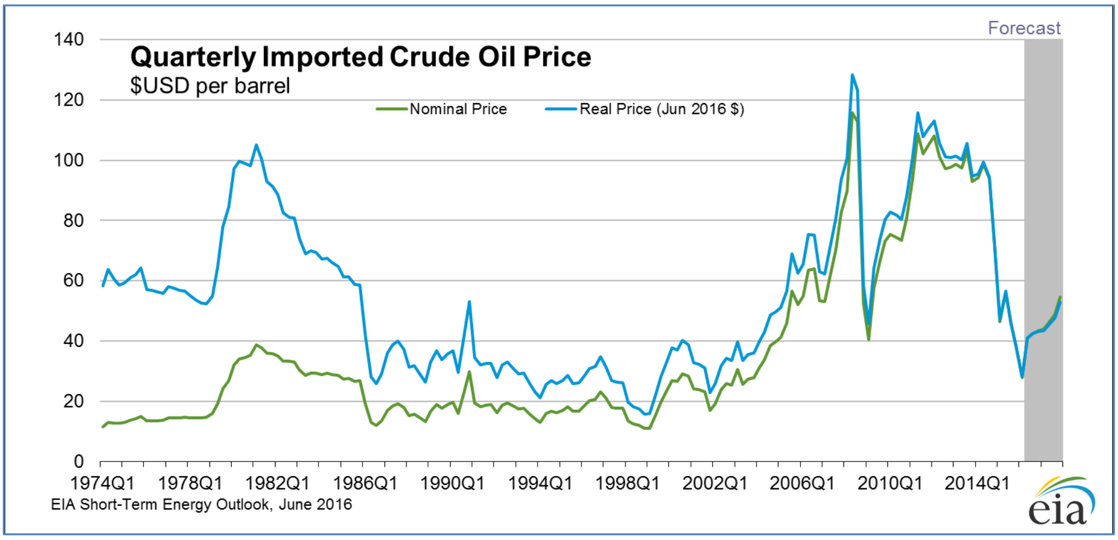

Figure 11: Development of the real and nominal oil price from 1974-2017 (projected) (EIA 2016)

Despite such sharp and variable fluctuations in energy prices, the majority of the world's population still relies on fossil fuel powered modes of transport for everyday mobility. This is despite the attempts of governments to decrease the growth trend towards individual motorized mobility. However, with the economic rise of large countries like Brazil, Russia, India, and China, there is an increasing demand for more oil at cheaper prices. Recent events have shown that volatility in oil prices can have dramatic impacts on the economic development of both oil-exporting and oil-importing countries.

In one example of fuel price increases, between 2002 and 2012 the pump price of petrol in Germany almost doubled from $US1.03/L to $US1.96/L (World Bank 2015). Coupled with only minor increases to real incomes during the same period (Brenke 2009), the combination of growing distances to daily mobility destinations and sharp increases in mobility costs are seen to have forced a greater share of the household budget to be spent on mobility (Büttner et al.

2013). As opposed to spending more on mobility, Hautzinger et al. (2005) demonstrated that fuel price increases can cause a reduction in private mobility demand. However, in line with Büttner et al. (2013) this reduction was found to be under proportional due to the lack of monetary flexibility in the household budget.

How will such increases in fuel prices possibly manifest themselves in the future? In quantitative terms, Hautzinger et al. (2005) highlighted how a fuel price increase of 10% resulted in a decrease of car usage of 2.9%, with only an increase of 0.4% in the usage of public transportation. In this way it is apparent that many households will spend a greater share of the budget on fuel to maintain the same level of motorized mobility.

While it is difficult to predict when another oil crisis will occur, there is no doubt that such a crisis will lead to a sharp and sudden leap in mobility costs. Therefore, an examination of the vulnerability on a regional level is needed in order to see which municipalities are exposed to sharp increases in mobility costs (see Part II: Büttner et al. 2013).

However, in the following individual elasticities regarding the impact of increasing costs on mobility behaviour will be examined to estimate the sensitivity of households.

2.2.3 Monetary factors affecting mobility behaviour

Transport prices, which are the direct, perceived costs of using goods, can affect the mobility behaviour of the people using transport systems. Along with monetary costs, travel time, discomfort and risks are also included in the transport prices. Effects on trip frequency, route, mode, destination, scheduling, vehicle type, parking location, and type of service selected can be seen due to the changes in prices. One of the common ways to measure these pricing impacts is by using elasticities. Elasticity is *“the percentage change in consumption (travel activity) that results from each 1% change in price”* (Litman 2013, p. 2).

Travel behaviour is affected by both monetary and non-monetary factors as described in Table 1. However, as the focus of this paper lies in examining the effects of costs on travel behaviour and accessibility, only the important monetary factors that influence travel behaviour are briefly discussed in this paper.

Table 1: Monetary and non-monetary factors affecting travel behaviour (Litman 2013)

Non-Monetary Factors					**Monetary Factors**
Demographics	**Commercial Activity**	**Transport Options**	**Land Use**	**Demand Management**	
Number of people (employees, residents and visitors)	Number of jobs	Walking	Density	Road use prioritization	Income
Employment rate	Business activity	Cycling	Land use mix	Pricing reforms	Vehicle Ownership
Age	Freight transport	Public transit	Walkability	Parking management	Fuel Price
Lifestyles	Tourist activity	Ridesharing	Connectivity	User information	Road pricing and tolls
Preferences		Taxi service	Transit service proximity	Promotion campaigns	Parking Price
			Roadway design		Transit Fare

2.2.3.1 Vehicle ownership

Vehicle ownership is influenced by a number of factors. Various factors, such as household demographics, income and location, that affect vehicle ownership were identified by Whelan (Whelan 2007). Goodwin et al. (2003) state that when fuel prices increase by 10%, the vehicle ownership decreases by 1% in the short-run and 2.5% in the long-run (Goodwin et al. 2003). Giuliano and Dargay (2006) studied the travel patterns in the UK and the US and found that UK residents owned fewer automobiles and made fewer and shorter motorised trips as compared to the US residents. This was due to UK residents having lower real incomes, higher vehicle costs (fuel taxes), and a variety of other good travel options (walking, cycling and PT) (Giuliano and Dargay 2006). According to Johansson and Schipper (1997), per capita vehicle ownership is also influenced by fuel prices with an elasticity of -0.1.

2.2.3.2 Income

The income of a household plays an important role in determining the vehicle ownership, mode choice, and location of residence and work. Schafer and Victor found that the vehicle ownership of a household in directly proportional to its wealth (Schafer and Victor, 2000). By taking a look at various sources, it was found that around $3,000 to $10,000 annual income per capita automobile ownership and mileage increase at a rate that is twice the rate of income growth (Dargay et al. 2007, Millard-Ball and Schipper 2010). Dargay states that while the vehicle ownership of a household increases with employment and incomes, it is less likely to decrease if the income and employment are reduced (Dargay 2007).

In places with poor walking and cycling conditions and where driving is cheaper and faster than public transit, households tend to have higher vehicle ownership rates. It is also interesting to note that the rebound effects of fuel price, which constitutes increased annual vehicle travel due to an increase in vehicle fuel economy, declines substantially with income (Small and van Dender 2005 and 2007).

2.2.3.3 Road pricing and tolls

The concept of making the car users pay a toll for using a particular roadway or driving in a particular area is called as *'Road Pricing'*. In contrast, the concept of making car users pay a higher toll during the peak hours as compared to off-peak hours in order to reduce traffic congestion is known as '*Congestion Pricing'* (Litman 2013).

Car users are more sensitive to road pricing as compared to other types of price changes (Evans et al. 2003, Lake and Ferreira 2002, Litman 2012). Spears, Boarnet and Handy (2010) studied the impacts of road pricing and concluded that the elasticity of traffic volumes with respect to tolls is generally -0.1 to -0.45 (Spears et al. 2010). This means that a 10% toll increase will reduce the traffic on that roadway by 1.0% to 4.5%. They also found that the elasticities are higher for roads with fewer essential trips, better alternatives or lower congestion levels. According to them, traffic volumes in five major European cities and Singapore have been reduced by 12% to 22% by using cordon tolls.

2.2.3.4 Parking price

Parking fees are a very direct charge and thus car users are very sensitive to it. Parking fees are found to have a greater effect on vehicle trips than any other out-of-pocket expenses. Building on the conclusions of USEPA's 1998 study, it can be said that a $1.00 per trip parking charge will result in the same traffic reduction as would result from a fuel price increase of $1.50 to $2.00 per trip (Deakin and Harvey 1998).

2.2.3.5 Travel time

Increase in travel distance is associated with reduced delays and increased travel speeds. When the speed of a particular mode is increased, it tends to attract trips from other modes operating on the same corridor (Litman 2013). People devote a constant amount of their time (generally 70-90 minutes daily) for travel. According to the 'constant travel time budget' hypothesis, this time remains constant. This implies that the elasticity of travel as compared to speed is 1 (Mokhtarian and Chen 2004). According to SACTRA, the elasticity between travel volume and travel time is -0.5 (in the short term) and -1.0 (over long term). This implies that if we increase the traffic speeds by 20%, we will end up increasing the traffic volumes by 10% in the short term and by 20% in the long term (SACTRA 1994).

2.2.3.6 Vehicle travel with respect to fuel prices

Fuel prices and per capita annual vehicle travel are inversely proportional to each other. The higher fuel prices are, the lower the per capita annual vehicle travel is. This is clearly illustrated in the figure 12 below (VTPI 2007). An interesting thing to note about this figure is the inherent difference between the values for US and the European countries. It can be seen that the European countries, in general, have higher fuel prices and relatively low per capita annual vehicle travel.

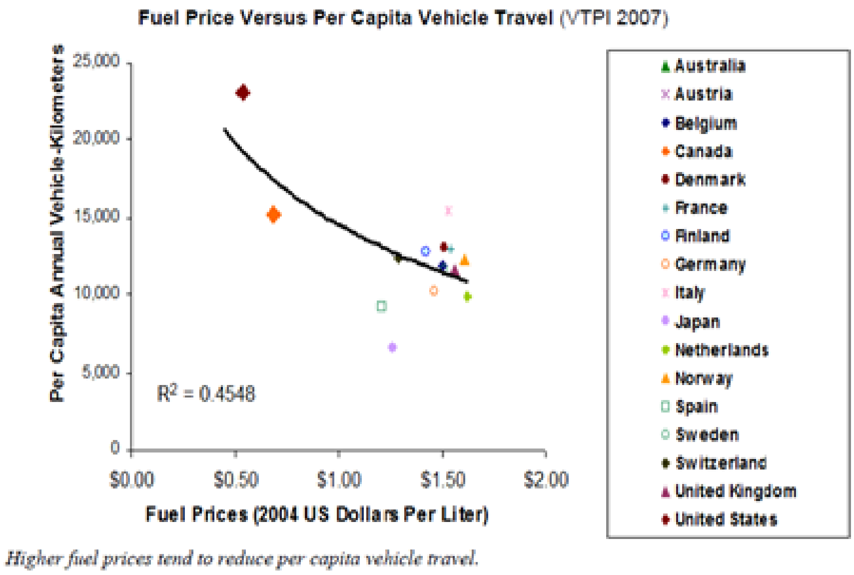

Figure 12 : Relationship between fuel prices and per capita vehicle travel (VTPI 2007)

A study conducted by the U.S. Congressional Budget Office indicates that an increase in fuel prices reduces the urban highway traffic speeds and volumes (CBO 2008). The travel impacts of a fuel tax increase in the California region were modelled by Harvey and Deakin in 1998. This study found that, in South Coast (Los Angeles), the total vehicle trips could be reduced by around 12.5% by increasing the fuel tax by $2.00 per gallon. The effects of this measure on congestion delays were even more notable. This measure would decrease the congestion delay by 28.5% (Harvey and Deakin 1998).

2.2.3.7 Patterns of pricing impacts on mobility

Various studies have been conducted world-wide in order to analyse the impacts of price changes on transport activity. The effects of price changes have been seen on trip generation, mode choice, destination choice, route selection, vehicle choice and parking location. Price changes of one mode can also have an impact on the demand of other modes. Litman describes this phenomenon as ‘cross-elasticities’. Price changes have a wide variety of impacts, but Litman was able to collect some of the patterns which are described below (Litman 2013):

- Higher value travel, such as business and commute travel, and lower value travel have different sensitivities to price changes. Higher value travel tends to be less sensitive to price changes than lower value travel.
- Consumers are more responsive to price changes that are considered durable by them than to temporary ones. Therefore, they tend to be more sensitive to increases in fuel tax than to oil market fluctuation.
- Price change sensitivity also differs among wealthy and lower income people. Wealthy people are less sensitive to pricing and more sensitive to service quality than lower-income people.
- Prices also affect the consumption as a proportion of household budgets.
- Pricing impacts are also correlated to time. They tend to increase over time. Litman (2013) states that the short-run (first year) effects are generally only a third as severe as the long-run (over five years) effects.
- Price sensitivity of travel tends to increase with the availability of better options, such as different routes, modes and destinations.
- Travelers are especially sensitive to frequent and visible costs, such as road tolls, parking fees and public transit fares.
- The manner in which the prices are structured, promoted and collected also have an effect on their impacts.

These patterns give a thorough idea about the impacts of price changes on transport activity. The analysis (see Part II: Büttner et al. 2016, Büttner 2016) will be built on some of these ideas presented in this section.

Concluding the literature review, it will be examined in the next chapter whether the concepts of vulnerability and resilience provide a suitable framework for tackling the issue of increasing mobility costs.

2.3 Vulnerability and resilience: catchphrase or a suitable concept?

2.3.1 Defining vulnerability

As stated by Turner et al. (2003), the common use of the word 'vulnerability' refers to the capacity to be suffering, i.e., *"the degree to which a system is likely to experience harm due to exposure to a hazard"*. Vulnerability describes a status, which is characterized by liability, insecurity, and defencelessness. When different population segments run into difficulties in coping with a crisis, shocks, or stresses in various aspects of their lives, they become vulnerable (Schneider 2015).

"Vulnerability is most often conceptualized as being constituted by components that include exposure and sensitivity to perturbations or external stresses, and the capacity to adapt." (Adger 2006, p. 270)

In 1982, research into vulnerability as a socioeconomic concept was conducted and eventually introduced into the economic and social science fields by Amartya Sen, a Nobel laureate in economics. While studying different hunger catastrophes, Sen found that hunger is not just the consequence of natural hazards (e.g. flooding, droughts, etc.), and that crop shortages can also lead to hunger catastrophes. Without protective measures against food shortage or political will directed towards food sustainability and protection, vulnerability begins to exist in the greater social security system (Sen 1999).

Many factors are changing over time. In the ecological tradition of vulnerability research 'sensitivity' denotes the degree to which a system is instantly affected by a perturbation whereas 'resilience' focusses on the ability of the system to maintain its basic functions and return to the original state after a perturbation (Füssel 2007).

The glossary of the Resilience Alliance (2006) defines vulnerability as follows:

“The propensity of social and ecological systems to suffer harm from exposure to external stresses and shocks. It involves exposure to events and stresses, sensitivity to such exposures (which may result in adverse effects and consequences), and resilience owing to adaptive capacity measures to anticipate and reduce future harm. Resilience and vulnerability are often considered opposites. Coping capacity is important, at all stages, to alter these major dimensions.” (Resilience Alliance 2006)

Füssel (2007) states that a clear description of the vulnerable situation is an important first step for avoiding misunderstandings around vulnerability. The term ‘vulnerability’ is used inconsistently by various scholarly communities which is a frequent cause for misunderstanding in interdisciplinary research and becomes a challenge for any attempt to develop formal models of vulnerability, including both static (Luers et al. 2003; Luers 2005; Metzger et al. 2005) and dynamic models (Ionescu et al. 2005).

2.3.2 Vulnerability as a conceptual framework for transport?

> *"Various initiatives identify the need for robust vulnerability analysis and, increasingly, sustainability and global change science is asked to improve the science problem and decision-making needs."* (B. L. Turner et al. 2003, p. 8078)

According to O’Brien et al. (2004a) and Gow (2005), ‘vulnerability’ has first been mentioned in geography and natural hazards research studies but is nowadays a key concept in many different fields of research. While natural scientists and engineers tend to apply the vulnerability in a descriptive manner, social scientists use it more often in specific explanatory model setting (Füssel 2007).

When speaking about vulnerability in terms of transportation, the term accessibility (see chapter 2.1) cannot be overlooked. In dealing with transportation networks, the term accessibility is often used synonymously with the effectiveness and efficiency of a specific route. While conducting a literary review, Reggiani et al. (2015) discovered that the majority of transport related vulnerability studies focus on road infrastructure, *“since after disaster events, the road network seems to be more important than other transportation modes (such as rail)”* (Reggiani et al 2015, p. 7). However, so far few authors have written about vulnerability and resilience with regard to transportation.

Many further papers define vulnerability by describing the use of road networks and their accessibility for usage. Berdica (2002) explains that the vulnerability of transportation networks is not defined by the safety of a road, but by its accessibility. She argues that the more accessible a road network is, the higher the effectiveness of the overall transport system, since more individuals are able to use the system. This in turn reduces the vulnerability of the network. Berdica (2002) then further defines the accessibility of a road network using the supply and demand of the road and links accessibility to the "serviceability" of the road and how this impacts the quality of transport. She then links the serviceability to vulnerability, measured in terms of traffic disturbances on the route, and explains that using the term 'vulnerability' when talking about transport should be saved for extremely rare events that cause severe strain on the transport system. She borrows this definition of transport vulnerability from Laurentius (1994), who defines vulnerability as *"…a susceptibility for rare, though big, risks, while the victims can hardly change the course of events and contribute little or nothing to recovery"* (Laurentius 1994, p. 278).

Bell et al. (2008) wrote about vulnerability in transport with regards to larger events that have extreme impacts on public transport services, and how society can use public transport systems to reduce the impact of such extreme events. They discussed issues regarding the vulnerable points of a network and how these weak points impact extreme situations. The term vulnerability is used as a synonym for weakness in the public transport system. Again, the use of accessibility was highlighted when Bell et al. (2008) discussed vulnerability in transportation. They speak to the solutions in improving weak points in public transport networks such that when/if an extreme event occurs in an urban centre there is greater safety and accessibility and flow on these routes.

Cats and Jenelius (2014) discuss the lack of research surrounding the vulnerability of public transportation networks, as most research has focused on infrastructure degradation and private vehicle usage in networks. They claim that *"both theoretical analysis and numerical applications have increased the understanding of how supply and demand together determine vulnerability, through the redundancy of the network and the travel patterns of the users"* (Cats and Jenelius 2014), but even less is known about the public transport. They claim that public transport is more dynamic in terms of vulnerability as *"[it] considers disruptions that imply a substantial reduction in the capacity of system components and hence their incapability to fulfil the purpose of the system… [they] need not be caused by degradations of the underlying physical infrastructure, but can also arise from degradations of the services, for example crew strike or limited infrastructure capacity (stops or tracks)."* (Cats and Jenelius, 2014).

As complex as the definition of vulnerability is in the social sciences, applying it to the transport planning and traffic engineering field is equally difficult. Depending on what aspect of subject is being referring to, vulnerability can have many different meanings. Vulnerability is only one way of looking at an issue; as mentioned previously, resilience can also be used to describe various development and social scenarios.

According to many, resilience does not imply avoiding shock scenarios (external changes), but rather having ways to effectively cope with the crisis (internal ability) (Schneider 2015). However, many authors have refuted that vulnerability and resilience are true opposites, insisting that they refer to separate situations. Therefore, to simply say they are opposites is an oversimplification. The concept of resilience will be examined next, followed by further explanation of the connection between vulnerability and resilience.

2.3.3 Defining resilience

According to Rose (2009), the word resilience is based on the Latin word ‘resilio’ which roughly translates to ‘bouncing back’. Resilience is the ability for someone or something to adapt to abrupt or difficult changes in their surroundings and then cope with these changes on a continuous basis (Rose 2009).

Defining the term resilience is not an easy task; similar to the term vulnerability, different disciplines utilize this word according to their needs.

“Social resilience has economic, spatial and social dimensions and hence its observation and appraisal require interdisciplinary understanding and analysis at various scales.” (Adger 2000, p. 349)

For instance, engineers understand resilience as the ability of a man-made feature to return to its initial form after an external natural encounter. In the field of emergency protection resilience is used to describe the speed which is needed to recover substantial systems after hazards; Ecologists use resilience to refer to preventing the irreversible destruction of ecosystems; In psychology, resilience stands for the human ability to recover from a trauma; Economists understand resilience as the installation of back-up systems, which ensure a system running fluidly without interruptions from natural hazards or human caused crises (Zolli and Healy 2013).

Resilience describes the essential ability of an existing system to adapt to environmental conditions and thereby maintain its existence. However, resilience as the ability to adapt is not just restricted to natural hazards, but also coping with societal changes (e.g. migration) and economic challenges (e.g. financial crisis). Regional resilience is describing the resistivity and adaptability of cities and regions in the face of sudden shocks or emerging crises (Hahne 2014).

Social researchers are using the resilience concept to define the strength of communities in the face of adversity (Seeliger and Turok 2013). According to Adger (2000), social resilience from an engineering point of view is the ability of groups to deal with external pressures without affecting their stability and cohesion.

2.3.4 Resilience: a path to improved sustainability or just vague expression?

While vulnerability may refer to the exposure to risk and susceptibility to shock in a system (Berdica 2002), resilience refers to the speed at which a system is able to overcome strife or shock or how well a system is able to absorb such strain (Gibson et al. 2000). Rose claims that *"vulnerability is predominately pre-disaster condition, but that resilience is the outcome of a post-disaster response"* (Rose 2009, p. 3).

Resilience can also be described as a fundamental condition for sustainable development. While resilience analyses can be used as a tool for encouraging innovation within communities, it has to fulfil some requirements, as is described in the following quote:

"For resilience analyses to identify and support process of social innovation within communities, they are likely to need to understand the vulnerabilities and social dynamics that exist in these places." (Seeliger and Turok 2013, p. 2124).

This means that at first, resilience-oriented urban planning should try to capture system dynamics. Based on rational comprehensible analysis, frameworks and aims, a steady and resilient strategy is built upon. Therefore, transparent planning steps are necessary which take into account the complexity of planning that is prepared to deal with uncertainties (Schmidt and Walloth 2012). In line with the importance of system dynamics, lessons from cybernetic research in the 1970s (see Vester 1976) seem to be forgotten in current planning processes.

"Certainly resilience is related to stability, but it is not clear weather this characteristic is always desirable, for example, in evolutionary terms." (Adger 2000, p. 349)

Within the discourse of sustainability the goal is to maintain and stabilize the status quo; contrary to this, the concept of resilience takes into account visions, unexpected events, shrinking, collapses and shock scenarios. The key is to envision and measure possible risks and try to avoid them beforehand. However, crises can happen overnight, and we have to ask ourselves how to survive with relatively little damage. The major advantage of the resilience concept is the explicit focus on danger and fear of loss which each and every stakeholder can relate to (Kaltenbrunner 2013).

„(…) a new „language of preparedness“ has emerged, and resilience has become a key term in this new language. It labels the ability of a threatened unit to survive anticipated damages. Resilience can either be achieved through the abilities of systems to be as robust as possible when external shocks occur, i.e. to be damaged as little as possible or to reach the original state again soon, or to change their internal structures through their flexibility and to cultivate a constant condition of adaptability.” (Kaltenbrunner 2013, p. 289)

Keeping this in mind, the question that planners have to face is whether to make our regions more resilient by making slight changes trying to solve the latest issues here and there or to instead use shock scenarios for fundamentally changing the regional spatial design (e.g., adapting land-use and transport systems in the non-resilient, vulnerable regions; see Part II: Büttner et al. 2016, Büttner 2016).

Östh et al. (2015, p.149) stated that *“job accessibility can be seen as a means for alleviating differences in resilience between smaller and adjacent spatial units”*. They also argue that “the improvement of accessibility is fundamental for the development of resilient economic networks” and claim that economic resilience and spatial economics are not given very much attention (Östh el at. 2015). They debate this as they see the interconnectivity of regions and their dependency on one another*. “A dichotomous, spatial delineation of economy has little resemblance to how economic activities are arranged spatially because it generalizes interaction within the region and disregards interaction with other regions”* (Östh et al. 2015, p. 149).

Östh et al. (2015) compared socio-economic resilience to accessibility (which they claim “*embeds both economic interaction and connectivity factors*”. In doing so they prove that socio-economic resilience is related to that of accessibility in a non-linear manner. Dealing with the same idea of economic systems, Östh et al. (2015) looked at the interaction factors between accessibility and socio-economic resilience by proving that a region may only be resilient if we take into consideration the effects of flows (economic, cultural, etc.) between regions.

According to Seeliger and Turok (2013) the resilience concept is a suitable approach in developing sustainable cities. Due to the "multiple interpretations of resilience which provide diverse insights into the broad attributes required to prepare a city for short and long term change". They suggest strengthening the resilience concept in respect to the social and technological innovations by taking into account the insights of the vulnerability and transition theory (Seeliger and Turok, 2013).

"My view is that vulnerability is primarily a pre-disaster condition, but that resilience is the outcome of a post-disaster response. Resilience is one of the several ways to reduce vulnerability, the others being adaption and the entirely separate strategy of mitigation" (Rose, 2009, p. 3).

Although the two terms are connected, it is important to note the relationship between vulnerability and resilience, where vulnerability deals more with the susceptibility of a system to danger, and the other primarily defines how successfully a system can recover.

In line with this quote by Rose (2009) the vulnerability assessment has been developed as a methodological approach. Therefore, this thesis intends to focus primarily on the vulnerability aspects of regional development, while resilience is seen as one out of three key factors concerning the ability to cope or absorb a shock scenario and therefore, also contributes to reducing the regional vulnerability (see chapter 3.1 and Part II: Büttner et al. 2013).

4. Methodology

“The future of land-use transport modelling will largely depend on whether emerging new models will live up to these challenges.” (Wegener 2004, p. 10)

The methodoloy used in order to answer the main research questions, such as whether regions will reveal their vulnerability in the face of sharp fuel price increase; or what options the households have in order to cope with such scenarios; and how to make decision makers aware of the risks of increasing mobility costs, is described in this section. The methodology is based on and makes frequent references to the state-of-the-art literature mentioned in Chapter 2.

Due to the complexities of modelling individual mobility behaviour, a set of diverse aims and approaches have been applied that focus on increases in mobility costs and their effects on accessibility of different user groups/stakeholders. To analyse and address the consequences that mobility cost increases have on accessibility, the three-step Scan-Explore-Prepare methodology was developed (see Figure 13).

1. Scan – A vulnerability assessment aims to scan and subsequently highlight which regions in Munich are most affected by increasing mobility costs (see Part II: Büttner et al. 2013).

2. Explore – An exploration of individual households is undertaken to develop a range of different storylines that portray potential real-life reactions to mobility cost shocks (see Part II: Büttner et al. 2016).

3. Prepare – Public authorities and decision makers are given sustainable accessibility recommendations in order for them to be better prepared in regards to land-use and transport planning measures (see Part II: Büttner 2016).

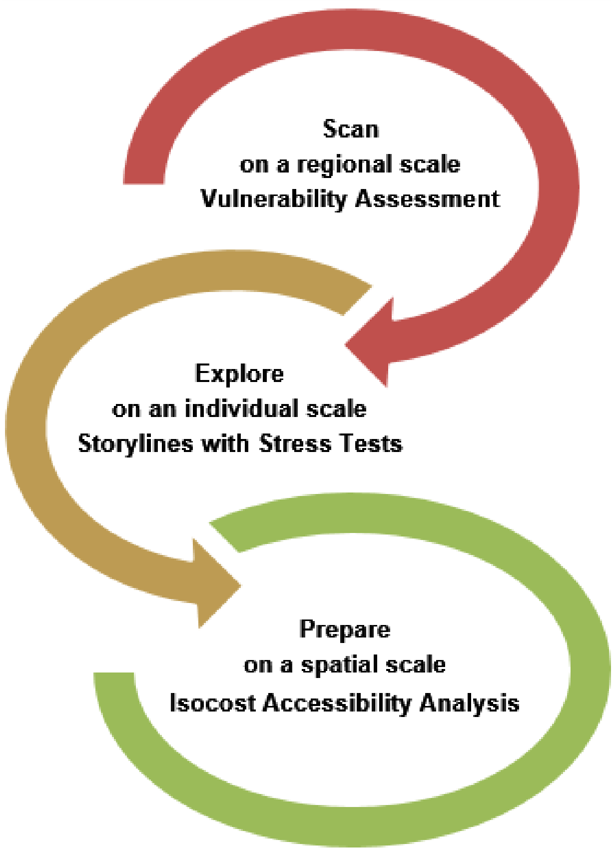

Figure 13: Scan-Explore-Prepare methodological approach

Throughout the Scan-Explore-Prepare steps, three municipalities are closely examined as case studies, with each representing a different type of settlement structure in the Munich region: the city of Fürstenfeldbruck, the suburban municipality of Haar near Munich, and the rural village of Kirchdorf an der Amper.

The following three subchapters highlight the respective methodology of each step of this approach.

4.1 Scan on a regional scale using a vulnerability assessment

“The challenge for vulnerability assessments is to find explanations […] that are […] robust and applicable to a wider set of contexts. This can be facilitated by working at regional scales.” (Leary and Beresfort 2007, p. 118)

For the first step, the exposure, sensitivity and resilience of the Munich study region was analysed using a fuel price vulnerability assessment (see Part II: Büttner et al. 2013) to highlight the municipalities in the Munich region that are at risk with respect to increasing mobility costs. This vulnerability concept was originally developed and applied to analyse susceptibility to, for example, famine and food security, hazards, and climate change (see chapter 2.3, Adger 2006). However, in this research it is adapted to search for regional vulnerability to drastic increases in mobility costs.

"Vulnerability is most often conceptualized as being constituted by components that include exposure and sensitivity to perturbations or external stresses, and the capacity to adapt." (Adger 2006, p. 270)

In order to adapt the vulnerability assessment to the issue of increasing fuel prices, appropriate indicators must be collected and specified. Based on Kasperson et al. (2006), the three vulnerability indicators of exposure, sensitivity and resilience are used in this work. Adapted to the municipal level, these indicators can be described as follows:

- Who will be most **exposed** to an increase in fuel prices?
  Those that have a high **fossil fuel consumption**.
  Measure of exposure: average vehicle kilometres travelled per capita by the residents of each municipality

- Which municipalities will be **sensitive** to rising fuel prices?
  Those that have a relatively **low income**.
  Measure of sensitivity: net income average of the municipality’s employed residents

- Which locations will be **resilient** in the face of increasing fuel prices?
  Those that have **alternatives to the private car**.
  Measure of resilience: accessibility to jobs by public transport

- Who will be **vulnerable** to an increase in fuel prices?
  Those who are **highly exposed** and **highly sensitive** with a **low resilience**.
  Therefore, the vulnerability index was calculated as the sum of the listed indicators

In general, transferring this methodology to other regions or even new research questions is possible. However, in the case of comparing and benchmarking different study regions, the framework and indicators must be adapted to conform to the available data and the measurements chosen for the indicators. An additional consideration is that the current index only demonstrates a municipality's vulnerability relative to others. To ensure a certain level of comparability, identical, or at least similar, data needs to be chosen[2]. It is also possible to combine indicators and weight them according to their perceived importance.

"The concept of vulnerability has been a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems, and for guiding normative analysis of actions to enhance well-being through reduction of risks." (Adger 2006, p. 268)

In this case, the context is an increase in fuel prices and the subsequent effects are analysed on the regional scale of municipalities. The scientific approach is based on the vulnerability and resilience research which was presented in the previous chapter 2.3.

For the vulnerability assessment, choosing appropriate indicators of vulnerability is crucial and these must be collected and specified when adapting the vulnerability assessment to the issue of increasing fuel prices. A range of indicators can be used to measure levels of vulnerability on a municipal scale. The regional vulnerability assessment using the indicators of exposure, sensitivity, and resilience can be found in "The impact of sharp increases in mobility costs analysed by means of the vulnerability assessment" (see Part II: Büttner et al. 2013).

Adequate study regions were selected with the help of a large number of databases and surveys. The chosen municipalities cover different settlement structures like rural, suburban and urban contexts. The TUM Accessibility Atlas combined with the vulnerability assessment, revealed regions in need of further investigation. The key indicators and the data used within the vulnerability assessment allowed representative study municipalities to be chosen, each reflecting a different settlement structure (see Part II: Büttner et al. 2013).

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[2] Within the French-German research project „Stress Tests for a sustainable mobility" the same data and indicators had to be collected for the regions of Lyon and Munich to ensure a comparability and transferability later on (see Mercier et al. 2013).

4.2 Explore on an individual scale using storylines with stress tests

"If we want to look at oil vulnerability aren't households the fundamental element that are *affected? There are also agglomeration effects due to oil vulnerability in the suburbs and on other scales but it seems clear that researchers talk about households being affected while continuing to hold analyses on the regional scale." (Fishman 2006, p. 18)*

After having determined the characteristics of the Munich region, an exploration of individual households was undertaken (see Part II: Büttner et al. 2016). The premise is that analysing a household's mobility behaviour helps to develop a range of different storylines that portray real-life reactions to mobility price shocks (see Büttner, Wulfhorst (2012) for additional storylines).

4.2.1 Household generation and behavior

For the analysis of social impacts (e.g. on the level of households), Geurs and Ritsema van Eck (2001) determined that activity based accessibility measures, which take into account the four components of accessibility (i.e. transport, land-use, temporal and individual), are the most effective (see chapter 2.1.1).

As mentioned in chapter 2.1.1 Kutter (1972) classified social attributes like the level of income, age, gender of car availability into "behaviourally homogenous groups"; the idea is that these attributes can predict activities of these groups. Additionally, the spatial structure (land-use) determines where activities and amenities are located and where further opportunities such as shopping or leisure are found. Consequently, the land-use, activities and attributes shape the travel pattern (Kutter 1972).

Synthetic households and each of their respective mobility behaviours were derived by analysing a range of regional databases. Spatial patterns of movement and their corresponding causes were determined based on the relocation analysis within the Munich Region (Wanderungsmotivuntersuchung II, Landeshauptstadt München 2012). The study "Mobility in Germany – for Munich region" (Mobilität in Deutschland (MiDMUC), Landeshauptstadt München 2010) yielded socio-demographic characteristics of the population, as well as spatial trip patterns and their corresponding modes of transport. The Bavarian State Office for Statistics and Data Processing provided population data on the municipality level. The GIS-based “TUM Accessibility Atlas” (Büttner et al. 2011), assisted with the initial estimation of the community structures, was subsequently used for the data collection and storage of the respective households. Housing and activity locations were primarily determined from the activity programs detailed in the Munich databases (MiDMUC 2010, WMU 2012), with the origins and destinations being spatially referenced.

Before applying the shock scenarios (stress-tests) the composition of the fictional households, their budget, activities and mobility behaviour were discussed and approved by actors from the respective case studies.

4.2.2 Application of price shocks

To calculate the current mobility costs and travel times for the synthetic households (based on the individual trip-chains and spatially referenced activities), the Munich Transport and Tariff Association (MVV) WoMo (Living and Mobility) calculator was used (see Haller et al. 2012). Using the current address data of the corresponding origin and destination relationships for the calculated activities (work and education, supply, leisure), the “TUM Accessibility Atlas” was used once again for the visualization of the individual mobility behaviours and spatial trip patterns. The residential costs were also considered in cases of relocation. In addition, CO_2 emissions and travel times were calculated for all trips.

Having prepared the data, stress-tests were established to match studies predicting a rise in the crude oil price to US$200 per barrel (e.g. ifmo 2010). Stress tests have been widely used in the financial sector but are rather uncommon in the urban planning context. However, stress is a handy summary of severe perturbations like natural hazards, refugee immigration, economic crisis, social freedom, maintenance of infrastructure or rapid exhaustion of fossil energy reserves (Sieverts 2013).

Stress-test n°1 aims to demonstrate the effects of such an increase, which would effectively cause the price of fuel at German petrol stations to rise to 2.11 €/L – a moderate shock (35% increase). Going beyond the scenario of crude oil prices reaching US$200 per barrel, stress-test n°2 details the effects of tripling of the fuel prices. This increase would force households into spending 4.65 €/L for fuel in Germany. In line with a simplified economic approach, the research did not focus on the economic theory and variables related to gradual oil price increases, but instead, on how households would react to sudden drastic oil price hikes.

For these stress tests, the following assumptions were made:

- Gas prices will rise in leaps that cannot be planned for by households and will have an immediate effect on the price consumers pay at the gas stations;

- Shock alternatives depended only on households. Public authorities could not respond to these shocks;
- No public measures such as tax decreases, fuel subsidies or fuel vouchers could be implemented to absorb, even partially, the shocks;
- Proposed shocks only referred to daily mobility; long distance travel was not impacted by these shocks as it was considered to be outside the scope of a household’s everyday needs.
- Public transport costs would rise more moderately and therefore allow people more time to adapt, since public transportation costs are based less on market forces and more on political forces. Additionally, infrastructure, fleet, maintenance, subsidies other costs that are factored into public transport prices mean that prices will increase in a smaller proportion than the rise in fuel prices. After numerous discussions with public transport officials it was assumed that the share of energy costs is 20% of public transport price, which subsequently is affected by the stress-tests and has been raised accordingly for the stress-tests.
- General effects on the local economy due to these shock scenarios, such closing down of local businesses, loss of jobs, over burdening or PT systems, etc. have been neglected.

By applying these stress-tests, the Explore step aims to dive deeper into the initial vulnerability assessment by exploring how changes in mobility constraints can impact daily activity schedules, mobility behaviour, and residential and activity locations.

4.3 Prepare on a spatial scale using an iso-cost accessibility analysis

> *„(…) the spatial resolution of present models is still too coarse to model neighbourhood scale policies and effects.”* (Wegener 2004, p. 9)

During the simulation of everyday mobility needs (see Part II: Büttner et al. 2016), it became evident that in most cases, vulnerable households are only able to adapt their mobility behaviour once they are offered more viable transport options or alternatives to reach amenities. Therefore, aiding governments in recognizing the interdependencies between land-use and transport can help vulnerable communities prepare for, as well as adapt to, increases in mobility costs (see chapter 2.3).

In order to foster sustainable spatial development, policies, intervention strategies, and recommendations should also be discussed (Hull et al. 2012). This is reinforced by Geurs et al. (2012) who state the importance of testing the current accessibility analysis in practice. Crozet et al. (2012) distinguishes between the two main accessibility measurements, namely isochronal-based and potential measures. Isochrones give information about the number of activities accessible within a defined distance, time, emission or monetary budget. On the one hand, these service areas are easy to read and communicate. On the other hand, these catchments do not allow for continuous measurement of opportunities outside the defined threshold, while the potential-based accessibility analysis is not limited to this “inside or outside” perspective. The gravity based accessibility analysis takes into account opportunities based on the resistance function, which can weigh the importance of the opportunities (Crozet et al. 2012). However, the gravity based accessibility indicators can be difficult to understand for actors which are not directly involved in that field (Büttner et al. 2014). Therefore, for the implementation of accessibility planning, a strong cooperation between researchers and planning practitioners is needed. That is why practitioners and local actors from the study municipalities have been involved in workshops throughout this research step.

In line with the Scan and Explore steps, the Prepare step places a special focus on three municipalities: the city of Fürstenfeldbruck, the rural town of Kirchdorf an der Amper and the suburban community of Haar near Munich. A detailed presentation of the municipalities was purposely omitted from this study as it would overlap with the analyses of the previous study "MOR€CO: Investigation of future living and mobility costs for households in the Munich region" (Büttner and Wulfhorst 2012).

With the help of the TUM Accessibility Atlas, different catchment areas and their respective potentials were calculated (see Büttner et al. 2011). These potentials were based on a detailed statistical datasets of the case-study locations and their surroundings, summarized by the categories of population, jobs, education, services, shopping, leisure and health.

In addition, the activities of the Open Street Map (OSM) dataset was incorporated for the entire Munich region and then further extended. This created an extensive dataset suitable to then perform an in-depth analysis of the three study areas with the help of georeferenced activities (e.g., supermarkets, chemists, restaurants, etc.).

Following this, the accessibility of the investigated areas was calculated for the private car, public transport and non-motorized transport network. Using the TUM Accessibility Atlas, the mobility costs were implemented for both private motorized transport[3] and public transport. The monetary catchment areas were calculated using Network Analyst in ArcGIS 10.0.

In 2010, private transport expenditure, according to the German national average, amounted to 305 €; this value corresponds to 14% of all private consumption expenditures (Federal Statistical Office 2013). In the districts around Munich almost one third of this 305 € expenditure is allocated to work and training purposes (commuting).

For commuting trips, an average commuting distance and five day workweek was used, which yields a commuting budget of €5 daily, €25 weekly and €100 monthly for the journeys that are related to work and training purposes. This budget corresponds to the commuter traffic share. For all other trips, a single one-way journey was assigned a budget of 2.50 € per trip.

By applying various stress-tests, the Prepare step aims to show how the potential to reach numerous activity locations will shrink with increasing fuel prices. The goal is that the decision-makers see the urgency to prepare their regions in terms of sustainable land-use and transport planning in such a way that they are resilient to unpredictable sharp increases in mobility costs. As a result of this, the neighbourhood scale was examined in detail by means of calculating the non-motorized accessibility to daily activities for each study municipality. By doing this, Wegener's concern has been addressed, where he states that the resolution of the current models is too coarse to model effects on the neighbourhood scale (Wegener 2004), as mentioned at the beginning of this sub-section.

[3] For the private motorized transport the Handbook Emission Factors for Road Transport (HBEFA) has been used to estimate the fuel consumption for rural and urban regions taking into account stop and go conditions. Based on this the fuel costs for the street network have been calculated (see Büttner et al. 2014a).

5. Synthesis of the research steps

"Shouldn't we, for example, think about the fuel prices being higher instead of lower by trend? After all, the price is the strongest tool that makes people change their behaviour."

Former German Federal President Horst Köhler, Focus Interview, March 2010

4.1 Summary of key findings

In the following chapter, summary of the three papers from Part II, various topics regarding the impacts of sharp increases of mobility costs on accessibility are discussed. Firstly, “Scan” looks at the impact of sharp increases in mobility costs analysed by means of a vulnerability assessment in the regions of Munich and Lyon (see Part II: Büttner et al. 2013). Secondly, “Explore”, explores how to maintain accessibility to daily activities for different population segments with respect to sharp increases in mobility costs in Munich (see Part II: Büttner et al. 2016). And lastly, “Prepare”, discusses the sharp increases in mobility costs as a trigger for sustainable mobility in the metropolitan region of Munich (see Part II: Büttner 2016).

Chapter 4.2 concludes with strategies and recommendations, which have been derived from the Scan-Explore-Prepare methodology.

4.1.1 Scan: The impact of sharp increases in mobility costs analysed by means of the vulnerability assessment

Do certain regions reveal their vulnerability to the risks of increasing fuel prices?

Peak oil and the scarcity of fossil fuels are topics that affect communities worldwide. However, it especially impacts the transportation industry and areas related to it (eg. economics, community development, etc.). This paper (Part II: Büttner et al. 2013) is based on a research project (see Mercier et al. 2013) funded by the French PREDIT program that aimed at assessing the regional vulnerability in both Munich, Germany and Lyon, France, in case of sharp increases in fuel costs. The methodological approach is based on the concept of Adger (2006) and Kasperson et al. (2006), who used a multi-dimensional approach in their research. This concept divides vulnerability into three dimensions, namely: exposure, sensitivity and resilience, which formed the basis for the paper, and discussed the process of collecting and specifying appropriate vulnerability indicators. Since the paper intended to use similar techniques for gathering data in each city, comparable data needed to be collected for both regions for the same time frame (see Part II: Büttner et al. 2013).

The exposure indicator used vehicle-kilometres travelled (VKT) for Munich and daily vehicle distance per resident for Lyon as the measure directly related to fuel consumption. For both regions, unemployment rate and monthly income were used as sensitivity indicators and the accessibility to jobs by public transportation was used to measure the level of resilience. The final composite vulnerability index, based on the three indicators, revealed the level of vulnerability of each municipality.

Overall, the key findings emphasize the importance of scanning to highlight the regions which are in danger of increasing mobility costs. If mobility costs rise, the vulnerable municipalities will be revealed by the assessment. In the case examples of Munich and Lyon, it was found that those who drive the most and earn the least are the most vulnerable. However, the more access one has to public transportation, the more resilient they will be when faced with shock scenarios. The findings of this paper reveal that the **most vulnerable areas were located in between railway axes, along the urban periphery, and in areas that lack public transport lines**. In contrast, zones located in the city-centre have very low vulnerability due to their proximity to amenities and their good public transport supply as seen in Figure 14.[4]

[4] 'Maps throughout this chapter were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright © Esri. All rights reserved. For more information about Esri® software, please visit www.esri.com.

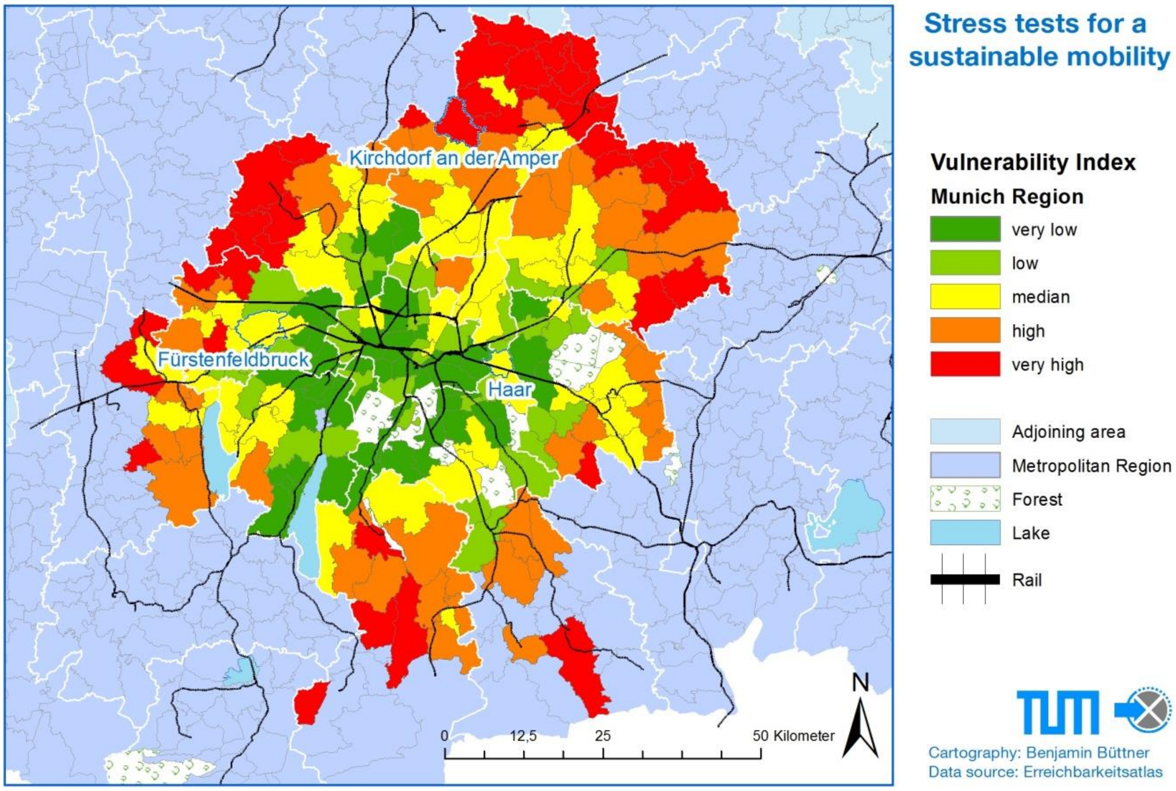

Figure 14: Vulnerability assessment concerning fuel price increases in the Munich region (Büttner et al. 2013)

This proves that there is a need to allocate mobility alternatives, facilities and activities to the more vulnerable municipalities.

One example could be the introduction of electric car sharing services along with P+R facilities at the nearest public transport station. This would ensure better utilization of vehicles as well as encourage the residents to use public transport, while at the same time facilitating their accessibility to the public transport.

Second potential solution could be introduction of shuttle services to and from these areas to the central areas. But this solution depends on the demand for such services. They would only be feasible if there is a constant and substantial demand for such a service.

Additionally, the introduction of electric bike sharing services which can be used for daily commute has great potential. The following chapter 4.2 is focussing of actual alternatives, strategies and measures.

Following this assessment, three municipalities representing different settlement structures (urban, sub-urban and rural) were selected to understand and characterize localized differences in vulnerability in greater detail (see Part II: Büttner et al. 2013).

The paper describes an analysis that can be applied to cities around the world, using a combination of indicators (fossil fuel consumption, income, and accessibility to public transport) from the available data. This research highlights the potential of shock scenarios to occur as oil prices become less predictable. Any municipality can apply this process in order to identify and focus their efforts on the most vulnerable areas, specifically regarding where and how they should focus their policies in order to mitigate the impact of shock scenarios.

4.1.2 Explore: Ensuring accessibility to daily activities for different population segments with respect to sharp increases in mobility costs

Are the options that the households have to cope with increasing mobility costs dependent on social status and location?

After analysing the “Scan” paper (see Part II: Büttner et al. 2013), which looked at regions from a broad perspective, the aim of this “Explore” paper (see Part II: Büttner et al. 2016) was to dig deeper into the individual accessibility issues of households in particular regions to determine whether certain areas of the Munich region have sufficient accessibility to their daily activities. After identifying the different levels of fuel vulnerability for municipalities within the Munich region, the consequences of sharp increases in mobility costs were explored for individual (fictional) households, using storylines to better analyse household behaviour. The paper then indicates the affected neighbourhoods and attempts to implement shock scenarios to gain understanding of the impacts of these shock scenarios on the region’s mobility costs. This step chooses the same three municipalities, representing different settlement structures, and applies two different shock scenarios to mobility costs.

As the results indicate, the first stress test assumed a rise in crude oil price to US$200 per barrel which would cause the price of fuel at a typical German petrol station to increase to €2.11/L (+ 36.12% compared to the base price of €1.55/L). The second scenario predicted a fuel price increase to €4.65/L, which triples the price compared to the base. It was found that the first scenario has a limited effect of the household activities as well as short term mobility behaviours. However, a tripling of the fuel price resulted in serious limiting impacts for the households. In particular, Household 1 (a four-person household located on the outskirts of town, with limited flexibility to change mobility behaviour) would be required to allocate an extra €429per month for transport in order to maintain the same level of mobility – something many households with low income will find difficult to cope with. As an alternative to reduce costs, this household would have to spend an extra 50 hours per month travelling by public transport to offset the additional costs. This reinforces the idea that **changes in mobility costs can**

severely impact a household's mobility behaviour highly depending on their location and social status.

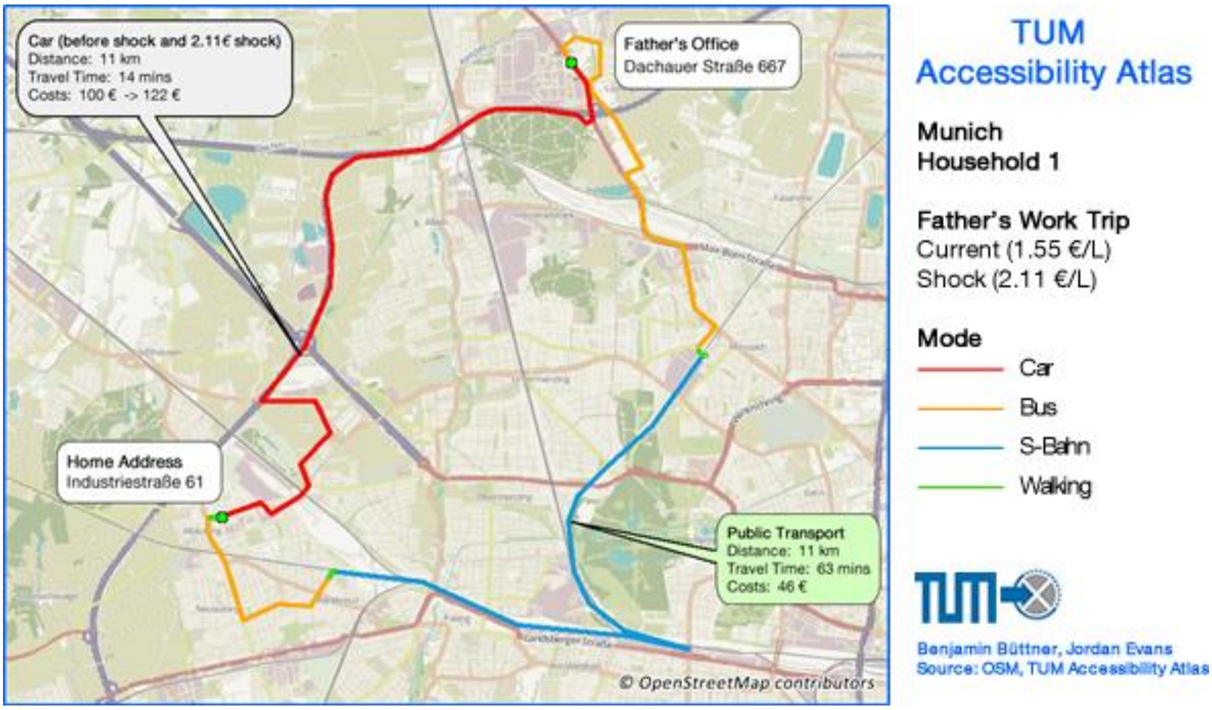

Figure 15: Assessing options for households while applying shock scenarios (Büttner et al. 2016)

Moreover, the second part of the paper attempts to emphasize that despite the outcomes of these shock scenarios, a household can implement a number of strategies to save money, such as, linking trip chains, choosing alternative transportation modes, carpooling and car sharing, and even teleworking a few times a week.

Overall, the scenario testing shows the level of resilience of different households, and especially reveals that vulnerable households can only alter their travel patterns if they are provided with more viable transport alternatives. It emphasizes that spatial planning plays a key role in transportation vulnerability. For example, when new greenfield developments rely on private cars as the sole transportation mode, this leaves many households in crisis should a shock scenario ever occur. The research helps to promote recommendations that people should live near the workplace and other activities, that planners should design accessible neighbourhoods (in terms of transportation and land uses) and emphasize on development in already built-up areas, promoting mixed-use, and that municipalities and workplaces should encourage e-mobility, especially in rural and peripheral areas. Recommendations to public stakeholders and decisions makers must be based on detailed regional level analyses, which take into account the future development of residential and mobility costs in order to foster more sustainable spatial development, policies and intervention strategies.

However, many of the measures mentioned are only achievable with higher-level funding from state or federal governments. Consequently, a supra-regional, cross-sectorial funding policy for the respective measures is needed.

The research continues to explore and evaluate the resilience of households by applying prospective shocks to mobility costs. With studies of the Munich region indicating that the mobility share of the household budget is increasing (Part II: Büttner et al. 2013, Büttner et al. 2016), it is increasingly important to try to understand how these price shocks influence household mobility. It also stresses the need for other municipalities to address similar issues.

4.1.3 Prepare: Sharp increases in mobility costs as a trigger for sustainable mobility in the metropolitan region of Munich

Does land-use and transport planning help to create more resilient communities, if decision-makers are aware of the risks of mobility cost increases?

This paper addresses the rising cost of mobility throughout the region of Munich. Compared to the “Explore” paper (see Part II: Büttner et al. 2016), this “Prepare” paper (see Part II: Büttner 2016) emphasizes the importance of policy development and the role of the municipal government. Due to the escalation in rent and land prices, residents are being pushed to the periphery of the city, creating longer commuting times, while the transportation system is hardly able to connect these areas to the rest of the region. Living on the periphery increases mobility costs and creates a noticeable rift between those that can afford to travel, and those that cannot. This unsustainable development process leads to highly vulnerable neighbourhoods and regions that will be particularly sensitive to changes in oil prices. These neighbourhoods will also experience sharp increases in mobility costs that effectively reduce residents’ net disposable income and, by extension, the living standard. With these sharp increases, it is appropriate to consider the vulnerability across all spatial scales within the metropolitan region of Munich. This process must recognize the multi-dimensional nature of vulnerability (see chapter 2.3) to enable better identification of problem areas and the creation of long-term sustainable planning solutions for these areas.

To summarize, this paper includes a comprehensive vulnerability assessment which assesses the exposure, sensitivity, and resilience of Munich at the regional level. It then goes on to give stress-test storylines to the level of individual households. This is done so that the reader can analyse how various changes in mobility constraints (even if they are relatively subtle) can impact daily life and schedules. With many studies on the Munich region indicating that the mobility share of the household budget is increasing (see Part II: Büttner et al. 2013, Büttner et al. 2016), understanding how these price shocks influence household mobility is becoming increasingly crucial.

One of the most important aspects of the paper is the focus on three municipalities and the iso-cost accessibility analysis on the spatial structure. Catchment areas for private cars as well as public transport were calculated for certain monetary budgets. These iso-cost accessibility analyses show how many different activities (e.g. number of workplaces, shopping destinations, and recreational activities) are accessible for those who have a certain monetary budget (see Figure 16).

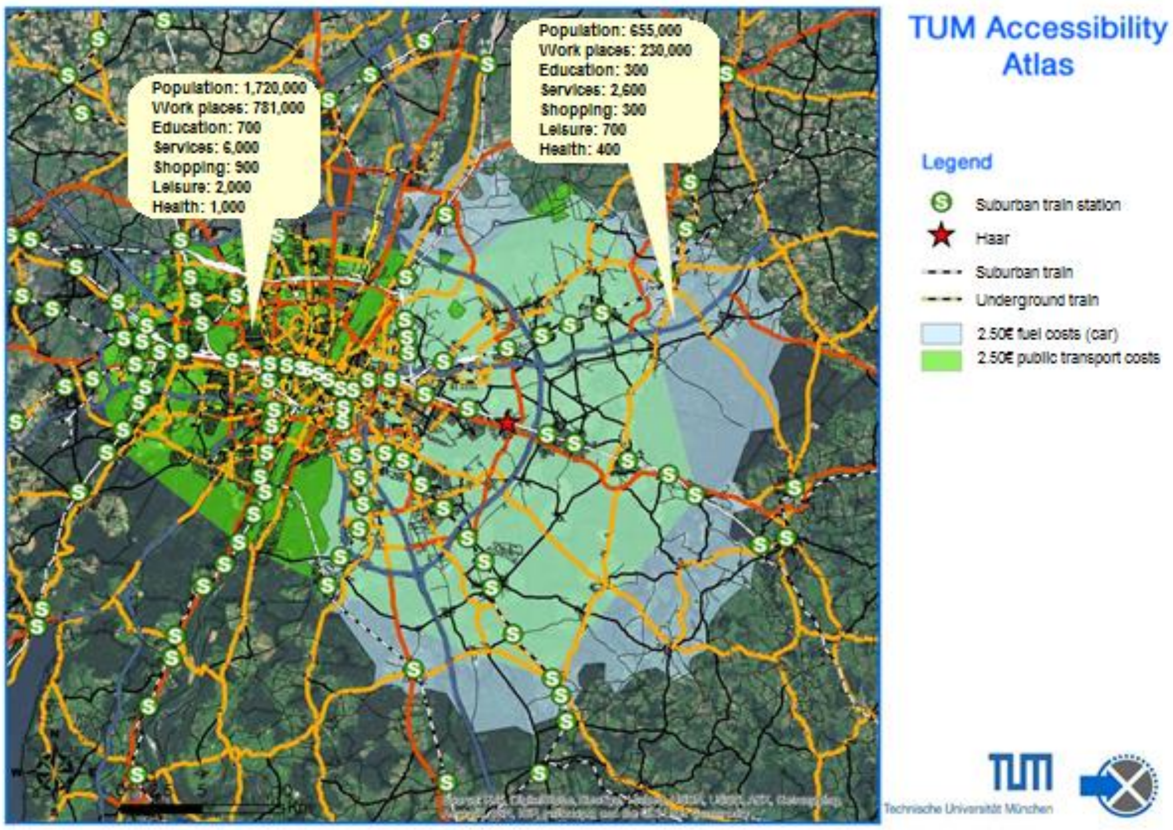

Figure 16: Iso-cost accessibility analysis for public transport and private car (Büttner 2016) [5]

The results indicate that it is important to promote local areas and support citizen engagement, self-supply, and mobile supply at the local level. The results also show that at the regional level, it is vital to have inter-municipal cooperation and balance management. This means that all levels of government have equal opportunity to give input on policy development and that the public interest is kept at the forefront of policy making decisions. Further, public transport expansion should be kept in line with the spatial development policies, as this helps to promote

[5] Sources: TUM Accessibility Atlas, Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

more accessible places, an economy based on sharing, and also e-mobility in poorly structured areas.

In this way, the paper highlights the **importance of developing strategies and policies in an integrated and cooperative way**. It also points out that **by making decision makers aware of the risks of increasing mobility costs, spatial planning tools can be used as a means to eliminate the vulnerability of communities.**

Emphasizing that approaches should target the increase in mobility costs directly, and that too in a sustainable way, such that as mobility costs increase, household will have options to cope with these increases with respect to their economic and social status. Many opportunities exist to increase the resilience of vulnerable municipalities and thereby preserve and enhance the quality of life for all citizens, regardless of their income and location.

Further, in order to foster such sustainable spatial development, policies, intervention strategies, and recommendations – which concern dense and mixed-use development patterns alongside the accessibility of jobs and daily activities – should be discussed in municipal settings (Hull et al. 2012). For the implementation of accessibility planning, a strong cooperation between researchers and planning practitioners is needed (Büttner 2016).

4.1.4 Overall Conclusions: Scan-Explore-Prepare

Taken as a whole, the three papers address the Scan-Explore-Prepare technique to look at accessibility in several municipalities, on individual household level as well as on the public strategic planning level. Each one addresses the issue of shock scenarios and municipal preparedness with increasing level of details. The overall emphasis of the papers is that further localized research in municipalities is required since vulnerable households are only able to change their mobility behaviour if and when they are offered more viable transport options or alternatives. If governmental bodies recognize the interdependencies between land-use and transport, they can help vulnerable communities better prepare for, and adapt to, increases in mobility costs. Recommendations to public stakeholders and decisions makers must be based on detailed accessibility analyses that take into account the development of future residential and mobility costs.

In order to give readers a better insight into the working of all these research studies, a chronological development of these works along with the motivation is discussed in the closing chapter 5, which also gives an insight into the various factors that led to the conception of this research project and reflects about the methodology used in order to gather data and conduct research. This paper concludes with an outlook on how academia can contribute in further improving the quality of decision making process when it comes to policy making in the face of shock scenarios.

After looking at the overall conclusions of the three papers, the next section thoroughly describes various strategies and measures that can be used for tackling rising mobility costs issues on different scales.

4.2 Individual and public strategies and measures for tackling rising mobility costs issues

The main objective of this work is to make authorities aware of the risks associated with sharply increasing mobility costs. This is done by analysing how different hypothetical scenarios would affect accessibility of different users to amenities in various regions.

By combining the findings obtained from these analyses with those from the workshop activities and strategies (see Büttner and Wulfhorst 2014a, Part II: Büttner 2016), the following recommendations can be formulated for households as well as public decision-makers and actors to respond to increasing mobility costs in the Munich region. Many of these recommendations can be transferred and implemented in other regions that wish to identify, understand, and improve vulnerable neighbourhoods, while taking into account their respective spatial and socio-demographic characteristics.

The household strategies are based on the stress-tests storyline calculation from the following reports and papers: Büttner and Wulfhorst (2012), Büttner et al. (2016), and Mercier et al. (2013). The strategies and policy-recommendations for public bodies are based on the papers and report: Büttner et al. (2014a), Büttner and Wulfhorst (2014), Büttner (2016).

4.2.1 Strategies concerning cost efficient mobility behaviour and sustainable location decisions on the household level

A number of different strategies can be employed by the households in order to become more resilient to mobility price shocks. These strategies can be categorized into short term and long term measures. Actions such as using carpooling or changing the mode of transport can be considered as short term measures, whereas decision to change the place of work or residence can be a long term measure. People usually only choose the latter option as a last resort when all other options have been exhausted. Some of these measures have been discussed briefly below:

Daily private vehicle commutes can be made more sustainable by sharing a ride with other people. Carpooling is an effective strategy to reduce the costs of commuting trips compared with driving alone, and it usually enables faster travel times than public transport.

Shifting to a different mode of transport, when available, can save money and reduce household's vulnerability to mobility cost shocks. Therefore, attractive public transport services which are easily accessible are required. A shift to non-motorized modes can be facilitated by implementing a dense and mixed settlement structure.

Activities like working and shopping can be linked efficiently, while unnecessary trips can be avoided. Therefore, smart location choices are required. Although this is not always possible, as some activity locations cannot be changed easily, trip chains (combing trip purposes e.g. commuting with shopping) offer enormous potential for saving both time and money.

Using park-and-rides is another alternative, as it combines the advantages of two modes. The private car offers flexibility and comfort in sparsely settled regions without any PT services. At the same time, congestion and time losses in densely populated urban centres can be avoided by transferring from a private car to public transport on the way into the city.

In some cases, telecommuting might be another possibility to save on mobility costs and reduce vulnerability. Consulting appointments which do not require the actual physical presence of the customers can be made into video conference appointment (For example: Skype appointments). E-commerce and online shopping could also be an effective solution for reducing the mobility cost vulnerability, while simultaneously increasing the convenience of the residents.

Generally, households are only able to change their mobility behaviour if they are offered other options or alternatives. In case of mobility price increase, the households are faced with a dilemma. The real estate prices closer to the city are increased so they do have an option to move to the outskirts of the city. But by doing so, they will increase their mobility costs. This can put the households in a locked-in situation where they are left with no viable options. This is a real challenge that the decision makers must take into consideration. Therefore, recommendations to public stakeholders and decisions makers must build on accessibility analyses which include the development of future residential and mobility costs.

4.2.2 Policies and strategies on a local to regional level: Municipalities

Promoting proximity

Local susceptibility, in the case of mobility cost increases, can be reduced through targeted internal spatial development and sustainable densification. Mixing land-uses is a key success factor (e.g., housing, shops, leisure, jobs and workplace activities). Local supply of everyday goods also plays a major role, both near the home and near the workplace.

This supply can be both pedestrian- and cycle-based so as to also strengthen local mobility in the process. Neighbourhood mobility plans should be developed in order to create attractive walkable and cycle-friendly localities. Recreational open spaces and local activities increase the attractiveness of the neighbourhood and support independence from mobility costs. Accordingly, decentralized, small-scale supply structures should be encouraged, rather than economically-driven consolidation of activities (i.e., economies of scale).

Support of citizen engagement, self-supply and mobile supply

In rural communities, public participation can, to some extent, maintain a temporary supply. For example, the citizens of Oberbiberg (a suburb to the south of Munich) have organized their own citizen bus route. As the public transport within Oberbiberg municipality is inadequate, there are 35 volunteers who drive the bus to the Deisenhofen S-Bahn station.

In addition, municipalities can create online forums to facilitate car sharing. By carpooling or by increasing car occupancy, mobility costs can be reduced.

A similar citizen engagement is also shown in village shops that frequently offer and even bundle a range of services - such as post-offices, cafes, pharmacies, delivery services etc. Through such arrangements, community character is developed through the creation of important social meeting places.

For dispersed locations it is also worthwhile, for economic reasons, for some of the supply to be partially maintained by mobile services. By this, rural municipalities can maintain a certain level of supply of services. For instance, once or twice a week markets can take place. Banks and pharmacies can offer basic services to their clients by coming to them. For this being successful, inter-municipal cooperation is a key necessity.

4.2.3 Regional level: Counties, Public Transport Authorities

Inter-municipal cooperation

Peripheral and fragile communities, which cannot alone provide the required supply, can cooperate with their neighbours to provide services. For example, several neighbouring municipalities can operate a common school. If distances are too large for pedestrians or cyclists, an adequate public transport offer (possibly a citizen bus) between these communities can be operated. This will strengthen the regional identity and cooperation.

Public transport expansion, but only in conjunction with spatial development policy

Especially in a region that is currently in a state of substantial growth, the expansion of public transport is necessary. However, such expansion should only be undertaken in conjunction with thorough spatial planning. Because of this, information concerning the future development of settlement structures (i.e., the location of not only jobs and supply, but also leisure) should be integrated with the demands that these will generate. In addition, the creation of dense nodes can help to form a polycentric network, thereby enabling an efficient public transport system. A sustainable public transport network should not only be linked radially to the regional centres, but also tangentially. This will ensure that the sub-centres and suburbs are also sufficiently connected with each other and the travellers do not have to make unnecessary trips to the centre of the city just to transfer to the respective PT line.

For sustainable development, especially in rural areas, it is necessary to focus on sub-spaces, clusters and centres of different hierarchies. In particular, workplace nodes should be integrated with high-quality public transport to create accessible locations. For this purposes, spatial planning instruments should be steadily employed to avoid mistakes and oversights.

Accessible places

The construction of business areas in greenfields often happens without a prior assessment of traffic impacts and sustainable mobility. These peripheral and non-integrated sites are not sustainable in the face of rising fuel costs as they promote or induce individual motorised transport. Along with being fuel cost intensive, these developments are also associated with higher travel times and resulting mobility emissions. In the future, public transport accessibility to and from business areas will also be an important factor (as already seen today with one particular company co-financed bus line in Munich).

Promotion of a "Sharing economy"

There is also great potential in mobility chains (i.e. in linking different modes of transport). A good example of this is bicycle-sharing stations, which can be implemented at public transport nodes such as train stations. This allows users to cycle from their homes to the regional train (S-Bahn), and also from the train station to the workplace, in order to solve the "last mile problem". This "last mile" can be further extended by providing e-bikes and accompanying charging infrastructure as this creates wider catchments around the public transport stations.

Innovative mobility services – such as bike- and car-sharing, carpooling, and mobility hubs – will make individual mobility behaviour more flexible in the future by giving alternatives to the rigid use of a single transport mode such as individual motorised transport.

Promote e-mobility, particularly in rural areas

With an increase in fuel costs, electric mobility is poised to become more attractive, as long as the price of electric energy (see German energy transition to renewable energy sources) does not increase to a similar extent. E-mobility also offers opportunities for sustainable transportation, especially for dispersed rural communities, since an efficient public transport system cannot be operated effectively and the distances required for sufficient local mobility are too large.

Spatial planning

On the regional level, it is crucial that the development of areas happens in a co-operative manner. It is very important to make sure that none of the regions is isolated from other major economic activity zones. Isolated regions are one of the most vulnerable areas and at the regional level it is important to develop multiple economic zones which are well connected, both in terms of transportation network and economy. In this way, an efficient and resilient poly-centric network can be established.

4.2.4 Higher level: State of Bavaria, Federal Republic of Germany, European Union

Many of the strategies discussed here are often only achieved through higher-level funding by the State of Bavaria, the federal government or the European Union. In addition to satisfying the funding requirements, these strategies and aims have also to be featured in the State of Bavaria’s Development Program (Landesentwicklungsprogramm (LEP)). Consequently, a supra-regional, cross-sectorial funding policy is needed for these measures, especially those that benefit, or are the responsibility of, these higher spatial and economic levels.

The responsibilities are also often not clearly defined. For example, whose responsibility is it to rollout widespread high-speed Internet access using broadband cables? If such a service was available, rural areas through e-services such as e-shopping, e-learning, e-banking etc., might have less transport demand, while receiving their goods through home delivery by drones. The clear benefits of these services would be the reduction of transport demand for the residents. However, these ventures would only succeed if there is enough demand for such services. In case there is there is not enough demand, the online shopping and delivery companies will have to spend money on delivering goods to few individuals, making their business model non-profitable. In addition to this, nationwide broadband coverage is not attractive and profitable for the private sector due to the lack of a high number of potential customers. Therefore, there is a real need for public funding in the peripheral regions in order to realize projects which avoid a loss of population and jobs to the well-equipped dense urban regions.

4.2.5 List of measures

The following table gives an overview of exemplary measures for coping with increasing mobility costs. For the implementation of each proposed measure, the corresponding settlement structure, implementation speed/time frame and costs have been roughly estimated by the author. Since these measures have been discussed in Büttner et al. (2014a) and partially in chapter 4.2, they will only be summarized here as an overview. These measures have been arranged according to their implementation speeds in table 2, with short term being at the top and the long term further down in the table.

Table 2: Measures for coping with increasing mobility costs

Measures	Settlement structure	Implementation speed	Costs
Inter-municipal/regional cooperation	Rural, suburban, urban	Short-term	Low
Organisation of ride-sharing	Rural, suburban	Short-term	Low
E-Services and teleworking	Rural, suburban	Short-term	Low
Mobile supply and services	Rural	Short-term	Average
Mobility hubs, inter-modality	Rural, suburban, urban	Mid-term	Average
Promotion of non-motorized transport (walking and cycling)	Suburban, urban	Mid-term	Average
Car-Sharing	Suburban, urban	Mid-term	Average
Expansion of public transport	Rural, suburban, urban	Long-term	High
Densify mixed land-use	Rural, suburban, urban	Long-term	High
E-Mobility	Rural, suburban	Long-term	High
Self-supply/-organisation	Rural	Long-term	High

In the long run it will not be sufficient to invest only in the cheap and quick measures. For instance, maintaining primary services by e-services and mobile supply should be considered as only temporary arrangements, filling the gap while working on long-term solutions.

Resilient regional development requires a long-term vision, closely related to regional goals. Sustainable and robust land-use and transport development can only be realized with aimful and cooperative planning and a lot of perseverance.

5. Reflection and outlook

5.1 Reflection

Chronology – development over time and risks involved

At the time this research project began the media was reporting drastic scenarios of how fuel prices were drastically increasing and people would soon be unable to afford their current mobility behaviour. However, for the last couple of years, the world has seen a surprising drop of fuel prices. This development has lowered the urgency with which decision-makers and planners plan and envision land-use and transport systems for a future with high mobility costs.

Households are again neglecting the high probability of increasing mobility costs. Especially in regions characterized by a scarcity of affordable housing, households tend to maximize their floor space according to their budget by moving further out from city centres (see Thierstein et al. 2016, Büttner et al. 2016, Mercier et al. 2013). Investing in immovable property in peripheral car-dependent areas will put these households in a locked-in situation as discussed briefly in the previous chapter. When fuel prices rise again, these once-affordable location choices will backfire. The disregarded mobility costs will cut severely into household budgets. Additionally, these remote properties might lose value as high mobility costs make them less attractive. Many of the heavily indebted US citizens had to go through such a situation as they were not able to pay their mortgages during the financial crisis of 2007-08 (Focus 2010).

The German policy “Pendlerpauschale” (commuting allowance) gives tax incentives to those who are constantly commuting. The deduction is dependent on the distance covered between home and work. This clearly acts as an incentive to settle far from the city, which can lead to a dispersed urban sprawl (Bohsem 2012). If fuel becomes cheaper, this commuting allowance (which is not dependant on fuel prices) becomes even more attractive while house hunting, because the households generally consider the financial benefits in the short term without taking into account the risks involved and the long term development of prices.

The relatively cheap fuel prices which led to the “drive till you qualify” practice (see chapter 2.2.2) trapped many households in remote locations where housing was affordable. Therefore, there is an immediate need to increase awareness among all actors and stakeholders that there are risks to living in distant car-dependant areas. With the aid of developing the Scan-Explore-Prepare methodology a wide variety of target groups could be reached.

Reflection on the methodology

The methodology, which consists of the Scan, Explore and Prepare steps (see chapter 4) has proven very suitable in capturing the risks associated with increasing mobility costs for both public bodies and individuals. Despite its success, it has some shortcomings:

The **vulnerability assessment** is limited by the available data, which can hinder goals like benchmarking or comparing international case studies from being achieved. The limited number of indicators and data could be increased and the indicators could be weighted according to their relevance, thereby improving the calculation of a composite vulnerability index. However, it is crucial that the weighting be based on (justified by) the impact of each indicator. The vulnerability assessment was calculated by using municipal average data. In general, the structure (e.g. density, socio-demographics) differs significantly within the analysed municipalities. Therefore, accurate strategies and recommendations cannot be built based on this first scan.

Despite its simplicity, this combination of suitable key indicators fulfilled its purpose in scanning the region for areas vulnerable to fuel price increases. It was achieved to benchmark all municipalities within Munich region, while merely assessing them only on their respective vulnerability score and not taking into account all local conditions. However, these scores and comparing regions with another can start a fruitful discussion on the issues as well as on the opportunities.

This rather simple method improved the communication between researchers, practitioners and decision-makers. Through this, it was able to achieve the fundamental goal of this research work, which was to raise **awareness about the risks involved in relying solely on private cars** (see Büttner et al. 2012) as mentioned in chapter 1.2 on ‘Hypotheses and Research objectives’.

To substitute the short-comings of the first municipal scan, **individual storylines** within the case study municipalities were applied. Due to strict German privacy regulations, fictional synthetic households were created based on statistical data and household surveys for each of the case study municipalities. Respective points of interests (e.g. home, workplace, leisure and shopping destinations) were geo-referenced, allowing typical household storylines to be simulated. For each case study, local stakeholders confirmed the authenticity of these synthetic households and storylines.

The chosen research methodology included a clear focus on individuals and their respective mobility behaviour. While agent-based microsimulation shows good results in simulating and estimating trip flows from origins to destinations from agent characteristics, the actual individual mobility behaviour for a respective region cannot be properly or realistically modelled when hypothetical stress tests are applied. The effects of increasing mobility costs on the household budget have been highlighted by adapting the mobility behaviour and location choice. However, these individual tipping points (e.g. changing modes, selling a car or relocate) were assumed in this study. Further research on these price elasticities when households have to cope with shock scenarios will be beneficial for gaining new insights on how mobility behaviour and location choice can be influenced (see chapter 2.3).

Additionally, spatial analysis, taking into account the actual location of important activities, was needed to complete the picture. An **accessibility analysis taking into account mobility costs** was applied to the case studies, building upon the regional vulnerability assessment and the individual storylines with shock scenarios. In doing so, spatial measures and recommendations for public agencies and decision-makers could then be formulated with the goal of more resilient and sustainable land-use and transport planning in the future.

Since "Sharp increases in mobility costs: A trigger for sustainable mobility" (see Step II: Büttner 2016) was a contribution to the book "Sustainable Mobility in Metropolitan Regions – Insights from interdisciplinary research for practice application", it was designed for use by planning practitioners, a brief overview of all methodological steps needed to be presented. The focus was primarily on the recommendations and policies. An in-depth description of how to calculate the iso-cost accessibility service areas and which data was used was therefore neglected. The concept of iso-cost accessibility analysis has been discussed in chapter 3.3.

While developing forecasts for mobility costs, some variables arose for which data was not available. Therefore, some simplifications and assumptions were needed (see chapter 3.2.1, Step II: Büttner et al. 2016, Büttner 2016). The calculation and prediction of the public transport costs was especially tricky since these costs incorporate many different factors (e.g. wages, infrastructure, fleet, maintenance, subsidies) that are not made available to the public. After discussing with regional public transport officials, it was revealed that energy costs represent about 20% of the total cost of operating the public transport service. Consequently, when stress tests are applied, public transport costs should increase by only about 20% of the fuel price increase (see Büttner et al. 2014).

When comparing private car and public transport accessibility catchment areas, only operating costs were considered. Basically, the iso-cost accessibility analysis shows how far, and more importantly how many potential activities, can be accessed within a certain monetary budget by a private car or by public transport. Hence, private car acquisition costs, maintenance, taxes, parking, and any other non-operating costs have been neglected. Essentially, operating costs compare private vehicle fuel costs versus public transport ticket price. Further research on cost transparency and its future development is needed for reasonable policy-making – especially when taking into account the rise of the sharing economy.

5.2 Outlook

How will the technologies of 'Self-Driving cars', 'E-Mobility', 'Wireless technology', and 'Drones' affect the mobility behaviour in the currently vulnerable areas?

It will be interesting to see how mobility behaviours will change when combining the E-mobility and self-driving technology. Will people drive more just because they can due to the low cost of electric energy? How will the concepts of 'tele-commuting' and 'drone deliveries' affect our mobility behaviour? Will people not have the need to travel for work and shopping anymore? These near-future scenarios will lead to a substantial change in mobility energy consumption patterns, and by extension in mobility cost patterns. By this, currently vulnerable areas can maintain their provisions with supplies; however, it is clear that these technology-driven measures will not lead to sustainable and liveable settlements. For this, public space or an old-fashioned supermarket is needed where people can meet, interact and build a community.

How can academia contribute to planning practice?

From the valuable feedback and cooperation that this research received from practitioners, it is obvious that such collaboration needs to be strengthened. In general, collaboration can be an inspiring and valuable experience for both sides. Practice can supplement scientific analysis with a pragmatic and realistic view.

The research was closely followed by a number of interested practitioners from the region of Munich. After important milestones, the intermediate findings were shown to a group of interdisciplinary stakeholders and practitioners. During the presentation of scientific results, the practitioners commented on the findings based on their practical experience, which ensured relevance to actual planning practice. The common discussions enriched and refined the scientific findings gained from simulations. These feedback loops between academia and practice are a key for successful implementation of proposed measures and policies (Büttner and Wulfhorst 2016).

Despite the aforementioned shortcomings in the methodology’s scientific complexity, the findings have been very well received by academia, practitioners and the media. Media attention raised awareness through numerous newspaper articles, presentations, discussion panels and a radio interview. This proves that there is widespread interest in the impact of increasing and unpredictable mobility costs – the unpredictability of the prices just adds to the importance of sound location choices and spatial planning, which can be achieved by collaboration between neighbouring municipalities, different disciplines as well as science and practice. It is interesting to note that the urgency with which planners and political leaders think about developing sustainable locations heavily depends on the global oil prices. A slump in the global oil markets cause the authorities to put these projects on the back burners, but as soon as there is a hint of a potential long term price rise, the interest in sustainable development is rekindled. Hence, it can be stated that an increase in mobility cost goes a long way in supporting and promoting the development of sustainable locations.

The results of this three-step approach demonstrate that sharp increases in mobility costs clearly impact accessibility for vulnerable households. However, sound location choices, strategic spatial planning, and a host of other measures provide a means to replace this vulnerability with sustainability and resilience.

List of literature

Adams, J. (1995), Risk. University College London Press, London.

Adger, W. (2006), Vulnerability. Global Environmental Change, 16(3), 268–281.

Adger, W. and Kelly, M. (1999), Social vulnerabililty to climate change and the architecture of entitlements. Mitigation and Adaptation Strategies for Global Change 4, 253–266.

Albrecht, M., Kaiser, A. and Marggraf, U. (2008), Wohnstandortwahl, Mobilitätskosten und Klimawandel. In: Raumplanung 137, 93-98.

Amcoff, J. (2009), Rapid regional enlargement in Sweden: A phenomenon missing an explanation. Geografiska Annaler, Series B. Human Geography, 91(3), 275-287.

Banister, D. (2008), The sustainable mobility paradigm. In: Transport Policy, 15(2), 73-80.

Barrows, H. (1923), Geography as human ecology. Annals of the Association of American Geographers 13, 1-14.

Berdica, K. (2002), An introduction to road vulnerability: what has been done, is done and should be done. Transport Policy, 9(2), 117-127.

Bertolini, L. and le Clercq, F. (2003), Urban Development without more Mobility by Car? Lessons from Amsterdam, a Multimodal Urban Region. AME – Amsterdam Study Centre for the Metropolitan Environment, Universiteit van Amsterdam, Amsterdam.

Bertolini, L., le Clercq, F. and Kapoen, L. (2005), Sustainable accessibility: a conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward.

Berube, A., Singer, A., Wilson, J.H. and Frey, W.H. (2006), Finding Exurbia: America's Fast-Growing Communities at the Metropolitan Fringe. In: Living Cities Census. The Brookings Institution.

Bohnet, M., Gertz, C., Maaß, J. and Altenburg, S. (2012), Integrierte Simulation von Raumentwicklung und Verkehr bei stark steigenden Energiepreisen. REAL CORP 2012. Vienna.

Bohsem, G. (2012), Der Kummer der Pendler in Süddeutsche (SZ), 12.02.2012. [online] Available at: http://www.sueddeutsche.de/wirtschaft/entfernungspauschale-der-kummer-der-pendler-1.1324719 [Accessed 3 July 2016].

Bracher, T., Apel, D. and Bracher-Haag-Holzapfel-Kiepe-Lehmbrock-Reutter (1992), Handbuch der kommunalen Verkehrsplanung. Unter Mitarbeit von Björn Schwarze Christian Holz-Rau. Berlin, Bonn: Wichmann; Economica-Verlag anfangs (Erschließungsqualität und Reisegeschwindigkeit der Verkehrsträger im Vergleich, 66. Ergänzungslieferung, 2012).

Brenke, K. (2009), Real wages in Germany: numerous years of decline. Weekly report, 5(28), 193-202.

Brooks, N. (2003), Vulnerability, risk and adaptation: a conceptual framework. Working Paper 38, Tyndall Centre for Climate Change Research, Norwich, UK.

Bundesamt, Statistisches (2011), Statistisches Jahrbuch 2011 für die Bundesrepublik Deutschland mit "Internationalen Übersichten".

Burton, I., Kates, R.W. and White, G.F. (1978), The Environment as Hazard. Oxford University Press, Oxford, UK.

Büttner, B. (2015), Consequences of Sharp Increases in Mobility Costs on Accessibility: Suggestions for Local and Regional Development Strategies. NECTAR 2015 Conference, Proceedings, Ann Arbor.

Büttner, B. (2016), Sharp increases in mobility costs: A trigger for sustainable mobility. In Wulfhorst, G., Klug, S. (Eds.), Sustainable Mobility in Metropolitan Regions – Insights from interdisciplinary research for practice application. Springer.

Büttner, B. and Schott, S. (2012), MOR€CO: Analysis of future residential and mobility costs for private households in Munich Region, Landeshauptstadt München, Referat für Stadtplanung und Bauordnung.

Büttner, B. and Wulfhorst, G. (2012), MORECO: Untersuchung der künftigen Wohn- und Mobilitätskosten für private Haushalte in der Region München, Munich.

Büttner, B. and Wulfhorst, G. (2014), MORECO II: Recommendations for decision-makers to respond to increasing mobility costs in the Munich region, Munich.

Büttner, B. and Wulfhorst, G. (2016), The TUM Accessibility Atlas as a tool for fostering decision making processes on sustainable mobility in the metropolitan region of Munich. 14th WCTR 2016, Proceedings. Shanghai.

Büttner, B., Franz, S., Reutter, U. and Wulfhorst, G. (2012), MOR€CO – Mobility and Residential Costs: Improving the Settlement Development in the Transnational Alpine Space Region, Vienna.

Büttner, B., Ji, C. and Wulfhorst, G. (2014), EMM Accessibility Atlas for Increasing Housing Demand. In: Te Brömmelstroet, M., Silva, S. and Bertolini, L. (Eds.): Assessing Usability of Accessibility Instruments. Amsterdam.

Büttner, B., Ji, C. and Wulfhorst, G. (2014a), MORECO II: Handlungsempfehlungen für öffentliche Akteure zur Reaktion auf steigende Mobilitätskosten im MVV-Raum, Munich.

Büttner, B., Keller, J. and Wulfhorst, G. (2011), Erreichbarkeitsatlas – Grundlagen für die Zukunft der Mobilität in der Metropolregion München, Munich: Europäische Metropolregion München e.V..

Büttner, B., Keller, J. and Wulfhorst, G. (2012), Erreichbarkeitsatlas der Europäischen Metropolregion München (EMM), in Angela Hull, Cecília Silva and Luca Bertolini (Eds.) Accessibility Instruments for Planning Practice. COST Office, 91-94.

Büttner, B., Wulfhorst, G. and Evans J. (2016), Ensuring accessibility to daily activities for different population segments with respect to sharp increases in mobility costs. In Geurs, K., Patuelli, R. and Dentinho, T. (eds.), Accessibility, Equity and Efficiency. Challenges for Transport and Public Services. Edward Elgar.

Büttner, B., Wulfhorst, G., Crozet, Y. and Mercier, A. (2013), The impact of sharp increases in mobility costs analysed by means of the Vulnerability Assessment, WCTR Paper presented at the World Conference on Transport Research (WCTR), Rio de Janeiro.

Büttner, B., Zhao, J., Thierstein, A., Wulfhorst, G., Förster, A. and Sterzer, L. (2014), Migration and Commuting – Consequences for Local Labour and Housing Markets, RSAI 10th World Congress, Bangkok.

Cardona, O.D. (2003), The need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management. In: Bankoff, G., Frerks, G. and Hilhorst, D. (Eds.), Mapping Vulnerability: Disasters, Development and People. Earthscan, London (Chapter 3).

Cats, O. and Jenelius, E. (2014), Dynamic Vulnerability Analysis of Public Transport Networks: Mitigation Effects of Real-Time Information. Networks and Spatial Economics, 14, 435-463.

CBO, Congressional Budget Office (2008), Effects of Gasoline Prices on Driving Behavior and Vehicle Markets.

Cervero, R. and Guerra, E. (2011), Urban Densities and Transit: A Multi-dimensional Perspective, Institute of Transportation Studies, University of California, Berkeley.

Chambers, R. (1989), Vulnerability, coping and policy. IDS Bulletin 20, 1-7.

Clark, W.A.V., Huang, Y.Q. and Withers, S. (2003), Does commuting distance matter? Commuting tolerance and residential change. Regional Science and Urban Economics, 33, 199-221.

Coburn, A.W., Spence, R.J.S. and Pomonis, A. (1994), Vulnerability and Risk Assessment, second ed. UNDP Disaster Management Training Programme.

Cornwell, T. (2013), Rethinking the 'Drive Till You Qualify' Life. [online] Available at: http://www.nationalmortgagenews.com/blogs/hearing/Rethinking-Drive-Till--Qualify-Life-1039273-1.html. [Accessed 2 July 2015].

Crozet, Y. and Wulfhorst, G. (2010), Urban Mobility and Public Policies at a Crossroad: 50 Years after W. Hansen, the paradoxical come-back of accessibility. 12th WCTR 2010 Proceedings. Lisbon.

Crozet, Y., Mercier, A. and Ovtracht, N. (2012), Accessibility: a key indicator to assess the past and future of urban mobility. In: Geurs, K., T., Krizek, K., J. and Reggiani, A. (eds.): Accessibility Analysis and Transport Planning. Challenges for Europe and North America. Edward Elgar.

Curtis, C. (2008), Planning for sustainable accessibility: The implementation challenge. In: Transport Policy, 15(2), 104-112.

Cutter, S.L. (1993), Living with Risk. Edward Arnold, London.

Cutter, S.L. (1996), Vulnerability to environmental hazards. Progress in Human Geography 20, 529–539.

Dargay, J. (2007), Effect of Prices and Income on Car Travel in the UK, Transportation Research Part A: Policy and Practice. 41(10), 949-960.

Dargay, J., Gately, D. and Sommer, M. (2007), Vehicle Ownership and Income Growth, Worldwide: 1960-2030, New York: New York University.

Deakin, E. and Harvey, G. (1998), Transportation Pricing Strategies for California, California Air Resources Board (Sacramento), Contract No. 92-316. Sacramento: USEPA.

Downing, T.E. and Patwardhan, A. (2004), Assessing vulnerability for climate adaptation. In: Lim, B., Spanger-Siegfried, E. (Eds.), Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies, and Measures. Cambridge University Press, Cambridge (Chapter 3).

Downing, T.E., Butterfield, R., Cohen, S., Huq, S., Moss, R., Rahman, A., Sokona, Y. and Stephen, L. (2001), Climate change vulnerability: linking impacts and adaptation. Report to the

Governing Council of the United Nations Programme. United Nations Environmental Programme, Nairobi, Kenya.

EIA - U.S. Energy Information Administration (2015), Short-term energy and summer fuels outlook, [online] Available at: http://www.eia.gov/forecasts/steo/realprices/ [Retrieved 10 March 2015].

EIA – U.S. Energy Information Administration (2016), [online] http://www.eia.gov/ [Retrieved 10 June 2016].

Ellis, F. (2000), The determinants of rural livelihood diversification in developing countries. Journal of Agricultural Economics 51, 289–302.

Emmerson, P. and Wegener, M. (2006), Scenario Assessment. Meta-analysis and consistency of model results. In: Monzón, A. and Nuijten, A. (Eds.), Transport strategies under the scarcity of energy supply. The Hague.

EPA (2015), Global Greenhouse Gas Emissions Data, [online] Available at: http://www.epa.gov/climatechange/ghgemissions/global.html [Retrieved 10 March 2015].

Evans, J., Bhatt, K. and Turnbull, K. (2003), Road Value Pricing: Traveler Response to Transport System Changes, Transit Cooperative Research Program Report 95.

Fishman, E. (2006), Petrol's painful formula. Herald Sun from 3 May 2006. Melbourne, 18.

FOCUS (2016), USA: Drastischer Wertverlust bei US-Immobilien. Focus Online. [online] Available at: http://www.focus.de/panorama/vermischtes/usa-drastischer-wertverlust-bei-us-immobilien_aid_580364.html. [Accessed 3 July 2016].

Ford, J. (2002), Vulnerability: concepts and issues, Ph.D. Scholarly Field Paper, University of Guelph, Guelph, Canada.

Füssel, H.-M. (2007), Vulnerability: A generally applicable conceptual framework for climate change research. Global Environmental Change 17 (2007), 155-167.

Gallagher, L. (2014), The end of the suburbs: Where the American dream is moving. New York.

Gerhards, E., Rauch, A. and Bohnet, M. (2012), Migration and Job Change Decisions in Times of Strongly Rising Energy Prices - The Microsimulation Model €LAN.

Gertz Gutsche Rümenapp (2008), Baustein Kostentransparenz. Gemeinsame Betrachtung von Wohn- und Mobilitätskosten der privaten Haushalte. In: Landeshauptstadt München, Gemeinden des MORO-Arbeitskreises (Hg.): Siedlungsentwicklung und Mobilität. München.

Gertz Gutsche Rümenapp, UBA (2006), Kosten- und Mobilitätsargumente für ein Leben in der Stadt. Gemeinsame Fachtagung des Umweltbundesamtes, des Deutschen Instituts für Urbanistik und des Deutschen Städtetages. Dessau.

Gertz, C., Maaß, J., Guimaraes, T. (eds.) (2015), Auswirkungen von steigenden Energiepresien auf die Mobilität und Landnutzung in der Metropolregion Hamburg. Ergebnisse des Projekts €LAN – Energiepreisentwicklung und Landnutzung. Hamburg.

Geurs, K., Haaijer, R. and van Wee, B. (2006), Option value of public transport: methodology for measurement and case study for regional rail links in the Netherlands. In: Transport Reviews. 26(5), 613-643.

Geurs, K., Krizek, K. and Reggiani, A. (2012), Accessibility analysis and transport planning. Challenges for Europe and North America. Cheltenham, UK, Northampton, MA: Edward Elgar (NECTAR series on transportation and communications networks research).

Geurs, K.T. and Ritsema van Eck, J.R. (2001), Accessibility Measures: Review and Applications. RIVM, Bilthoven.

Geurs, K.T. and van Wee, B. (2004), Accessibility evaluation of land-use and transport strategies: review and research directions. Journal of Transport Geography. 12(2), 127-140.

Giuliano, G. and Dargay, J. (2006), Car Ownership, Travel And Land Use: A Comparison Of The US And Great Britain, Transportation Research A. 40(2), 106-124.

Goodwin, P., Dargay, J. and Hanly, M. (2003), Elasticities Of Road Traffic And Fuel Consumption With Respect To Price And Income: A Review. London: ESRC Transport Studies Unit, University College London.

Gould, P. (1969), Spatial diffusion. Paper presented at the Association of American Geographers, Washington, DC.

Gow, G.A. (2005), Policymaking for Critical Infrastructure. Ashgate, Aldershot.

Grieco, M. (2012), Gender and Transport: Transaction Costs, Competing Resources and Transport Policy Gaps. Research in Transportation Economics. 34(1).

Grieco, M. and Urry, J. (2012), Mobilities: new perspectives on transport and society. Aldershot: Ashgate Publishing Limited.

Guimarães, T., Maaß, J. and Gertz, C. (2014), Integrating a land use transport model with a serious game for supporting planning decisions under rising energy prices, Mobil. TUM 2014 “Sustainable Mobility in Metropolitan Regions”.

Gutsche, J.M. (2008), Kosten- und Mobilitätsargumente für ein Leben in der Stadt. Gemeinsame Fachtagung des Umweltbundesamtes, des Deutschen Instituts für Urbanistik und des Deutschen Städtetages. Dessau.

Hägerstrand, T. (1970). What about people in regional science? Papers and Proceedings, North American Regional Science Association, 24, 7-21.

Hahne, U. (2014), Regionale Resilienz und postfossile Raumstrukturen – Zur Transformation schrumpfender Regionen. In: Hahne, U. (Ed.): Transformation der Gesellschaft für eine resiliente Stadt- und Regionalentwicklung - Ansatzpunkte und Handlungsperspektiven für die regionale Arena. Detmold 2014: Verlag Dorothea Rohn, 11-32.

Halden, D. (2002), City Region Boundaries Study. Derek Halden Consultancy Limited. Edinburgh.

Haller, M., Fink, B., Albrecht, M. and Gutsche, J-M. (2012), Billiger wohnen im Umland? Mobilitätskosten von Wohnorten. MVV-WoMo - Der Wohn- und Mobilitätsrechner des MVV. In: Nahverkehr, 1-2, 46–50.

Ham, M. (2002), Job access, workplace mobility, and occupational achievement. Delft: Eburon.

Handy, S. (2005), Planning for accessibility: In theory and in practice. In: Levinson & Krizek (eds.), Access to Destinations. Elsevier.

Handy, S. and Clifton, K. (2001), Local shopping as a strategy for reducing automobile travel. In: Transportation 28, 317-346.

Hansen W.G, (1959), How accessibility shapes land use, Journal of the American Institute of Planners 25, 73-76.

Harvey, G. and Deakin, E. (1998), The STEP Analysis Package: Description and Application Examples, Appendix B, in USEPA, Technical Methods for Analyzing Pricing Measures to Reduce Transportation Emissions, Report 231-R-98-006.

Hautzinger, H., Haag, G., Helms, M. and Hugo, J. (2005), Autofahren um jeden Preis? Wie private Haushalte auf Änderungen der Kraftstoffpreise reagieren. In: Internationales Verkehrswesen, Heft 5, 3(2005), 77-82.

Hewitt, K. (1997), Regions of Risk. A Geographical Introduction to Disasters. Addison Wesley Longman, Essex, UK.

Holden, E. (2007), Achieving sustainable mobility. Everyday and leisure-time travel in the EU. Aldershot, England ;, Burlington, VT: Ashgate.

Holz-Rau, C. (ed.) (2009), Subject oriented approaches to transport. Dortmund: IRPUD.

Hull, A., Silva, C. and Bertolini, L. (ed.) (2012), Accessibility Instruments for Planning Practice. COST Office.

IEA (2013), Medium-Term Oil Market Report 2013. International Energy Agency. [online] Available at: http://www.iea.org/publications/freepublications/publication/MTOMR2013_free.pdf. [Accessed 3 July 2016].

IMU (2002), Raus aus der Stadt? Untersuchung der Motive für Fortzüge aus München in das Umland 1998–2002, München: IMU-Institut für Medienforschung.

Institut für Mobilitätsforschung (ed.) (2010), Zukunft der Mobilität. Szenarien für das Jahr 2030. 1. Aufl. Berlin: Ifmo.

Ionescu, C., Klein, R.J.T., Hinkel, J., KaviKumar, K.S. and Klein, R. (2005), Towards a formal framework of vulnerability to climate change. NeWater Working Paper 2, Potsdam Institute for Climate Impact Research, Potsdam, Germany.

Johansson, O. and Schipper, L. (1997), Measuring the Long-Run Fuel Demand for Cars, Journal of Transport Economics and Policy. 31(3), 277-292.

Kahn Ribeiro, S., Kobayashi, S., Beuthe, M., Gasca, J., Greene, D., Lee, D. S. and Sperling, D. (2007), Transport and its infrastructure. Climate Change, 323–385.

Kaltenbrunner, R. (2013), Mobilisierung gesellschaftlicher Bewegungsenergien. Von der Nachhaltigkeit zur Resilienz – und retour? In: Informationen zur Raumentwicklung, Heft 4(2013), 287-295.

Kasperson, J.X, Kasperson, R.E, Turner, B.L., Hsieh, W. and Schiller, A. (2006), Vulnerability to global environmental change. In: A. Diekman, T. Dietz, C.C. Jaeger and E.A. Rosa (Eds), The Human Dimensions of Global Environmental Change. MIT Press, Cambridge, MA.

Kasperson, J.X. and Kasperson, R.E. (2001), International workshop on vulnerability and global environmental change. SEI Risk and Vulnerability Programme Report 2001-01, Stockholm Environment Institute, Stockholm, Sweden.

Kasperson, J.X., Kasperson, R.E., Turner II, B.L., AMD Schiller, A. and Hsieh, W. (2005), Vulnerability to global environmental change. In: Kasperson, J.X., Kasperson, R.E. (Eds.), Social Contours of Risk. Vol. II: Risk Analysis Corporations and the Globalization of Risk. Earthscan, London, 245–285.

Kates, R.W. (1985), The interaction of climate and society. In: Kates, R.W., Ausubel, H., Berberian, M. (Eds.), Climate Impact Assessment. Wiley, Chichester, UK.

Kelly, P. and Adger, W. (2000), Theory and practice in assessing vulnerability to climate change and faciliting adaptation. Climatic change 47, 325-352.

Kelman, I. (2003), Defining risk. FloodRiskNet Newsletter 2 (Winter 2003), 6–8.

Korsu, E. (2012), Tolerance to commuting in urban household location choice: evidence from the Paris metropolitan area. Environment and Planning A, 44, 1951-1968.

Krizek, K.J., Horning, J. and El-Geneidy, A. (2012), Perceptions of Accessibility to Neighborhood Retial and Other Public Services. In K.Geurs, K. Krizek & A. Reggiani (Eds.), Accessibility and Transport Planning: Challenges for Europe and North America (pp. 96-117). Edward Elgar, London, UK.

Kutter, E. (1972), Demographische Determinanten städtischen Personenverkehrs. Veröffentlichungen des Instituts für Stadtbauwesen der TU Braunschweig 9. TU Braunschweig, Braunschweig.

Lake, M. and Ferreira, L. (2002), Demand For Toll Roads: A Summary Of Elasticities, Travel Time Values And Modelling Approaches, Transport Research Consortium Queensland University Of Technology.

Landeshauptstadt München, Referat für Stadtplanung und Bauordnung (Eds.) (2010), Mobilität in Deutschland (MiD), Alltagsverkehr in München, im Münchner Umland und im MVV-Verbundraum, Munich.

Landeshauptstadt München, Referat für Stadtplanung und Bauordnung (Eds.), (2012), Wanderungsmotivuntersuchung II. Munich.

Leary, N. and Beresford, S. (2007), Vulnerability of people, places, and systems to environmental change. In: Knight, G. and Jaeger, J. (Eds): Integrated regional assessment. Cambridge University Press, Cambridge, UK.

Levinson, D.M. (1998), Accessibility and the journey to work. Journal of Transport Geography, 6**,** 11-21. LHM (2012), Demographiebericht Teil 1.

Litman, T. (2012). Changing North American Vehicle-Travel Price Sensitivities: Implications For Transport and Energy Policy.

Litman, T. (2013), Understanding Transport Demands and Elasticities - How Prices and Other Factors Affect Travel Behaviour, Victoria: Victoria Transport Policy Institute.

Liverman, D.M. (1990), Vulnerability to global environmental change. In: Kasperson, R.E., Dow, K., Golding, D., Kasperson, J.X. (Eds.), Understanding Global Environmental Change: The Contributions of Risk Analysis and Management. Clark University, Worcester, MA, 27–44 (Chapter 26).

Luers, A.L. (2005), The surface of vulnerability: an analytical framework for examining environmental change. Global Environmental Change 15, 214–223.

Luers, A.L., Lobell, D.B., Sklar, L.S., Addams, C.L. and Matson, P.A. (2003), A method for quantifying vulnerability, applied to the Yaqui Valley, Mexico. Global Environmental Change 13, 255–267.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (Eds.), (2001), Climate Change 2001: Impacts, Adaptation and Vulnerability. Cambridge University Press, Cambridge.

McDermott-Levy, R., Kaktins, N. and Sattler, B. (2013), Fracking, the Environment, and Health: New energy practices may threaten public health. The American Journal of Nursing 113, 46-52.

Mercier, A., Crozet, Y., Ovtracht, N., Büttner, B. and Wulfhorst, G. (2013), Stress tests on urban mobility: lessons for public policies. 13th WCTR, Proceedings, Rio de Janeiro.

Mercier, A., Crozet, Y., Ovtracht, N., Büttner, B., Ji, C., Keller, J. and Wulfhorst, G. (2013), Stress tests for a sustainable mobility: an accessibility approach. Lyon.

Merriman, D. and Hellerstein, D. (1994), Compensation for Commutes in the Land and Labor-Markets – Some Evidence from the Tokyo Metropolitan-Area. Journal of Regional Science, 34**,** 297-324.

Messenger, T. and Ewing, R. (1996), Transit-oriented development in the sunbelt. Transportation Research Record: Journal of the Transportation Research Board, 1552**,** 145-153.

Metzger, M.J., Leemans, R. and Schröter, D. (2005), A multidisciplinary multi-scale framework for assessing vulnerabilities to global change. International Journal of Applied Earth Observation and Geoinformation 7, 253–267.

Millard-Ball, A. and Schipper, L. (2010). Are We Reaching Peak Travel? Trends in Passenger Transport in Eight Industrialized Countries. Transport Reviews. 31(2), 357-378.

Miller, E. J. and Ibrahim, A. (1998), Urban form and vehicular travel: some empirical findings. Transportation Research Record: Journal of the Transportation Research Board, 1617**,** 18-27.

Mokhtarian, P. L., and Chen, C. (2004), TTB Or Not TTB, That Is The Question: A Review And Analysis Of The Empirical Literature On Travel Time (And Money) Budgets Transportation Research A. 38(9-10), 643-675.

Monzón, A. and Nuijten, A. (Eds.) (2006), Transport strategies under the scarcity of energy supply. The Hague.

Moss, R.H., Brenkert, A.L. and Malone, E.L. (2001), Vulnerability to climate change: a quantitative approach. Technical Report PNNL-SA-33642, Pacific Northwest National Laboratories, Richland, WA.

MTS-K (2016), Markttransparenzstelle für Kraftstoffe. [online] Available at: http://www.bundeskartellamt.de/DE/Wirtschaftsbereiche/Mineral%C3%B6l/MTS-Kraftstoffe/Verbraucher/verbraucher_node.html [Retrieved 30 June 2016].

Mumford, L. (1956), Neighborhood and neighborhood unit. In: Mumford, L. (ed.: The Urban Prospect. Harcourt, Brace & World, New York, 56-88.

Næss, P. (2006), Central Dimensions in a Sustainable Urban Development. Sustainable Development, 3, 120-129.

Newman, P. and Kenworthy,J. (1989), Cities and Automobile Dependence: An International Sourcebook. Gower, Aldershot, UK.

O'Brien, K., Eriksen, S., Schjolen, A. and Nygaard, L. (2004), What's in a word? Conflicting interpretations of vulnerability in climate change research. CICERO Working Paper 2004:04, CICERO, Oslo University, Oslo, Norway.

Östh, J., Reggiani, A. and Galiazzo, G. (2015), Spatial economic resilience and accessibility: A joint perspective. In: Computers, Environment and Urban Systems. 49(2015), 148-159.

Peng, Z.-R. (1997), The Jobs-Housing Balance and Urban Commuting. Urban Studies (Routledge), 34, 1215-1235.

Pielke Sr., R.A. and Bravo de Guenni, L. (2003), How to evaluate vulnerability in changing environmental conditions? In: Kabat, P., Claussen, M., Dirmeyer, P.A., Gash, H.J.C., Bravo de Guenni, L., Meybeck, M., Pielke, Sr., R.A., Vo¨ ro¨ smarty, C.J., Hutjes, R.W.A., Lutkemeyer, S. (Eds.), Vegetation, Water Humans and the Climate: A New Perspective on an Interactive System. Springer, Berlin.

Prowse, M. (2003), Towards a clearer understanding of 'vulnerability' in relation to chronic poverty. CPRC Working Paper No. 24, Chronic Poverty Research Centre, University of Manchester, Manchester, UK.

Reggiani, A., Nijkamp, P. and Lanzi, D. (2015), Transport resilience and vulnerability: The role of connectivity. Transportation Research Part A. 81, 4-15.

Robinson, R.V.F. and Vickerman, R.W. (1976), The demand for shopping travel: a theoretical and empirical study. In: Applied Economics. 8, 267-281.

Romani, J., Surinach, J. and Artiis, M. (2003), Are commuting and residential mobility decisions simultaneous? The case of Catalonia, Spain. Regional Studies. 37, 813-826.

Rose, A. and Stonor, T. (2009), Syntax: Planning Urban Accessibility. In: Christ, W. (ed.)

Rouwendal, J. (1998), Search theory, spatial labor markets, and commuting. Journal of Urban Economics. 43, 1-22.

SACTRA (1994), Trunk Roads and the Generation of Traffic, UKDoT, HMSO. [online] Available at: www.roads.detr.gov.uk/roadnetwork [Accessed 3 July 2016].

Sarewitz, D., Pielke Jr., R. and Keykhah, M. (2003), Vulnerability and risk: some thoughts from a political and policy perspective. Risk Analysis. 23, 805–810.

Schafer, A. and Victor, D.G. (2000), The Future Mobility of the World Population, Transportation Research A. 34(3), 171-205.

Scheiner, J. (2006), Does individualisation of travel behaviour exist? Determinants and determination of travel participation and mode choice in West Germany, 1976-2002. Die Erde, 137(4), 355–377.

Schindler and Held, M. (2009), Postfossile Mobilität. Wegweiser für die Zeit nach dem Peak Oil. Bad Homburg.

Schmidt, A. and Walloth, C. (2012), Die Stadt als komplexes System. Urbane Anpassungsfähigkeit und Resilience. In: RaumPlanung 164, 14-18.

Schneider, M. (2015), Resilienz – Perspektiven für widerstandsfähige und lernende ländliche Räume. In: Bayerische Akademie ländlicher Raum e.V. (ed.): Impulse zur Zukunft des ländlichen Raums in Bayern.

Seeliger, L. and Turok, I. (2013), Towards Sustainable Cities: Extending Resilience with Insights from Vulnerability and Transition Theory. Sustainability, 5, 2108-2128.

Sen, A. (1999), Ökonomie für den Menschen. Wege zur Gerechtigkeit und Solidarität in der Marktwirtschaft. München.

Shi, J., Tong, X., Zhang, H. and Tao, D. (2013), Spatial interaction of urban residence and workplace: an urbansim application in Yichang, China. Acta Scientiarum Naturalium Universitatis Pekinensis.

Sieverts, T. (2013), Am Beginn einer Stadtentwicklungsepoche der Resilienz? Folgen für Architektur, Städtebau und Politik. In: Informationen zur Raumentwicklung. 4(2013), 315-323.

Small, K. A. and Van Dender, K. (2005), The Effect of Improved Fuel Economy on Vehicle Miles Traveled: Estimating the Rebound Effect Using U.S. State Data, 1966-2001. University of California Energy Institute's (UCEI) Energy Policy and Economics Working Paper Series.

Small, K. A. and Van Dender, K. (2007), Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect, Energy Journal. 28(1), 25-51.

Smith, L. (2016), Conventional discoveries outside North America continue their decline; 2015 marked lowest year for discovered oil and gas volumes since 1952. IHS Blogs. Blog.ihs.com. [online] http://blog.ihs.com/conventional-discoveries-outside-north-america-continue-their-decline. [Accessed 3 July 2016].

Snyder, T. (2016), CNT Busts “Drive Till You Qualify” Myth in the D.C. Region. Streetsblog USA. Usa.streetsblog.org. [online] Available at: http://usa.streetsblog.org/2011/08/05/cnt-busts-drive-till-you-qualify-myth-in-the-d-c-region/ [Accessed 3 July 2016].

Spears, S., Boarnet, M. and Handy, S. (2010), Draft Policy Brief on the Impacts of Parking Pricing Based on a Review of the Empirical Literature, Research on Impacts of Transportation and Land Use-Related Policies, California Air Resources Board.

te Brömmelstroet, M. and Bertolini, L. (2008), Developing land use and transport PSS: meaningful information through a dialogue between modelers and planners. Transport Policy. 15(4), 251-259.

Thierstein, A., Wulfhorst, G., Bentlage, M., Klug, S., Gilliard, L., Ji, C., Kinigadner, J., Steiner, H., Sterzer, L., Wenner, F. and Zhao, J. (2016), WAM Wohnen Arbeiten Mobilität. Veränderungsdynamik und Entwicklungsoptionen für die Metropolregion München.

Timmermann, P. (1981), Vulnerability, resilience and the collapse of society. Environmental Monograph, vol. 1. Institute for Environmental Studies, University of Toronto, Toronto, Canada.

TRACE (1999), Elasticity Handbook: Elasticities for Prototypical Contexts, European Commission, Directorate-General for Transport, (www.cordis.lu/transport/src/tracerep.htm); [online] Available at: www.transport-research.info/Upload/Documents/200310/trace.pdf. [Accessed 3 July 2016].

Turner, X. et al. (2003), A framework for vulnerability analysis in sustainable science. In: PNAS. 100(14), 8074–8079.

UN DHA (1993), Internationally agreed glossary of basic terms related to disaster management. DNA/93/36, United Nations Department of Humanitarian Affairs, Geneva, Switzerland.

UNEP (2002), Assessing human vulnerability due to environmental change: Concepts, issues, methods and case studies. UNEP/DEWA/ RS.03-5, United Nations Environmental Programme, Nairobi, Kenya.

United Nations (2004), Living with Risk: A Global Review of Disaster Reduction Initiatives. United Nations International Strategy for Disaster Reduction, Geneva, Switzerland.

van Ommeren, J., Rietveld, P. and Nijkamp, P. (1999), Job moving, residential moving, and commuting: A search perspective. Journal of Urban Economics, 46, 230-253.

Vermeulen, W. and Vermeer, N. (2012), External Benefits of Brownfield Redevelopment: An Applied Urban General Equilibrium Analysis. Journal of Benefit-Cost Analysis. 3(3), 6.

Vester, F. (1976), Ballungsgebiete in der Krise: eine Anleitung zum Verstehen und Planen menschlicher Lebensräume mit Hilfe der Biokybernetik. Frankfurt am Main

VTPI (2007), OECD Country Data Summary Spreadsheet, Victoria Transport Policy Institute. [online] Available at: www.vtpi.org/OECD2006.xls.

Wachs, M., Taylor, B.D., Levine, N. and Ong, P. (1993), The Changing Commute – A Case-Study of the Jobs-Housing Relationship Over Time. Urban Studies. 30, 1711-1729.

Wegener, M. (2004), Overview of Land-Use Transport Models. In: Hensher, D., Button, K. (Eds.): Transport Geography and Spatial Systems. Handbook 5 of the Handbook in Transport. Pergamon/Elsevier Science, Kidlington, UK, 127-146.

Wegener, M. (2009), Energie, Raum und Verkehr. Auswirkungen hoher Energiepreise auf Stadtentwicklung und Mobilität. In: Wissenschaft & Umwelt. Interdisziplinär. 12, 67-75.

Wegener, M. (2009), Energy Scarcity and Climate Change: The Challenge for Urban Models. Paper presented at the 11th International Conference on Computers in Urban Planning and Urban Management (CUPUM): Paper 56. Hong Kong.

Wegener, M. and Fürst, F. (1999), Land-Use Transport Interaction: State of the Art. Berichte aus dem Institut für Raumplanung 46. Institut für Raumplanung, Universität Dortmund, Dortmund.

Whelan, G. (2007), Modelling Car Ownership In Great Britain. Transportation Research Record A. 41(3), 205-219.

World Bank (2015), Pump price for gasoline (US$ per liter). [online] Available at: http://data.worldbank.org/indicator/EP.PMP.SGAS.CD/countries [Retrieved 10 March 2015].

Wulfhorst, G. (2008), Erreichbarkeit – Accessibility – Accessibilité, Proceedings from the mobil.TUM 2008 – International conference on Mobility & Transport. Munich.

Wulfhorst, G. (2010), Mobilität gestalten - zur Sicherung unserer Zukunft in Stadt und Region. In: Technik in Bayern. 2(2010), 8-9.

Zahavi, Y. (1974), Traveltime Budgets and Mobility in Urban Areas. Report FHW PL-8183. US Department of Transportation, Washington.

Zahavi, Y. (1981), The unified mechanism of travel model should be available for policy analysis by the end of the year. Traffic Engineering and Control. October 1981.

Zheng, S. and Sun, C. (2011), Urban Spatial Structure: Housing, Jobs and Related Urban Issues. Southern Economics. 8, 18-31.

Zolli, A. and Healy, A.M. (2013), Resilience: Why things bounce back. New York.

List of abbreviations

EIA	Energy Information Administration
EMM	Europäische Metropolregion München
GHG	Greenhouse Gas
GIS	Geographic Information System
HBEFA	Handbook Emission Factors for Road Transport
IEA	International Energy Agency
ILUMASS	Integrated Land Use Modelling and Transportation System Simulation
IMU	Institute of Media research and Urbanism
IPCC	Intergovernmental Panel on Climate Change
IRPUD	Institute of Spatial Planning of the University of Dortmund
LHM	Landeshauptstadt München
MOR€CO	Mobility and Residential Costs
MTS-K	Markttransparenzstelle für Kraftstoffe (market transparency authority for fuels)
MVV	München Verkehrs- und Tarifverbund
OECD	Organization for Economic Cooperation and Development

OPEC	Organization of the Petroleum Exporting Countries
OSM	Open Street Maps
PROPOLIS	Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability
PrT	Private Motorized Transport
PuT	Public Transport
SASI	Spatial and Socio-economic Impacts of Transport Investments and Transport System Improvements
TUM	Technische Universität München
UMOT	Unified Mechanism of Travel
UN	United Nations
UNDHA	United Nations Department of Humanitarian Affairs
VKT	Vehicle Kilometers Travelled
WoMo	Wohn- und Mobilitätsrechner (Housing and Mobility Calculator)
STEPs	Scenarios for the Transport System and Energy Supply and their Potential Effects
LEP	Landesentwicklungsprogramm

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PART II

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Peer reviewed conference paper 13th WCTR, July 15-18, 2013 – Rio de Janeiro, Brazil.

Büttner, B., Wulfhorst, G., Evans, J. (2016):
Ensuring accessibility to daily activities for different population segments with respect to sharp increases in mobility costs.
Peer reviewed monograph book chapter in Accessibility, Equity and Efficiency. Challenges for Transport and Public Services. Edited by Geurs, K., Patuelli, R., Dentinho, T., Edward Elgar.

Büttner, B. (2016):
Sharp increases in mobility costs: A trigger for sustainable mobility.
Peer reviewed monograph book chapter in Sustainable Mobility in Metropolitan Regions – Insights from interdisciplinary research for practice application. Edited by Wulfhorst, G., Klug, S., Springer.

PART II: PAPER 1

The Impact of Sharp Increases in Mobility Costs Analysed By Means of The Vulnerability Assessment

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Abstract

The combination of peak oil and scarcity of fossil fuel with political instability in oil producing states might cause sharp increases in mobility costs in the near future. In this research, municipalities will be tested regarding their susceptibility to sharp increases in mobility costs by means of the vulnerability assessment. Therefore, this ever-growing increase is leading to mobility impairments for certain social classes. The amount spent on mobility costs of the household budget is rising dramatically.

To see which regions are in danger of increasing mobility costs the vulnerability assessment has been performed with a combination of indicators for the dimensions exposure (e.g. fossil fuel consumption), sensitivity (income) and resilience (accessibility to jobs by public transport) within the Munich region as well as the Lyon region.

The feasibility of transferring the vulnerability assessment to different regions and households based on the socio-demographic and transport data is crucial to test the future viability.

Displaying and visualizing the vulnerable locations through mapping can assist in the development of sustainable spatial and transport policies to cope with issues arising from increased mobility costs (e.g. social exclusion…).

1. Introduction

The majority of people still rely on fossil fuel powered modes of transport for everyday mobility, despite the recent attempts of governments to decrease the growth trend towards individual motorized mobility. However, the economic rise of BRIC countries – Brazil, Russia, India and China - is increasing the need for more and at the same time affordable oil.

In the current global economic situation an oil price increase has a dramatic impact on a country's economic development, as has been proved in the last oil crisis. History offers worrying messages and the last oil crisis was just a few years ago in 2008.

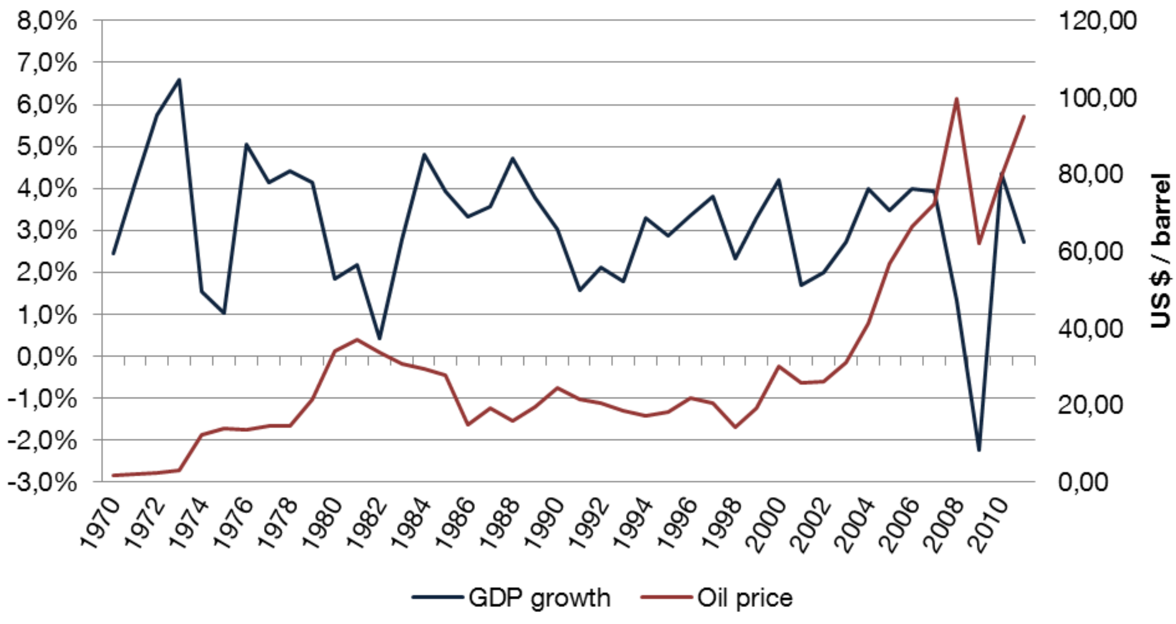

Figure 1: Development of the oil price and world GDP growth from 1970 till 2011. Source: Based on data by World Bank database for the GDP growth (2012) and Earth Policy Institute (2012))

Figure 1 shows the development of the real oil price from 1970 till the present compared to the real GDP growth rate in that time frame. Scarcity of fossil energy and the uncertainty of peak oil combined with political instability in oil producing nations will result in higher mobility costs in the near future. During the last oil crisis the oil price jumped from about US$40/bbl in 2004 to more than US$100/bbl in just four years. Meanwhile the world's real GDP growth rate declined from almost 5.5 % to 4% in that same time frame. Shortly afterwards, the global economy collapsed, which shows a strong correlation between oil price and economic growth. Furthermore, the events in 2008 confirmed a pattern seemingly in place since the 1970s.

Due to extreme variability in oil prices any accurate prediction is difficult. The drop of the real oil price in 2009 was immediately followed by a sharp increase from about US$60/bbl to US$100/bbl in 2011. Still, it is plausible to conclude that the (fuel) prices that households have to pay remain at a high level and will continue to escalate (Energy Information Administration, 2012).

Based on the combination of fear and uncertainty another oil crisis cannot be ruled out or predicted, that will lead to a sharp and sudden leap in costs. Therefore, an examination of the vulnerability on a regional level is needed in order to see which municipalities are susceptible to sharp increases in mobility costs.

2. Vulnerability Assessment

The resilience of the study regions Lyon and Munich (see chapter 3) is analysed by the means of the vulnerability assessment. The concept – which was formerly used to test the susceptibility to e.g. famine and food security, hazards, climate change (Adger, 2006) - is in this research adapted to regional vulnerability in the case of dramatic increases in mobility costs. The following subchapter will explain the methodological approach.

2.1 Methodological approach

"*Vulnerability is most often conceptualized as being constituted by components that include exposure and sensitivity to perturbations or external stresses, and the capacity to adapt*" (Adger, 2006).

According to this, Kasperson et al. (2006) divides vulnerability into the following three dimensions:

1. **Exposure** is the contact between system and stress.
2. **Sensitivity** is the degree to which something/someone is affected by exposure to stress.
3. **Resilience** is the ability of something/someone to absorb perturbations or stresses without changes in its fundamental structure or function that would drive it into different state.

In this case the context is an increase in fuel prices and the subsequently effects are analysed on the regional scale of municipalities.

Within the vulnerability assessment the measurement of vulnerability is a crucial issue. As underlined by Leary and Beresford (2007) vulnerability is a non-observable, complex, and multi-dimensional concept. Consequently, researchers are in the process of developing appropriate indicators for a wide range of different fields.

2.2 Thematic adaption regarding mobility costs on a regional scale

Until now, the concept of vulnerability has not taken into account transport related fields like mobility costs (Adger, 2006).

"The challenge for vulnerability assessments is to find explanations […] that are […] robust and applicable to a wider set of contexts. This can be facilitated by working at regional scales" (Leary and Beresfort, 2007).

In order to adapt the vulnerability assessment to the issue of increasing fuel prices, appropriate indicators have to be collected and specified. A range of indicators can be used to measure levels of vulnerability at a municipal level.

- Who will be **exposed** by an increase in fuel prices?

  Those that have a high **fossil fuel consumption**.
  Therefore, the appropriate key indicator is the municipal average of vehicle kilometres per capita by private cars (see chapter 4.1).

- Who will be **sensitive** to rising fuel prices?

  Those that have a relatively **low income**.
  Therefore, our analysis in Munich uses the municipal average of net income and in Lyon the unemployment rate as key indicators (see chapter 4.2).

- Who will be **resilient** in the case of increasing fuel prices?

  Those that have **alternatives to the private car**.
  Therefore, the appropriate key indicator is the accessibility to jobs by public transport (see chapter 4.3).

- Who will be **vulnerable** to an increase in fuel prices?

  Those that are **highly exposed** and **highly sensitive** combined with a **low resilience**.
  Therefore, the vulnerability index is calculated as the sum of the listed indicators (see chapter 4.4).

In general transferring this methodology to other regions or even thematic questions is possible. However, in the case of comparing and benchmarking different study regions, this framework and indicators have to be adapted in respect to issues like data availability. To ensure a certain level of comparability the same or at least similar/comparable data needs for to be chosen.

3. Study Regions

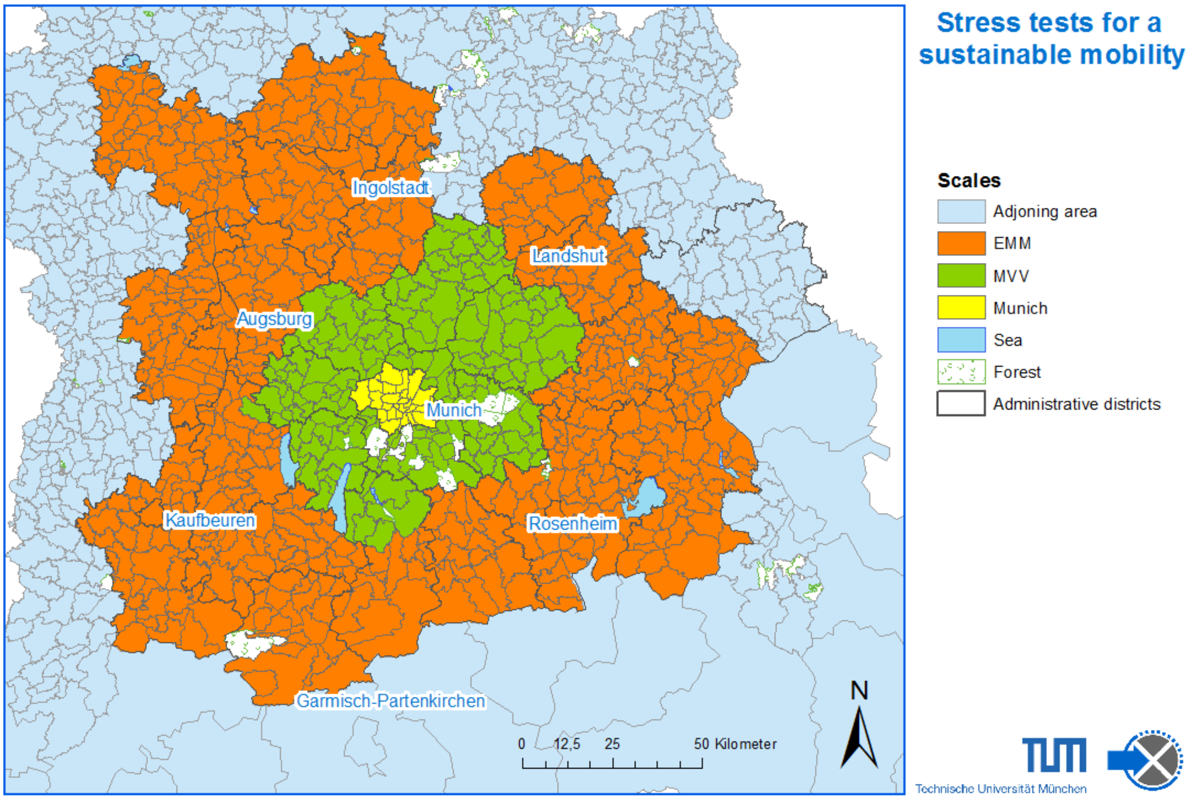

Figure 2: Analyzed scales: Munich Metropolitan Region (EMM), Munich Region (MVV) and City of Munich

The Munich Metropolitan Region (EMM) with its population of 5.5 million is located in the south of Germany and includes several important cities like Ingolstadt and Augsburg. Destinations for tourism like Garmisch-Partenkirchen in the German Alps are also part of the Munich Metropolitan Region. The total area is more than 24.000 km² with an average GDP of about 209 billion €. The purchasing power for the inhabitants is at 23.000 €. The average daily distance by private car is 23.5 km, while the commuting distance is 17.6 km. For benchmarking and analysis, the proper scales have to be chosen. Therefore, most analysis will focus on a smaller scale like the Munich Region (MVV) so it is comparable to Lyon Metropolitan Area (see Table 1).

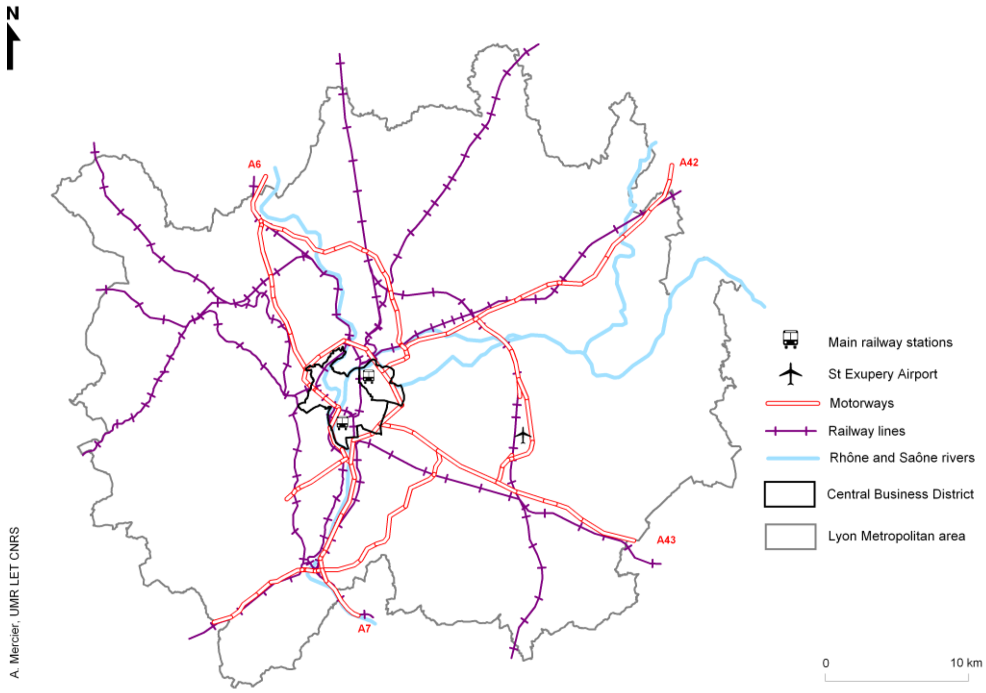

Figure 3: Lyon metropolitan area, with main transport infrastructures

The Lyon Metropolitan area (see Figure 3) is the second largest metropolitan area in France (after Paris) and covers more than 3,356 km² and contains 296 “communes” (the smallest administrative subdivision in France). The overall metropolitan area has a population of 1.7 million people (INSEE RGP, 1999), and a population density of 508 inhabitants per km². Population growth is significant (0.8% per year) and higher than in any other French Metropolitan region (Paris, Marseille, Lille). Population tends to be concentrated in the central zones (Lyon and Villeurbanne) and their outlying “communes” with densities higher than 900 inhabitants per km². The Lyon Metropolitan Area offers more than 800,000 jobs (in 1999) for 765.000 employees living in the area.

Table 1: Benchmarking of the regions

	Grand Lyon	Lyon Metropolitan Area	Region Rhone Alpes	Munich	Munich Region (MVV)	Munich Metropolitan Region
Area	510 km²	3.356 km²	43.698 km²	311 km² (2009)	5.470 km²	24.094 km²
Average income per person	18.280 € per year (per household income)	N.C	18.997 € per year	23.145 € per year	39.172 € per year (gross income)	21.518 € per year
GDP	52 Billion €	N.C	188 Billion €	73.8 Billion €	N.C	209.48 Billion €
Inhabitants	1.257 Mio	1.757 Mio	6.160 Mio	1.364 Mio (2009)	2.603 Mio	5.5 Mio
Length of public transport	1.232 km	N.C	2.660 km (train – RFF)	625 km	5.377km	N.C
Population density	2.455 inhabitants per km²	509 inhabitants per km²	141 inhabitants per km²	4.400 inhabitants per km²	494 inhabitants per km²	282 inhabitants per km²
Rate of unemployment	11.40 %	8.8 %	9 %	5,0 %	2,12 %	N.C
Cars per 1000 inhabitants	N.C	Around 455	Around 525	503	546	

Source: Bayerisches Landesamt für Statistik und Datenverarbeitung, 2010.

For benchmarking a general comparison of the two study regions is needed. Therefore, a wide range of structural as well as mobility data was collected. Grand Lyon will be compared to

Munich, Metropolitan Region Lyon with Region Munich and Region Rhone Alpes will be benchmarked with Munich Metropolitan Region. Therefore size and population will fit quite well and will enable a detailed comparison (see Table 1). In this paper the results are based on the analyses of the Metropolitan Region Lyon and Region of Munich due to the importance of this regional scale.

4. Regional vulnerability in case of sharp increases in mobility costs

4.1 Exposure assessment

Munich case study

For measuring exposure two sources to obtain data are used. The first is a national database of regional statistics (GENESIS online, operated by the public statistics agencies of the German states) that provides population data (see Table 1). The second source is the regional transport model which is run jointly by the city of Munich, the regional public transport authority (MVV) and the public transport operating company of the city of Munich (MVG). This model allows the calculation of vehicle-kilometers travelled (VKT) by the inhabitants of each municipality within the coverage of the MVV network. This key indicator for measuring exposure was chosen because vehicle-kilometers travelled (VKT) are directly related to fuel consumption.

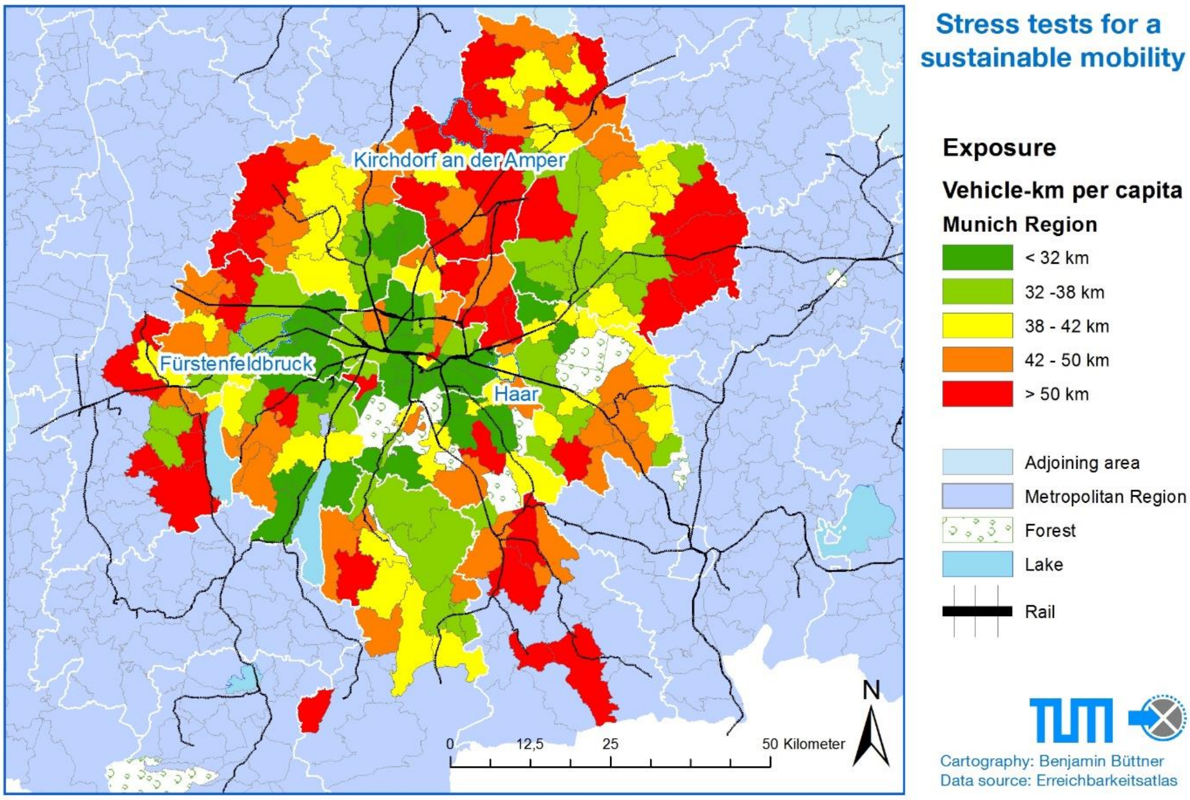

Figure 4: Municipal average of vehicle-km travelled per inhabitant for Munich region

The red municipalities (administrative districts) show a very high exposure due their high VKT per inhabitant. In average the inhabitants use their car more than 50 kilometers for daily trips. Locations with higher exposure tend to be located on the periphery of Munich, with a cluster in the far north. The more exposed municipalities are characterized by close to no public transport service mostly located in rural regions. Hence the red municipalities are very car dependent.

Lyon case study

Using a 2006 travel survey, car user trip data was extracted according to travel analysis zones. This allowed the computation of daily vehicle distance per Grand Lyon resident.

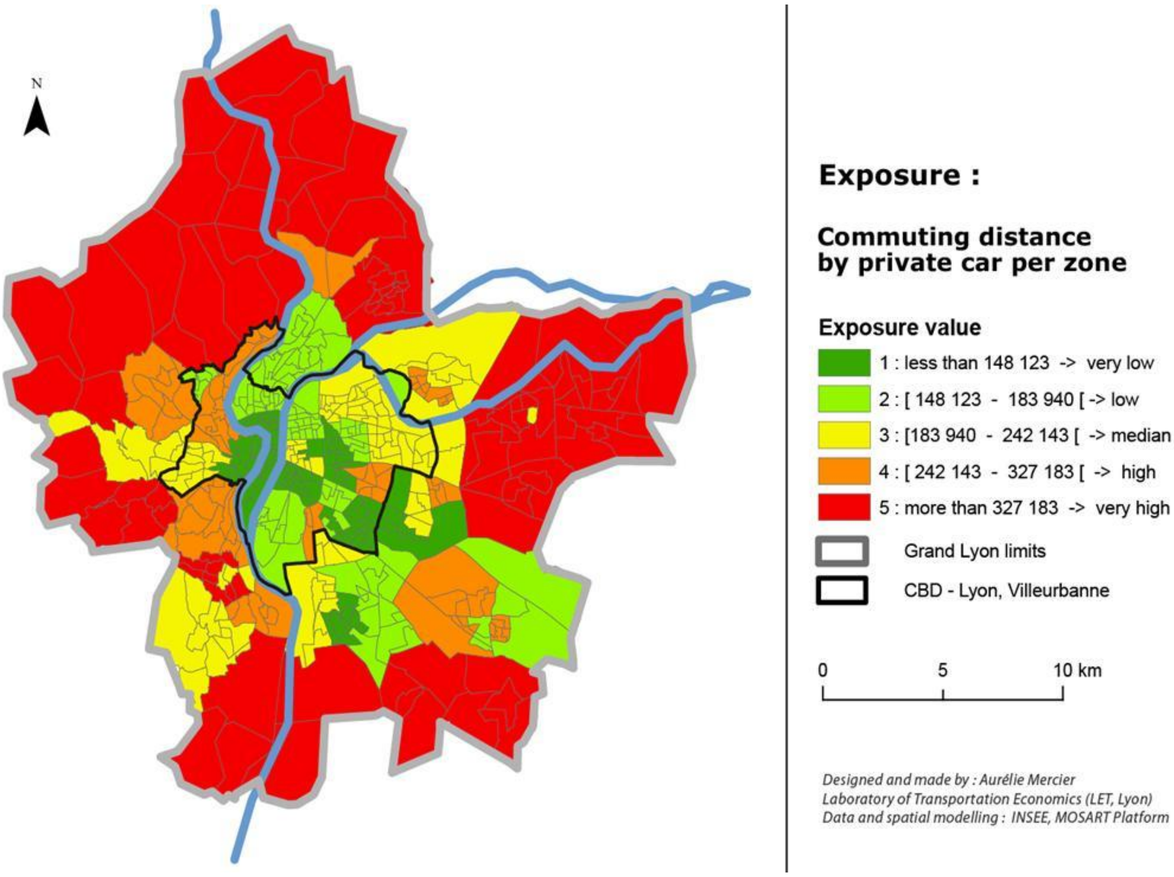

Figure 5: Commuting distance by private car per zone

Commuting distance by private car is higher in municipalities located in the second belt than in the city center or in the first belt. Indeed many inhabitants located on the suburbs have to access the city center for working. Therefore travel distances are longer than for inhabitants living and working in the city center. Moreover from the second belt, car is often more efficient than public transports to access the city center, in spite of congestion in peak hours. Second belt municipalities are not well served by public transport: frequencies are very low and travel time often longer. Urban sprawl and peripheral locations result clearly in a higher level of exposure. In the city center, high impact of metro and tram lines is observed. In areas served by metro or tram, commuting distance by car is lower than other areas always located in Lyon or Villeurbanne.

4.2 Sensitivity assessment

Munich case study

The measurement of sensitivity relies on the two indicators ‘unemployment rate’ and ‘average monthly income’. Both datasets are drawn from the GENESIS online database provided by the Bavaria department of data and statistics (2010). They are available on municipality level. The values of these indicators are illustrated in the maps below.

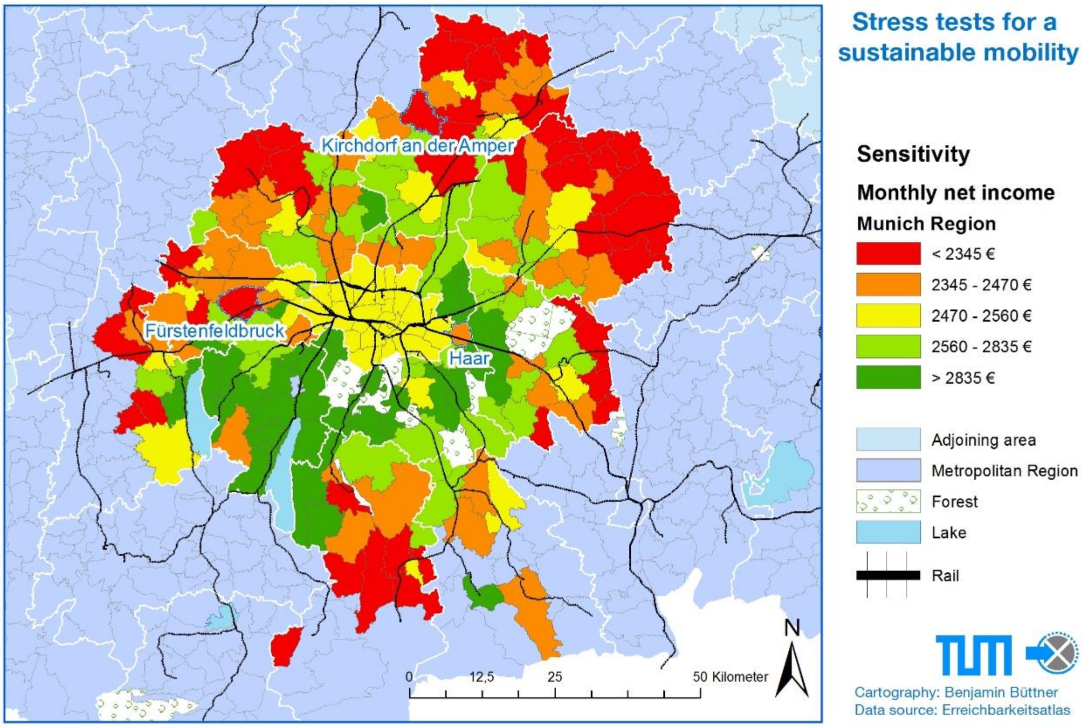

Figure 6: Monthly income in the Munich metropolitan region

The average monthly net income for employees is illustrated in Figure 6. Sensitive municipalities are located mainly at the outskirts of Munich region. On the one hand, combining less than 2.345€ net income with a high VKT these municipalities will suffer severely in the face of an increase in mobility costs. On the other hand, the southwest municipalities have a very low sensitivity due to their relatively high net income of above 2.835€. Therefore even with high number of VKT the green municipalities will not be struck as hard as poorer car dependent regions.

Lyon case study

At the Lyon metropolitan area level, the unemployment rate is calculated as follows:

Unemployment rate is equal to the number of jobs seekers enrolled at Pôle Emploi (2009) divided through the total population (2008). Monthly income refers to data from INSEE. The median income has been chosen to represent sensitivity.

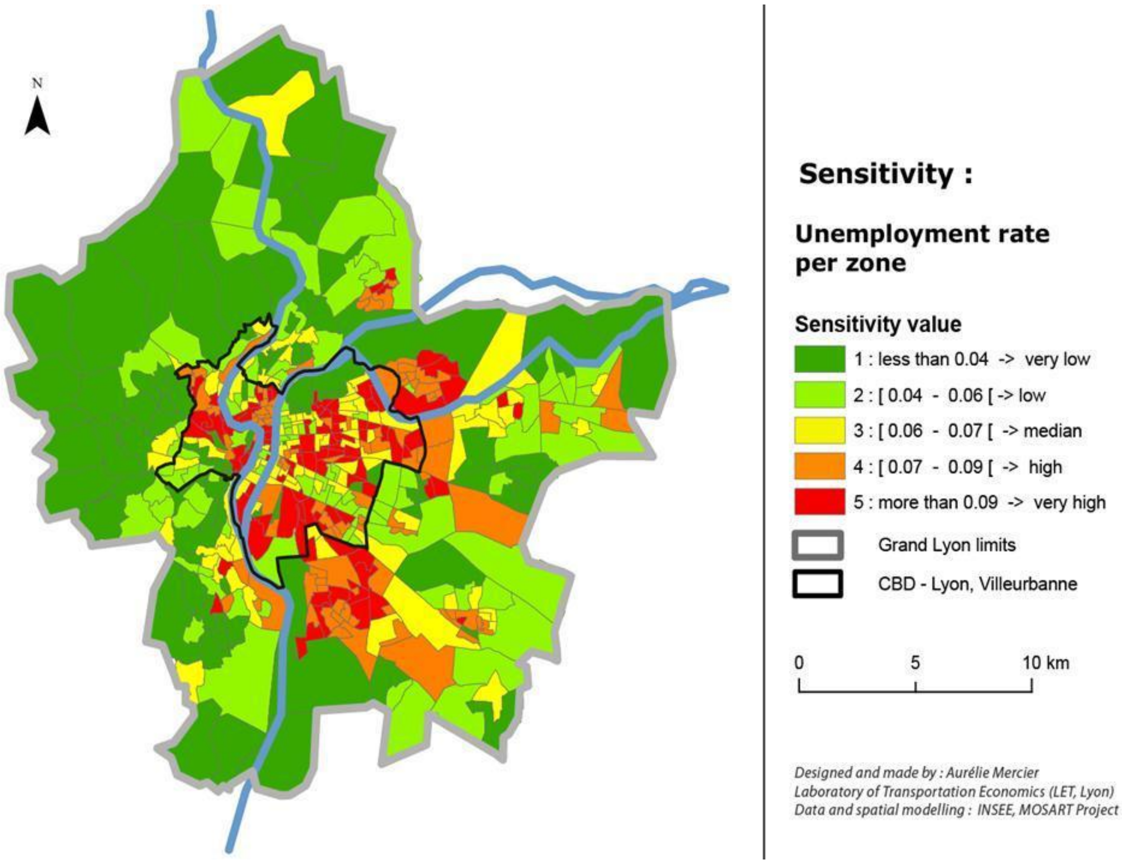

Figure 7: Unemployment rate per zone in the Grand Lyon area

Sensitive areas are mainly located in the city center (municipalities of Lyon and Villeurbanne) and in the east first belt of Grand Lyon. The west belt of the Grand Lyon is not sensitive. Unemployment rate is often lower than 4% of the working population.

Note that in the city there is a significant disparity between areas. The 8th, 9th and the city of Villeurbanne are more sensitive than other parts of the city center. In these zones unemployment rate is higher than 7% and, in some parts higher than 9%.

4.3 Resilience assessment

The level of resilience is measured by accessibility to jobs by public transportation.

Accessibility can be defined by the ease with which opportunities may be reached from a given location using a particular transportation system (Morris et al., 1978). Among the different measures proposed in the literature, the gravity-based measure is used in this case.

The following expression is considered after Hansen (1959):

$$A_i = \sum_{j=1}^{n} E_j \exp^{(-\beta C_{ij})}$$

where E_j represents opportunities in zone j, C_{ij} denotes the travel cost (or generalized cost) between zones i and j, β represents cost sensitivity parameter and n the number of zones.

In this case, the opportunities are defined as jobs due to their high importance in generating traffic.

Munich case study

The accessibility to jobs by public transport during the peak period in the morning serves as key indicator for resilience. Figure 8 displays the total number of accessible jobs within one hour for every municipality.

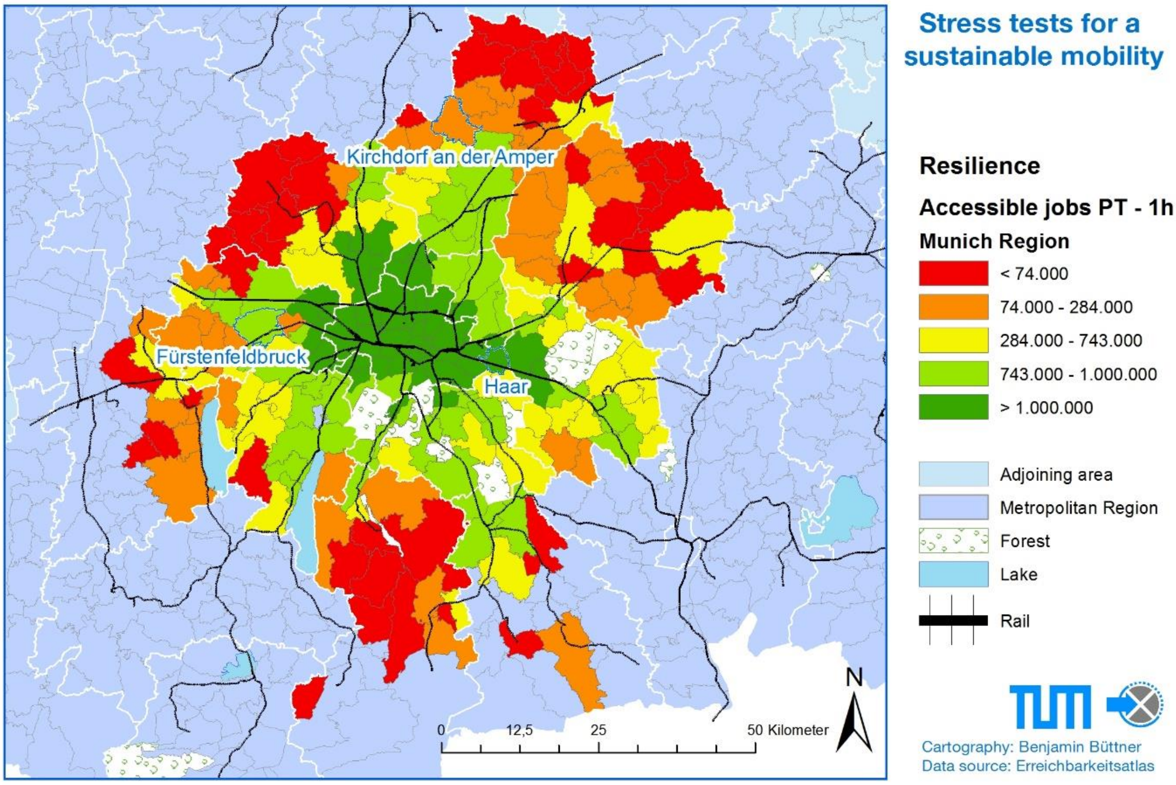

Figure 8: Accessibility to the number of jobs by public transport within in the Munich Region

From the green municipalities more than 1.000.000 jobs are accessible by public transport within one hour. Red municipalities are lacking proper supply of public transport and in most cases closely located jobs. The inhabitants in structurally weak municipalities have limited alternatives to shift to non-fuel powered modes of transport. Thus, the inhabitants are not resilient in the case of escalating fuel prices.

Lyon case study

Isochrone accessibility to jobs is measured for public transport commuters, in the morning peak period. Travel time is computed using a “shortest path algorithm”. Connection and waiting time are also considered for public transport trips.

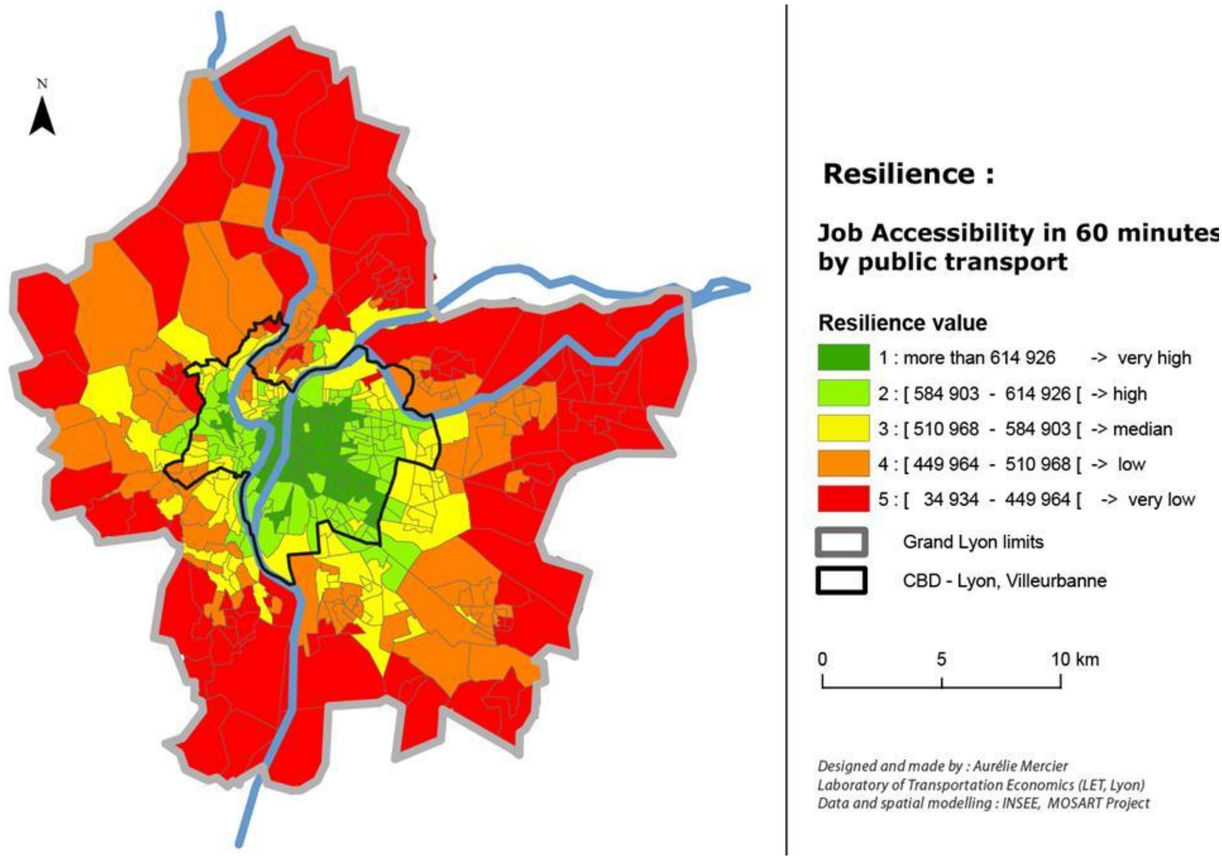

Figure 9: Job Accessibility in 60 minutes by public transport in the Lyon Urban area

The structure of accessibility is given by concentric circles around the city center. The higher distance from the city center is, the lower the accessibility.

Level of accessibility and resilience are highly dependent on tram and subway lines which offer high levels of frequencies and travel speed to link to the city center. Note that the regional rail lines can also offer high level of resilience for inhabitants located around them. Higher levels of service of these lines are mainly observed during morning and evening peak periods. So it is possible to live in a peripheral area but to benefit from a low vulnerability during the peak period when public transit operates at high frequencies. It is also important to notice that it is a targeted resilience. For instance you can shift from car to public transit for the daily trips between home and work. But for other kinds of mobility (leisure, shopping…) this change may not be possible and thus people are less resilient for these types of trips (see Büttner et al. 2012).

4.4 Vulnerability assessment

Munich case study

The vulnerability index is calculated based upon three key indicators for the dimensions exposure, sensitivity and resilience as described in chapter 2.2. Due to the different measures of valuing the three indicators, the order of magnitude varies from each other to a large extent:

exposure has a range from 10 to 100 for driven kilometers, sensitivity ranges from below 2.345 € till more than 2.835 € of net income and resilience from up to 1.000.000 jobs accessible by public transport. In order to make the three indicators qualitatively comparable to each other, a rank from 1 to 100 has been applied to the indicators.

The following assumptions are adopted when assigning the ranks: the more one drives (highly exposed), the more vulnerable she or he is; the less one earns (highly sensible), the more vulnerable; the better public transport accessibility one has (highly resilient), the less vulnerable. From minimum to maximum value of the three indices, the ranks are respectively from 1 to 100 for Exposure, from 100 to 1 for Sensitivity and from 100 to 1 for Resilience, which means with a higher rank, one is more vulnerable. Thus the vulnerability index is defined as the sum of the rank values of these three indices.

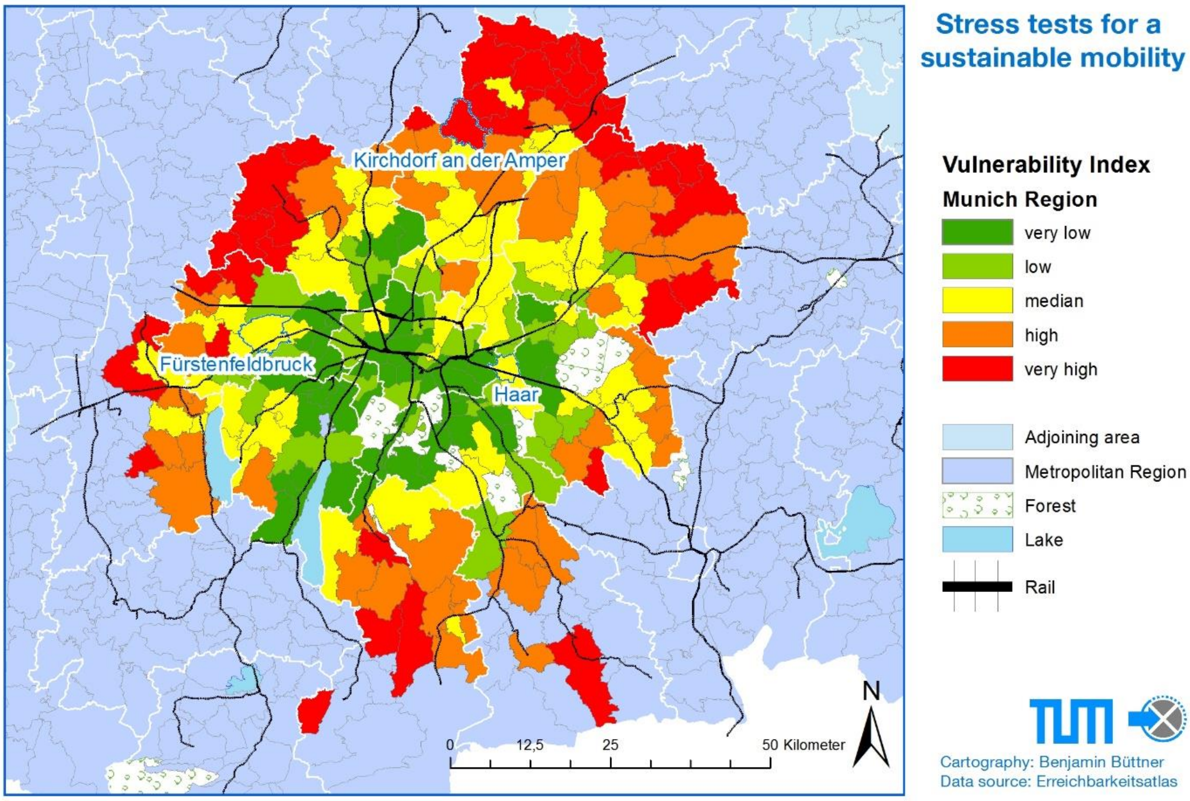

Figure 10: Vulnerability assessment concerning an increase in fossil fuel for Munich region

The green municipalities show low vulnerability to escalating fuel prices in Figure 10. These municipalities are able to cope with sharp future increases in fuel costs. In contrast, the highly vulnerable red municipalities will suffer heavily due to heavy car dependency and use as well as a low average net income. The majority of the vulnerable municipalities are located in between the railway axes or in the peripheral outskirts. Therefore, for a resilient development of the region transit oriented development close to high level public transport stations has to be further fostered.

To maintain the quality of life within these vulnerable municipalities there is an urgent need to allocate mobility alternatives (e.g. public transport supply) as well as facilities/activities for daily needs (e.g. supermarkets, jobs, schools).

Lyon case study

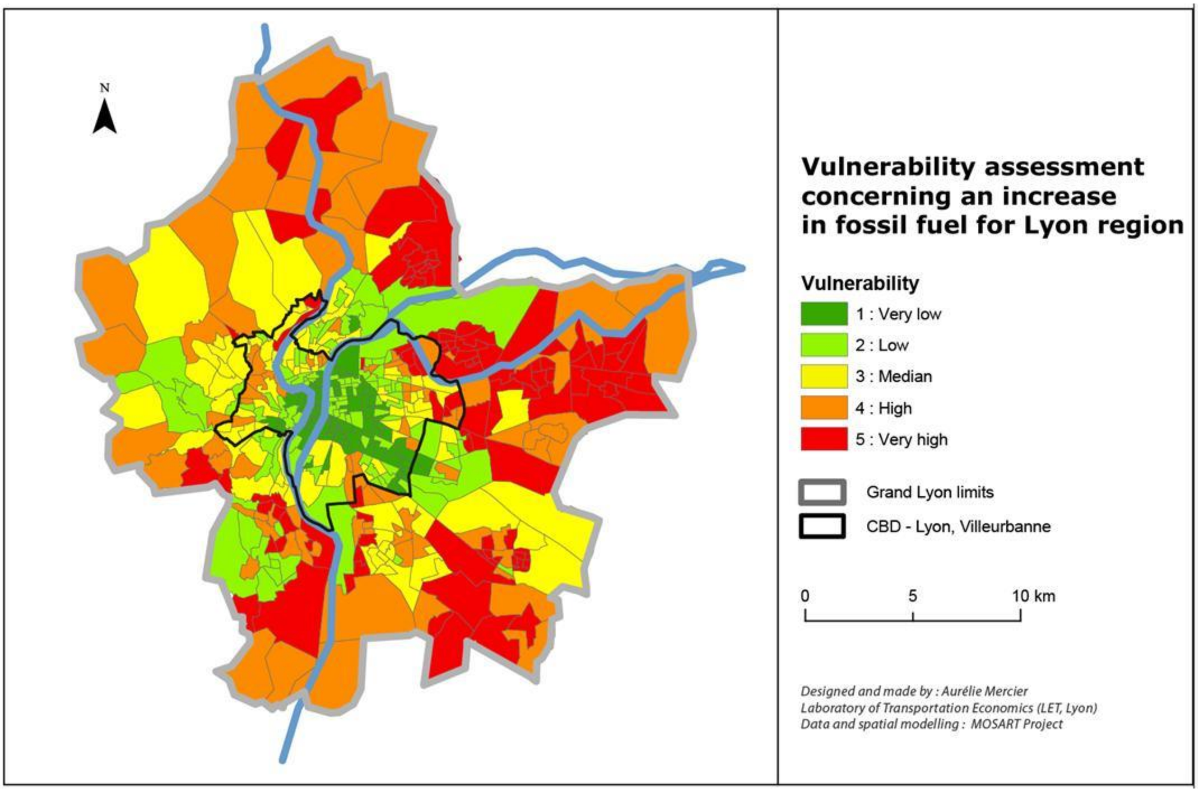

Figure 11: Vulnerability assessment concerning an increase in fossil fuel for Grand Lyon

As for the Munich case study, the vulnerability index is calculated based upon three key indicators for the dimensions exposure, sensitivity and resilience. It is not surprising to observe that zones located in the city center have a very low level of vulnerability. Indeed, in spite of unemployment rate often higher than 6%, these zones are not very exposed owing to a high quality of services offered by public transport lines like tram or subway. Outside the city center, north-eastern and southern municipalities are faced with higher levels of vulnerability. Because of a lack of public transport lines, their inhabitants have to use a private car for their daily trips. Their resilience level is very low. This vulnerability explains why the “Region Rhône-Alpes”, the public authority in charge of local trains, has developed an ambitious program of new trains, and even tram-trains, with a higher frequency. The result is a growing saturation of these trains during peak hours, another source of vulnerability.

5. Discussion and Outlook

By adapting the methodology of vulnerability assessment, regions (municipalities or zones) can be tested for their respective future viability in case of a sharp increase in mobility costs. While dependent on data availability, for proper analysis it is of high importance to select reasonable indicators. For benchmarking and comparing two case studies the same regional scales as well as the same indicators need to be chosen.

However it is not advisable to state individual impacts of increasing mobility costs on municipal averages. Therefore, an analysis of households has been performed in the study regions, to point out the individual effects and differences persons are facing (see Büttner et al. 2012). As a result of drastic stress tests scenarios, individual strategies are formulated for maintaining social and economic participation, even while tripling gas prices.

Severely affected municipalities by increasing fuel prices have been elaborated for Munich as well as for Lyon. In these case studies the vulnerability assessment has been proven to be a very capable platform for discussing how to prepare municipalities with the respective decision makers (compare Turner et al., 2003). Recommendations, strategies and policies can be developed upon this. In the end this will lead to more sustainable mobility behaviour and ensures the quality of life for all, no matter the spatial location or the social standing.

Literature

Adger, W. Neil (2006): Vulnerability. In: Global Environmental Change 16 (3), pp. 268–281.

Büttner, B., Franz, S., Reutter, U., Wulfhorst, G. (2012): MOR€CO – Mobility and Residential Costs: Improving the Settlement Development in the Transnational Alpine Space Region, Vienna.

Earth Policy Institute (Ed.), 2012: Search | Earth Policy Institute. Online: http://www.earth-policy.org/search?q=oil%20prices, 31.10.2012.

Hansen W.G., 1959: How accessibility shapes land use, Journal of the American Institute of Planners 25, pp. 73-76.

Kasperson, J.X, Kasperson, R.E, Turner, B.L., Hsieh, W., Schiller, A., 2006: Vulnerability to global environmental change. In: Rosa, E. et al. (eds.): The Human dimension of Global Environmental Change. Cambridge, MA: MIT Press.

Kelly, P.M., Adger, W.N., 2000: Theory and practice in assessing vulnerability to climate change and faciliting adaptation", In: Climatic change 47, 325-352.

Leary, N., Beresford, S., 2007: Vulnerability of people, places, and systems to environmental change. In: Knight, G. and Jaeger, J. (eds): Integrated regional assessment. Cambridge University Press, Cambridge, UK.

Morris J.M., Dumble P. L., Wigan M. R., 1978: Accessibility indicators for transport planning, Transportation research A 13, pp. 91-109.

The World Bank (Ed.), 2012: GDP growth (annual %) | Data | Table. Online: http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG/countries, 31.10.2012.

Turner et al. (2003): A framework for vulnerability analysis in sustainable science. In: PNAS (100), pp. 8074–8079.

PART II: PAPER 2

Ensuring accessibility to daily activities for different population segments with respect to sharp increases in mobility costs

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This draft chapter has been published by Edward Elgar Publishing in “Accessibility, Equity and Efficiency: Challenges for Transport and Public Services” edited by Karst T. Geurs, Roberto Patuelli and Tomaz Ponce Dentinho published in 2016.

https://www.elgaronline.com/view/9781784717889.00013.xml

Abstract

The share of the household budget being spent on mobility is rising dramatically (Büttner et al., 2013). While residential costs can be estimated both easily and accurately, mobility costs and travel times are often underestimated or even ignored in household location decisions (see Büttner et al. 2012). This disconnect between mobility costs and household location decisions is having a serious impact on the budgets of households in the Munich region of Germany.

This paper aims to analyze how changes in mobility constraints – due to the influence of rising mobility costs on household budgets – can impact daily activity schedules, mobility behavior, and residential and activity locations. By applying prospective shocks to mobility costs, the research seeks to explore and evaluate the resilience of different households to such shocks (i.e., the ability of a household to absorb mobility cost stresses without changing its fundamental structure).

The study found that a fuel price shock based on US $200 per barrel would have a limited impact on household activities and only a limited effect on short-term mobility behaviors. The shock tripling of petrol prices however, was found to greatly test household resilience. Under such a shock, households would be either forced to modify or completely revamp their mobility behaviors, scenarios of which are difficult to achieve for the most vulnerable households – often private car reliant lower to middle class demographics living in suburban areas with poor public transport access.

Communities can better prepare for and adapt to increases in mobility costs only once governments recognize the interdependencies between land-use and transport. Through discussing with local stakeholders and decision makers; intervention strategies, policies and recommendations can be established so as to improve public transport infrastructure and to better implement more efficient land-use and accessibility measures. These measures should aim to place a greater emphasis on dense and mixed-use development patterns that focus on improving the (non-motorized) accessibility of jobs and daily activities.

1. Background

Despite the mobility share of the household budget rising dramatically, mobility costs and travel times are often underestimated or even ignored in household relocation decisions (Büttner et al., 2013; Büttner et al. 2012). At the same time residential costs – a monthly mortgage, for example – remain the focal point for households in deciding where to relocate (Haller et al. 2012).

The Munich region is a prominent example of how migration and especially the growth of labor can effectively cause such a disconnect between residential location decisions and mobility costs. The current shortage of housing in Munich is resulting in sharp increases in housing costs (Bulwiengesa 2014), with the most expensive housing market in Germany standing as a barrier between the less skilled and the wealthy. As a consequence, immigration to the city of Munich is very costly and in most cases ends in the outer suburbs or even in more remote and correspondingly affordable locations (Lohr 2013). This lack of proper regional planning, in terms of labour as well as housing, is resulting in growing distances for both commuting and completing activities as well as fulfilling basic needs.

2. Research Context and Objective

The majority of the world's population relies on fossil fuels for their everyday mobility, mostly by means of a private car (Kahn Ribeiro et al. 2007). However, the combination of a multitude of factors – including political instability in oil producing countries, volatility in supply, increasing consumer demand, and peak oil – is resulting in sharp and unpredictable increases in mobility costs for households (Wegener 2009). In this context, it is important to research transportation alternatives and strategies so that households can adapt to these increases in mobility costs.

The complete three-paper series (see Figure), details the consequences of sharp increases in mobility costs on accessibility. The first paper (a vulnerability assessment) aims to scan and subsequently highlight which regions in Munich are in danger of increasing mobility costs (see Büttner et al. 2013). After having determined the characteristics of each region, an exploration of individual households is undertaken by the second paper, with each household's mobility behaviors analyzed in order to develop a range of different storylines which portray real-life reactions to mobility price shocks. To conclude, the third paper aims to give local stakeholders and decision makers accessibility recommendations in order for them to be better prepared on the spatial scale.

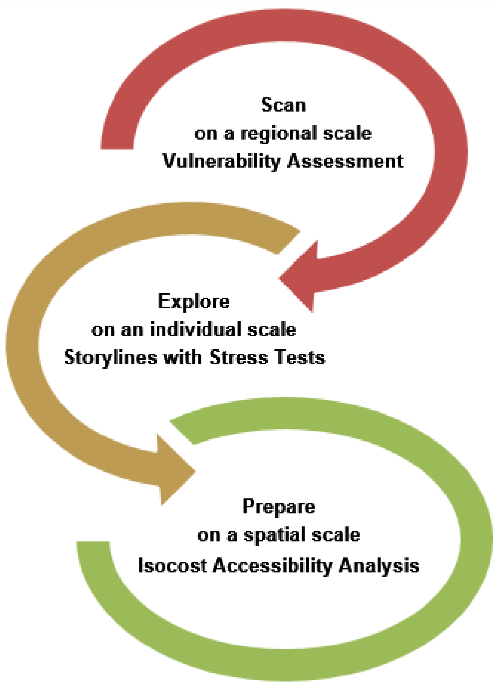

Figure 1: Scan-Explore-Prepare paper series methodology

The first paper, entitled "The impact of sharp increases in mobility costs analyzed by means of the Vulnerability Assessment" (Büttner et al., 2013) presents the methodological approach of a vulnerability assessment (adapted from Kelly and Adger 2000; Kasperson et al. 2006) used within the Munich region. This assessment was performed with a combination of three key indicators: exposure (fossil fuel consumption), sensitivity (income) and resilience (accessibility to jobs by public transport). Following the assessment, three municipalities representing different settlement structures (urban, sub-urban and rural) were selected in order to better understand and characterize localized differences in vulnerability. The vulnerability assessment resulted in the composite vulnerability index shown in Figure .

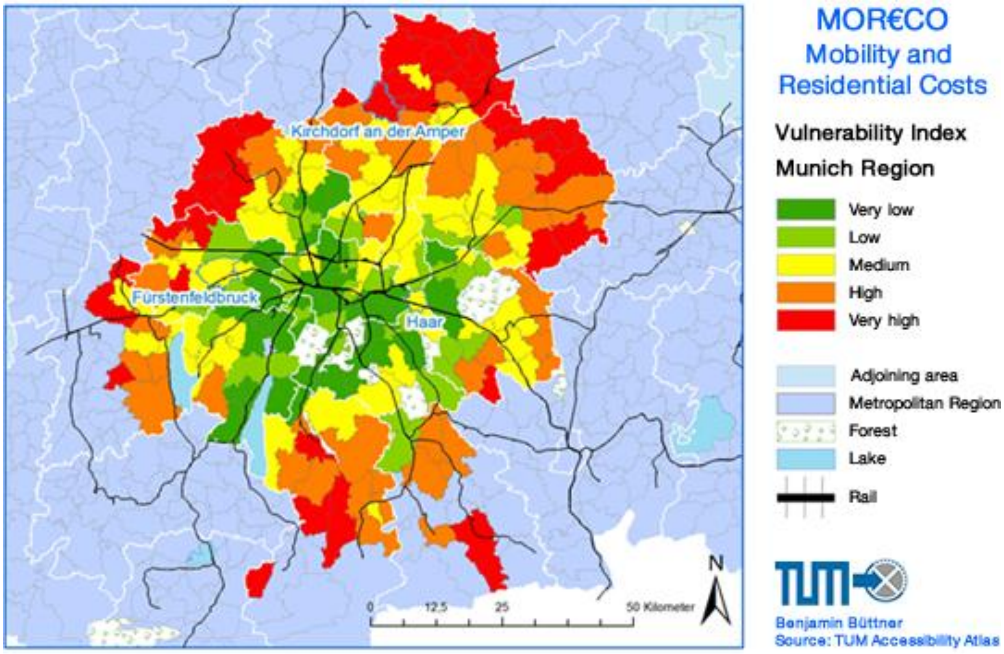

Figure 2: Vulnerability related to increases in fuel prices in the Munich region

This paper, the second part of the series, aims to investigate the initial vulnerability assessment through analyzing how different changes in mobility constraints can impact daily activity schedules, mobility behavior, and residential and activity locations. The research seeks to explore and evaluate the resilience of three households by applying prospective shocks to mobility costs (i.e., severe mobility price increases). With studies on the Munich region indicating that the mobility share of the household budget is increasing (Büttner et al., 2013), making sense of how these price shocks influence household mobility is becoming ever more crucial.

In most cases, vulnerable households are only able to change their mobility behavior once they are offered more viable transport options or alternatives. Aiding governments in recognizing the interdependencies between land-use and transport can help vulnerable communities better prepare for as well as adapt to increases in mobility costs. Recommendations to public stakeholders and decisions makers have to be based on detailed analyses on a regional level taking into account the development of future residential and mobility costs. In order to foster such sustainable spatial development, policies, intervention strategies, and recommendations – which concern dense and mixed-use development patterns alongside the accessibility of jobs and daily activities – should be discussed (Hull et al. 2012). This is reinforced by Geurs et al. (2012) which states the importance of testing the current accessibility analysis in practice. For the implementation of accessibility planning, a strong collaboration between researchers and planning practitioners is needed.

In this paper, stress-tests have been adapted to urban mobility in order to test the effects of potential external shocks on accessibility and mobility. The next section presents the data and methodology developed to implement the stress-test approach, with the subsequent section analyzing each household’s reaction to these external mobility shocks.

3. Data and Methodology

This section establishes the methodology implemented to apply stress-tests on the urban mobility of three households in Munich, Germany. Households consisting of varying representative demographics and structural data were used so as to possibly highlight a range of reactions to fuel price shocks.

3.1 Household identification

Synthetic households and each of their respective mobility behaviors were derived by analyzing a range of regional databases. Spatial patterns of movement and their corresponding causes were determined based on the migration analysis within the Munich region (Wanderungsmotivuntersuchung II, Landeshauptstadt München 2012). The study “Mobility in Germany on the level of the region of Munich” (Mobilität in Deutschland (MiDMUC), Landeshauptstadt München 2010) yielded socio-demographic characteristics of the population, as well as spatial trip patterns and their corresponding modes of transport. The Bavarian State Office for Statistics and Data Processing provided population data on the municipality level. The GIS-based “TUM Accessibility Atlas” (Büttner et al. 2011) helped with the initial estimation of the community structures and was subsequently used for the implementation of the data and households. The local communities reviewed in advance the generated synthetic households (including the individual mobility patterns) and confirmed whether they were relevant and reasonable.

3.2 Mobility and activity behavior

Housing and activity locations were primarily determined from the activity programs detailed in the Munich databases, with the origins and destinations being spatially referenced. To calculate the mobility costs and travel times for the synthetic households (based on the individual trip-chains and spatially referenced activities), the Munich Transport and Tariff Association (MVV) WoMo calculator was used (see Haller et al. 2012). In the case of relocation, residential costs were also considered. Using the actual address data of the corresponding origin and destination relationships for the calculated activities (work and education, supply, leisure), the GIS-based TUM Accessibility Atlas facilitated the initial estimation and visualization of the individual mobility behaviors and spatial trip patterns. The

TUM Accessibility Atlas was subsequently used for the implementation of the data and households.

3.2.1 Stress-tests and assumptions

The primary purpose of this research was to analyze the impacts of oil shocks on daily mobility costs and travel behavior, following a ceteris paribus approach.

Many studies (e.g., Institut für Mobilitätsforschung 2010) predict a rise in the crude oil price to US $200 per barrel. Stress-test n°1 aims to demonstrate the effects of such an increase, which would effectively cause the price of fuel at German petrol stations to rise to 2.11 €/L. The jump from 1.55 €/L to 2.11 €/L can be considered to be only a moderate shock (a 35% increase).

Outside the reality of crude oil prices reaching US $200 per barrel, stress-test n°2 details the effects of fuel prices tripling. This increase, which became a reality in the US between the years of 2007 and 2008, would force German households into spending 4.65 €/L for fuel.

The stress-test scenarios were implemented in line with a simplified economic approach. The research did not focus on the economic theory and variables related to gradual oil price increases, but instead, concentrated on how households would react to sudden drastic oil price hikes. Because of this, it was assumed that a rise in fuel prices would appear rather suddenly, which would have an immediate effect on the price consumers pay when refueling.

With these conditions in mind, the following assumptions were made:

- Shocks on mobility appeared suddenly and consequently were not planned for by households, allowing for no rapid household structural changes in terms of size and location;
- Oil price shocks did not have any effect on housing and rent prices, resulting in households maintaining their housing budgets;
- Shock alternatives depended only on households. Public authorities could not respond to these shocks;
- No public measure such as tax decreases, fuel subsidies or fuel vouchers could be implemented to absorb, even partially, the shocks;
- Proposed shocks only referred to daily mobility; long distance travel was not impacted by these shocks as it was considered to be outside the scope of a household’s everyday needs.

- Public transport costs would rise more moderately and therefore allow people more time to adapt, since public transportation costs are based less on market forces and more on ones of a political nature.

4. Stress-Tests Reactions

This chapter is dedicated to three households, all of which are based on varying representative demographics and structural data.

- Household 1: a four person family who move from the inner-city to the city outskirts, characterized by their inability to make flexible changes to their mobility behavior.
- Household 2: a 31 year old single male who recently moved interstate to Bavaria for his new job within the city of Munich.
- Household 3: a married couple in their 70s, living on the rural periphery of the city who rely on a car for their mobility.

Within the MOR€CO project report (see Büttner, Wulfhorst 2012), further representative households are included for a range of different structural settings (e.g., age, income, residential locations, etc).

4.1 Household 1

Current mobility behavior

A family of four, living in the inner-city of Munich represents the first household. With the father having accepted a new job on the outskirts of the city, the family eventually decide to move from the city center closer to the father’s place of employment.

Table 1: Members of Household 1

Person	Age	Work / Education
Father	40	Full time
Mother	39	Part time
Son	9	Elementary school
Daughter	5	Kindergarten

Table 2: Household 1 in Au-Haidhausen

Address	Floor Space (m²)	Living Costs (€/month)	Income (€/month)	Number of Rooms	Number of Cars
Preysingstraße 67 Au-Haidhausen	89	1,332	3,750	3	2

Work and education

The father initially works full time for a company whose offices are located in the city center (Ottostraße 13). In order to avoid traffic jams during peak hours, he takes advantage of their house's high public transport accessibility to travel to his work place.

The mother in contrast has a part-time job and works five days a week nearby the city center (Kapuzinerplatz 1). She is not always able to use public transport because of the high flexibility demanded by her lifestyle which requires combining daily activities (e.g., taking the children to school and then driving to work). As she is more car dependent, she uses her own car twice a week to go to work. This allows her to link several activities easily and flexibly.

The children's school (Flurstraße 8) is located close to their home and the kindergarten can be reached by foot.

Leisure

On Tuesday evenings the father usually plays soccer with his friends in the Olympic Park (Connollystraße 32). Even though he could go there with public transport he prefers to use his own car.

The mother meets her friends in the city center once a week (Hohenzollernstraße 25). Most of the time she goes by public transport, however, she also thinks about potential trip chains that could be conveniently linked by car.

The central location of the family's home is an advantage, as leisure activities for the children (e.g., music and sports) are located within walking distance (Flurstraße 8).

Infrequent trips

Possibilities for daily shopping are available close to the family's home location. On weekends, however, they use their car for going to a bigger shopping center on the outskirts of Munich while trying to combine these trips with leisure activities like going bowling or to the cinema (Thomas-Dehler-Straße 12).

Once a month, the entire family goes for a day trip outside Munich, for example hiking or visiting friends (Beccostraße 12). For this activity they usually take one of their cars.

Other infrequent trips – for example going to the barber (Innere Wiener Straße 48), special occasion dinners or meetings – are made by public transport. On the other hand, the parents use the car to drive their children to other infrequent activities, e.g., going to the doctor (Karl-Theodor-Straße 97).

Table 3: Activities of Household 1

Person	Frequent Activities				Infrequent Activities (Monthly)	
	Work Days		Leisure (Weekly)			
Father	Full time	Ottostraße 13 (City center)	Soccer	Connollystraße 32 (Olympic Park)	Barber	Innere Wiener Straße 48 (Au-Haidhausen)
Mother	Part time	Kapuzinerplatz 1 (Isarvorstadt)	Meeting friends / dinner	Hohenzollernstraße 25 (Schwabing)	-	
Son	School	Flurstraße 8 (Au-Haidhausen)	Music academy	Flurstraße 8 (Au-Haidhausen)	Doctor	Karl-Theodor-Straße 97 (Schwabing)
Daughter	Kindergarten	Flurstraße 8 (Au-Haidhausen)			Doctor	Karl-Theodor-Straße 97 (Schwabing)
Together			Shopping / bowling / movie theatre	Thomas-Dehler-Straße 12 (Neuperlach)	Visiting family / hiking	Beccostraße 12 (Pöcking)

After the father accepts a new job in Karlsfeld, and considering the commuting time from their place in Au-Haidhausen, the family decides to move to a closer residence in Aubing. From here, Karlsfeld can be reached by car within 14 minutes via the A99 highway. The drive from the new residence to the mother's work takes 24 minutes, which is acceptable as well. Additionally, the new location is accessible by the S-Bahn suburban train, which provides direct services to the city center. The station is quite close to the new house, at just 1 km away.

Moving to the outskirts, in order to be closer to the father's new job, also enables the family to live in a green area where rent prices are lower compared to the city center.

Table 4: Household 1 in Aubing

Address	Floor Space (m²)	Living Costs (€/month)	Income (€/month)	Number of Rooms	Number of Cars
Industriestraße 61 Aubing	120	1,400	3,750	4	2

Since they neither want to lose contact with friends nor dramatically change their habits, they continue to practice exactly the same activities as before. Leisure activities such as playing soccer and meeting friends in Munich are going to remain part of their weekly schedule.

Overall, Aubing has a high public transport accessibility, but the move will still influence the family's monthly transportation expenditure significantly.

Shock scenario - increase to 2.11 €/L

An increase in fuel prices to 2.11 €/L (US $200/barrel) would not have a dramatic impact on the family's household budget. Only €77 less would be available per month, compared to the pre-shock scenario.

This slight increase in expenditure would most likely not cause a change in the family's mobility behavior. Nevertheless, some suggestions can be made concerning potential modifications in order to reach the same level of mobility costs as before the price shock.

The mother could use park and ride (P+R) four times a week to go to work, instead of solely relying on her car. Only when she meets her friends in the city center should she take the car, in order to remain flexible. Another simple alternative to save €30 per month would be to change the weekly route to the music academy. In the pre-shock scenario the mother drives her child to school via highway A99 (35 km), however, using a more direct route (22 km) would also save money.

These changes in mobility behavior have important drawbacks concerning time expenditure. If mobility patterns are modified as suggested, the household would spend an extra 477 minutes travelling per month.

Table 5: Increase to 2.11 €/L – expenditure summary for Household 1 in Aubing

Type of Expenditure		Mobility Scenario Costs		
		1.55 €/L	**2.11 €/L**	**2.11 €/L (incl. P+R change)**
Living costs per month	Net rent	1,100	1,100	1,100
	Additional living costs	300	300	300
	Total	1,400	1,400	1,400
Mobility costs per month	Car ownership	800	800	800
	Car use	348	426	284
	Public transport	25	25	0
	Commuting allowance savings	91	91	91
	Total	1,082	1,159	1,059
Travel time (minutes/month)		2,572	2,572	3,049

Table 6: Increase to 2.11 €/L – budget summary for Household 1 in Aubing

Income and Expenditure	Mobility Scenario Total Costs		
	1.55 €/L	**2.11 €/L**	**2.11 €/L (incl. P+R change)**
Net income (€)	3,750	3,750	3,750
Mobility and living costs (€)	2,482	2,559	2,459
Ratio	66%	68%	66%
Disposable income (€)	1,268	1,191	1,291

Shock scenario - increase to 4.65 €/L

A jump in fuel prices to 4.65 €/L (i.e., a tripling of current prices) would have a drastic impact on the household budget. Each month, the family would spend an extra €429 compared to their current situation, leaving approximately 20% of their budget for disposable income.

Assuming the family wants to maintain the same budget as before the price shock, they aim to become more budget efficient in relation to their mobility patterns. All family members have to contribute to this aim by using public transport for daily activities. The mother will experience a time loss of 20 minutes on her way to work (one way). She continues using the car for a trip chain once a week (leisure activities combined with work) as this requires a certain level of flexibility. The son will also go to music school by public transport, losing 10 minutes per trip (one way). The father suffers most from this new situation, as he is forced to spend an extra 49 minutes traveling on his way to work.

The father's extra travel time is one major drawback of the chosen residential location, as the public transport connection to his work place in Karlsfeld is very inconvenient compared to the car. For all remaining car trips, the shortest route will be chosen in order to minimize fuel consumption. Due to these changes in everyday mobility, the family's small car is not necessary anymore and can be sold. This saves €350 of fixed car ownership costs per month.

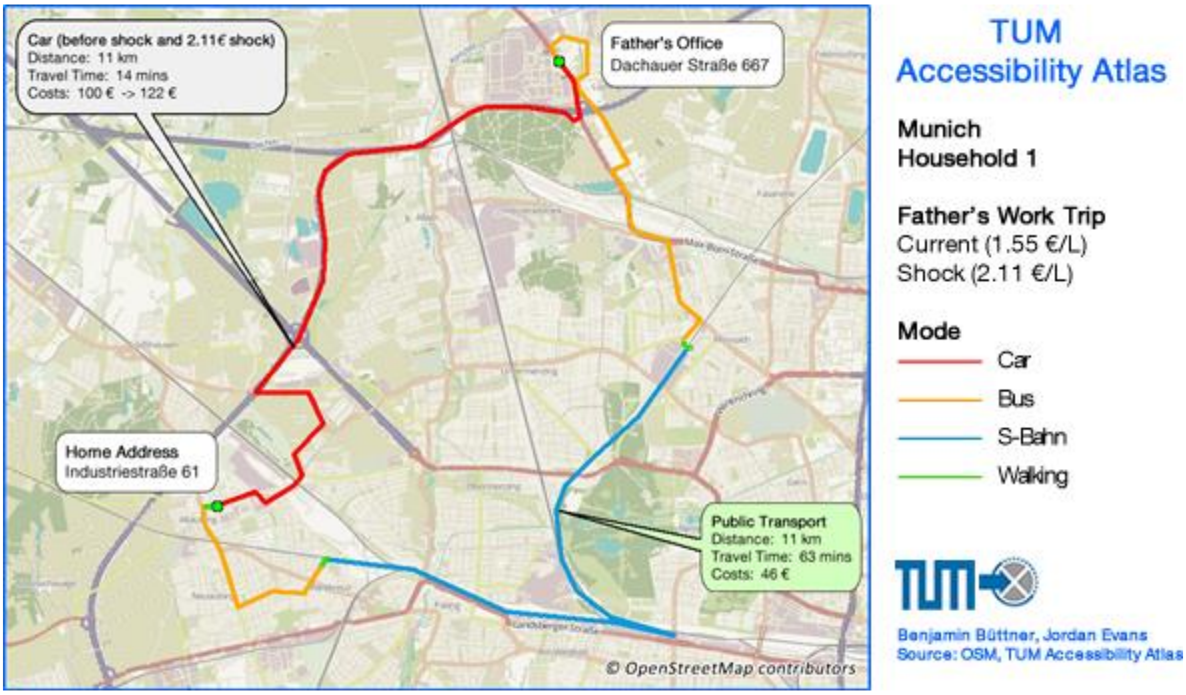

Figure 17: Household 1 shock scenarios and alternatives

If mobility patterns are modified as suggested above, the household would spend an additional 2 997 minutes or 50 hours travelling per month. However the negative aspects regarding time losses can be deemed to be levelled out by the financial gains. Selling one car and adapting the family's trip behavior will save €408 per month (compared to the pre-shock situation). A pure change in mobility patterns without selling the car would still leave available an extra €74 in the family's budget.

Table 7: Increase to 4.65 €/L – expenditure summary for Household 1 in Aubing

Type of Expenditure		**Mobility Scenario Individual Costs**			
		1.55 €/L	**4.65 €/L**	**4.65 €/L (incl. PuT)**	**4.65 €/L (incl. PuT + Selling Car)**
Living costs per month	Net rent	1,100	1,100	1,100	1,100
	Additional living costs	300	300	300	300
	Total	1,400	1,400	1,400	1,400
Mobility costs per month	Car ownership	800	800	800	450
	Car use	348	777	164	180
	Public transport	25	25	136	136
	Commuting allowance savings	91	91	91	91
	Total	1,082	1,159	1,008	674
Travel time (minutes/month)		2,572	2,572	5,569	5,569

Table 8: Increase to 4.65 €/L – budget summary for Household 1 in Aubing

Income and Expenditure	Mobility Scenario Total Costs			
	1.55 €/L	4.65 €/L	4.65 €/L (incl. PuT)	4.65 €/L (incl. PuT + Selling Car)
Net income (€)	3,750	3,750	3,750	3,750
Mobility and living costs (€)	2,482	2,911	2,408	2,074
Ratio	66%	78%	64%	55%
Disposable income (€)	1,268	839	1,342	1,676

4.2 Household 2

Current mobility behavior

A 31-year old man, residing in Haar, represents the second household. He works full time and has recently moved to Bavaria due to accepting a new employment opportunity. As his new workplace is located in Messestadt Ost, he is concentrating his apartment searching efforts in the area.

Table 9: Members of Household 2

Person	Age	Work / Education
Single male	31	Full time

Table 10: Household 2 in Haar

Address	Floor Space (m²)	Living Costs (€/month)	Income (€/month)	Number of Rooms	Number of Cars
Ludwig-Thoma-Straße 33 Haar	61	813	2,500	2	1

Work and education

The man’s workplace is located in Hans-Schwindt-Straße and is not far from his apartment. By car he needs only 14 minutes to reach the office, while with commuter and underground rail services he requires 51 minutes (see Figure).

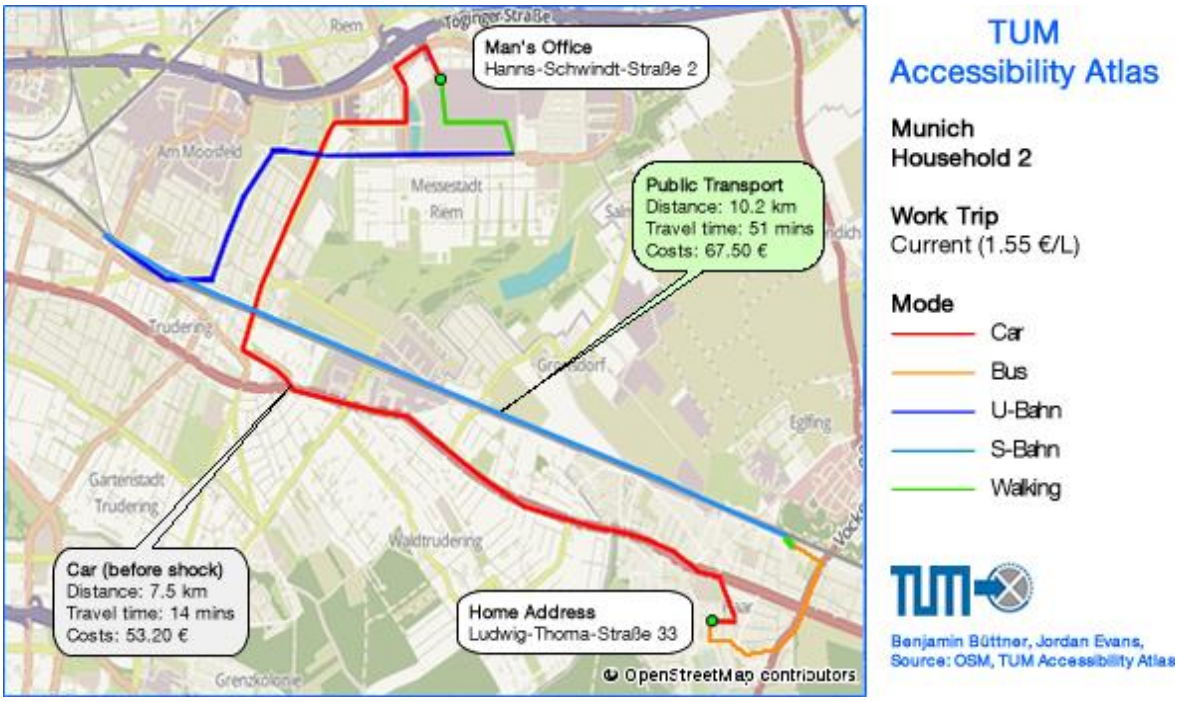

Figure 4: Household 2 shock scenarios and alternatives

Leisure

Through using the car, the man can be rather flexible while trying to combine activities (e.g., sport and shopping) with his trip to work. By doing this he saves both time and money, however, he can clearly save more by either cycling or using public transport. Despite the offered flexibility, the car-based trip-chains are not the most efficient in terms of cost and emission savings.

As the man's friends live in Munich, he drives relatively often on the weekends to eat out, as well as to go walking and shopping through the pedestrian mall. Although the commuter rail service would provide the most optimal connection for these activities, the man prefers to use his car so as to not be dependent on public transport. He is willing to accept the traffic on the road as well as the time taken to search for a parking-spot and the related parking fees.

Infrequent trips

In his free time, the man drives to the mountains to go hiking or skiing. In addition, he uses his car to go to the lake in order to go swimming with friends (Untere Seefeldstraße 14, Weßling).

Table 11: Activities of Household 2

Person	Frequent Activities				Infrequent Activities (Monthly)	
	Work Days		Leisure (Weekly)			
Single male	Full time	Hanns-Schwindt-Straße, Munich	Sport/Supermarket	Münchener Straße, Haar	Hiking / Lake	Untere Seefeldstraße 14, Weßling
			Meeting with friends	Leopoldstraße 48, Munich		

Shock scenario - increase to 2.11 €/L

The man, who is both young and living alone, is only slightly affected by the fuel price increases to 2.11 €/L. In line with spending half his income on mobility and living expenses, such an increase in fuel prices only equates to an extra 33 € in the man's mobility costs each month.

Just like Household 1, the man's mobility behavior would most likely not be affected by this minor increase in mobility expenses. His flexibility, in terms of being single and having half his income for disposable means, offers him resilience in being able to absorb mobility cost stresses without changing the fundamental structure of his mobility behavior.

Assuming the man is willing to change his mobility behavior, so as to prepare himself for future fuel price spikes, he can also choose to start using public transport. Through offsetting the extra 33 € in mobility costs to public transport instead, while reducing the use of his car and hence the costs involved in doing so, the man can approximately maintain the same mobility costs.

Table 12: Increase to 2.11 €/L – expenditure summary for Household 2 in Haar

Type of Expenditure		Mobility Scenario Individual Costs		
		1.55 €/L	**2.11 €/L**	**2.11 €/L (incl. PuT)**
Living costs per month	Net rent	641	641	641
	Additional living costs	172	172	172
	Car ownership	350	350	350
	Total	813	813	813
Mobility costs per month	Car use	151	184	118
	Public transport	0	0	68
	Commuting allowance savings	26	26	26
	Total	475	508	510
Travel time (minutes/month)		1,538	1,538	2,708

Table 13: Increase to 2.11 €/L – budget summary for Household 2 in Haar

Income and Expenditure	Mobility Scenario Total Costs		
	1.55 €/L	**2.11 €/L**	**2.11 €/L**
Net income (€)	2,500	2,500	2,500
Mobility and living costs (€)	1,288	1,321	1,323
Ratio	52%	53%	53%
Disposable income (€)	1,212	1,179	1,177

Shock scenario - increase to 4.65 €/L

In the event of a fuel price increase to 4.65 €/L, the man would have 183 € less disposable income in the month. Despite such a large increase in driving costs, he can be deemed as not being so dramatically affected, predominantly due to his initial less than economical mobility behavior.

For example, the man can save money by using public transport for his commute to work, while relying on park and ride services for leisure activities. Such changes in his mobility patterns would take up an extra 50 minutes of time per day (see Table).

If the man were to decide to use public transport more frequently, it would be economical for him to sell his car. This would allow for a further mobility cost reductions, which could be used to purchase a public transport ticket subscription.

Table 14: Increase to 4.65 €/L – expenditure summary for Household 2 in Haar

Type of Expenditure		Mobility Scenario Individual Costs		
		1.55 €/L	**4.65 €/L**	**4.65 €/L (incl. P+R and PuT)**
Living costs per month	Net rent	641	641	641
	Additional living costs	172	172	172
	Total	813	813	813
Mobility costs per month	Car ownership	350	350	350
	Car use	151	334	126
	Public transport	0	0	68
	Commuting allowance savings	26	26	26
	Total	475	658	518
Travel time (minutes/month)		1,538	1,538	2,843

Table 15: Increase to 4.65 €/L – budget summary for Household 2 in Haar

Income and Expenditure	Mobility Scenario Total Costs		
	1.55 €/L	**4.65 €/L**	**4.65 €/L**
Net income (€)	2,500	2,500	2,500
Mobility and living costs (€)	1,288	1,471	1,331
Ratio	52%	59%	53%
Disposable income (€)	1,212	1,029	1,169

4.3 Household 3

Current mobility behavior

Having always lived in Kirchdorf, the old married couple still reside in their family home despite all their children moving out in the years past. The wife relies on her husband for her own mobility, as he is the only one who can drive their car.

Table 16: Members of Household 3

Person	Age	Work / Education
Husband	77	Pensioner
Wife	74	Pensioner

Table 17: Household 3 in Kirchdorf

Address	Floor Space (m²)	Living Costs (€/month)	Income (€/month)	Number of Rooms	Number of Cars
Frühlingstraße 3 Kirchdorf	95	361	1,600	3	1

Frequent trips and activities

Every Sunday, the couple attend a service at their local church. Even though the journey on foot takes only 10 minutes, they both choose to use their car.

Twice a week the couple drive almost 20 kilometers to Pfaffenhofen, so as to buy groceries alongside other items that are not available in Kirchdorf. Despite there being more local shopping options, the couple prefer to go to the larger supermarket in Pfaffenhofen.

Every Wednesday, the husband also meets with his friends at the local tavern, whereby he also uses the car.

Infrequent trips

Once a month the wife meets with a friend in a neighboring village. As she herself does not drive, her husband instead drives.

The husband is also a football fan and therefore goes to watch games at Munich’s Allianz Arena. As taking public transport to the stadium is generally time-consuming and rather crowded during games, he drives his car instead.

Table 18: Activities of Household 3

<table>
<tr><th>Person</th><th colspan="4">Frequent Activities (Weekly)</th><th colspan="2">Infrequent Activities (Monthly)</th></tr>
<tr><td>Husband</td><td rowspan="2">Church service</td><td rowspan="2">Obere Hauptstraße 6, Kirchdorf</td><td>Shopping</td><td>Joseph-Fraunhofer-Straße 31, Pfaffenhofen</td><td>Visiting friends</td><td>Wolfersdorf</td></tr>
<tr><td>Wife</td><td>Restaurant</td><td>Plantage 2, Freising</td><td>Football</td><td>Werner-Heisenberg-Allee 25, München</td></tr>
</table>

Shock scenario - increase to 2.11 €/L

Although the additional costs due to the increased fuel price amount to only 30 € a month, the couple would still like to adapt their mobility behavior so as to have the same amount of disposable income as before the fuel price spike.

For this reason, the couple decide to use a closer supermarket in Freising for their grocery shopping. The husband also chooses to drive less frequently (around every four weeks instead of every six) to football matches at the Allianz Arena.

By implementing these measures, the initial 30 € additional cost can be prevented while also allowing for time savings that can be used for other purposes.

Table 19: Increase to 2.11 €/L – expenditure summary for Household 3 in Kirchdorf

Type of Expenditure		Mobility Scenario Costs		
		1.55 €/L	**2.11 €/L**	**2.11 €/L**
Living costs per month	Net rent	0	0	0
	Additional living costs	361	361	361
	Total	361	361	361
Mobility costs per month	Car ownership	350	350	350
	Car use	130	159	128
	Public transport	0	0	0
	Commuting allowance savings	0	0	0
	Total	480	509	478
Travel time (minutes/month)		671	671	554

Table 20: Increase to 2.11 €/L – budget summary for Household 3 in Kirchdorf

Income and Expenditure	Mobility Scenario Total Costs		
	1.55 €/L	**2.11 €/L**	**2.11 €/L**
Net income (€)	1,600	1,600	1,600
Mobility and living costs (€)	841	870	839
Ratio	53%	54%	52%
Disposable income (€)	759	730	761

Shock Scenario - Increase to 4.65 €/L

Due to their old-age and the high costs of keeping their car on the road, the couple decide to no longer own a car. Through eliminating the fixed costs of car ownership, the couple can immediately save 350 €. The clear downside however, is that they have to limit their mobility. Previously the couple drove the short way to church, however, as they are still physically fit, they now either walk or cycle.

The husband travels once a week with Bus 601 to the tavern. From "Kirchdorf a.d. Amper, Rathaus" he can go directly in less than 15 minutes to "Freising Waldsiedlung". Taking into account the walking time to and from the bus stops, one trip takes approximately 30 minutes. For the outward journey, the only reasonably scheduled bus is timetabled at 1:59 p.m., with the other four daily journeys being either too early in the morning or too late in the evening. The two suitable return journeys are scheduled at 5:01 and 6:05 p.m.

In the wife's case, she also decides to take the bus on the way to her friend's place. With the bus from "Kirchdorf a.d. Amper, Rathaus" to “Wolfersdorf, Siedlung” running only at 5:56 and 8:28 a.m., the wife must plan her trips rather precisely. Later options include only an on-demand call-a-bus service, while the return journey back to Kirchdorf drives only once at 5:11 p.m.

In order to still be able to go to games at the Allianz Arena, the husband goes with at a friend who owns a car as the journey by public transport to and from Kirchdorf would be too cumbersome. Due to the husband being dependent on another person, with game dates having to be coordinated, he doesn't succeed to often in being able to watch the games (only every 6 weeks).

With the couple now using public transportation more often, both purchase a year-ticket for the outer-zone of the public transport tariff area, costing the couple 387 € each per year.

Table 21: Increase to 4.65 €/L – expenditure summary for Household 3 in Kirchdorf

Type of Expenditure		**Mobility Scenario Individual Costs**		
		1.55 €/L	**4.65 €/L**	**4.65 €/L**
Living costs per month	Net rent	0	0	0
	Additional living costs	361	361	361
	Total	361	361	361
Mobility costs per month	Car ownership	350	350	0
	Car use	130	289	8
	Public transport	0	0	65
	Commuting allowance savings	0	0	0
	Total	480	639	73
Travel time (minutes/month)		671	671	734

Table 22: Increase to 4.65 €/L – budget summary for Household 3 in Kirchdorf

Income and Expenditure	**Mobility Scenario Total Costs**		
	1.55 €/L	**4.65 €/L**	**4.65 €/L**
Net income (€)	1,600	1,600	1,600
Mobility and living costs (€)	841	1,000	434
Ratio	53%	63%	27%
Disposable income (€)	759	600	1,166

5. Conclusion and Outlook

This paper investigates the effects of two different oil shock scenarios on the mobility of a three representative households in Munich, Germany. These two scenarios include a fuel price based on US $200 a barrel (2.11 €/L) and a tripling of fuel prices (4.65 €/L).

The results show that a fuel price based on US $200 per barrel has a limited impact on household activities and only a limited effect on short-term mobility behaviors. The shock tripling of the price at the fuel station however, begins to greatly affect the household budget.

In the case of Household 1 and a tripling of oil prices, an extra 429 €/month in fuel costs would need to be allocated to the mobility budget so as to reach the same level of mobility compared to their initial situation. In order to offset these costs, the household is forced to travel an additional 50 hours per month using public transport. Evidently, the consequences of such a shock to a household’s mobility is drastic. For the most vulnerable households – often lower to middle class demographics living in the outer suburban areas with poor public transport access – attempting to circumvent such mobility price shocks by switching from private car to public transport might not be an option.

Nevertheless, potential alternatives such as using public transportation, car-pooling or changing activities or residential locations can relieve the cost shock imposed on household budgets. Despite increasing fuel prices, households can become less vulnerable to mobility price shocks by employing a number of different strategies:

- Activities like working and shopping can be linked efficiently, while unnecessary trips can be avoided. This is not always possible, as some activity locations cannot be changed so easily. In any case, trip chains can offer an enormous potential in saving time as well as money.
- Choosing a different mode of transportation, when available, can save money and reduce a household’s vulnerability to mobility price shocks. This requires attractive public transport services that are easily accessible. It is also possible to bring about a shift to non-motorized modes by implementing a dense and mixed-use settlement structure.
- Private vehicle commuting can be made more sustainable through sharing rides with other people. Carpooling is an effective strategy to save on the costs of driving alone and can offer faster travel times compared to public transport.
- Park and Ride (P+R) is another alternative, as it combines the advantages of two modes. It offers flexibility and comfort in sparsely settled regions without any public transport

services. At the same time congestion and time losses in densely populated urban centers can be avoided.

- In some instances, teleworking might be another possibility to save on mobility costs.

In most cases, vulnerable households are only able to change their mobility behavior once they are offered more viable transport options or alternatives. Recommendations to public stakeholders and decisions makers have to be based on detailed regional level analyses, which take into account the future development of residential and mobility costs. So as to foster more sustainable spatial development, policies and intervention strategies – which concern dense and mixed-use development patterns alongside the (non-motorized) accessibility of jobs and daily activities – will be discussed between researchers as well as planning practitioners and decision makers within workshops held in the study municipalities.

Literature

Bulwiengesa (2014), *Marktstudie – Neubau-ETW-Projekte in der Innenstadt und innenstadtnahen Stadtteilen in München 2014*, Munich.

Büttner, B., Franz, S., Reutter, U., Wulfhorst, G. (2012), *MOR€CO – Mobility and Residential Costs: Improving the Settlement Development in the Transnational Alpine Space Region*, Vienna.

Büttner, B., Wulfhorst, G. (2012), *MOR€CO. Untersuchung der künftigen Wohn- und Mobilitätskosten für private Haushalte in der Region München*, Munich.

Büttner, B., Wulfhorst, G., Crozet, Y., Mercier, A. (2013), *The impact of sharp increases in mobility costs analysed by means of the Vulnerability Assessment, WCTR*, Rio de Janeiro.

Büttner, B.; Keller, J.; Wulfhorst, G. (2011), *Erreichbarkeitsatlas - Grundlagen für die Zukunft der Mobilität in der Metropolregion München*, Munich.

Geurs, Karst T.; Krizek, Kevin J.; Reggiani, Aura (2012), *Accessibility analysis and transport planning. Challenges for Europe and North America*. Cheltenham, UK, Northampton, MA: Edward Elgar (NECTAR series on transportation and communications networks research).

Haller, M.; Fink, B.; Albrecht, M.; Gutsche, J.M. (2012), *Billiger wohnen im Umland? Mobilitätskosten von Wohnorten*. MVV-WoMo - Der Wohn- und Mobilitätsrechner des MVV. In: Nahverkehr (1-2), 46–50.

Hull, A.; Silva, C.; Bertolini, L. (Hg.) (2012), *Accessibility Instruments for Planning Practice.* [S.l.]: COST Office.

Institut für Mobilitätsforschung (ed.) (2010), *Zukunft der Mobilität. Szenarien für das Jahr 2030*. 1. Aufl. Berlin: Ifmo.

Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D. S. Lee, Y. Muromachi, P. J. Newton, S. Plotkin, D. Sperling, R. Wit, P. J. Zhou, 2007, *Transport and its infrastructure. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kasperson, J.X., Kasperson, R.E., Turner, B.L., Hsieh, W., Schiller, A. (2006), *Vulnerability to global environmental change*. In: Rosa, E. et al. (eds.): The Human dimension of Global Environmental Change. Cambridge, MA: MIT Press.

Kelly, P.M., Adger, W.N. (2000), *Theory and practice in assessing vulnerability to climate change and faciliting adaptation*, In: Climatic change 47, 325-352.

Landeshauptstadt München, Referat für Stadtplanung und Bauordnung (Hrsg.) (2012), *Wanderungsmotivuntersuchung II. 2011*. Unter Mitarbeit von Alexander Lang und Hubert Müller, Munich.

Landeshauptstadt München, Referat für Stadtplanung und Bauordnung (Hrsg.) (2010), *Mobilität in Deutschland (MiD)*. Alltagsverkehr in München, im Münchner Umland und im MVV-Verbundraum, Munich.

Lohr, B. (2013), *Teure Flucht ins Umland. Viele Menschen unterschätzen die Kosten der Mobilität, die ein Umzug mit sich bringt*. In: Süddeutsche Zeitung (2013), Nr,112, p.57.

The World Bank (Ed.) (2012), *GDP growth (annual %)* **|** *Data* **|** *Table.* Online: http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG/countries, 31.10.2012.

Wegener, M. (2009), *Energie, Raum und Verkehr. Auswirkungen hoher Energiepreise auf Stadtentwicklung und Mobilität*. In: Wissenschaft & Umwelt INTERDISZIPLINÄR (12).

PART II: PAPER 3

Sharp Increases in Mobility Costs as a Trigger for Sustainable Mobility in the Metropolitan Region of Munich

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This draft chapter has been published by Springer VS in "Sustainable Mobility in Metropolitan Regions: Insights from Interdisciplinary Research for Practice Application" edited by Gebhard Wulfhorst and Stefan Klug published in 2016.

http://link.springer.com/chapter/10.1007%2F978-3-658-14428-9_8

Abstract

The growing Munich region is facing increasing pressures on its housing market and its citizens' everyday mobility. Rising land and rent prices are resulting in greater development of residential sites in peripheral locations and dispersed transport links on the regional level. This situation highlights an urgent need for coordinated control by decision makers on different scales of the Munich region. Along with the potential of rising mobility costs, the Munich region faces a significant risk of housing misallocation in relatively hard-to-reach locations on the regional level. The potential negative impact of these developments is exacerbated by shortages in fossil fuel supplies, political instability in oil-producing countries, and energy price increases (in the context of the energy turnaround). These scenarios were observed during the recent energy crisis and will inevitably lead to increases in mobility costs (Wegener 2009; Büttner & Wulfhorst 2013).

In the context of rising energy prices, assessing the vulnerability of regions in terms of not only their exposure (e.g., their level of fossil fuel consumption) but also their sensitivity (average income) and resilience (accessibility of jobs by public transport) allows for a better identification of long-term sustainable planning opportunities. Such vulnerability assessments, which allow for methods of sustainably improving mobility to directly address mobility cost increases, can better prepare municipalities and their respective decision makers. For example, reshaping land-use with an emphasis on multi-functionality and density, enabling non-motorized transport, and enhancing community solutions (e.g., carpooling and community buses) all offer ways to increase the sustainability of vulnerable municipalities.

Public decision makers and actors at the local and regional levels must make sustainable provisions for the future, taking increasing mobility costs into account in their decision-making processes on real estate and transport development. To do this, they need appropriate and accessible tools that can help them assess the possible effects of changes in mobility costs within their area of responsibility.

1. Background and problem statement

Even though the share of transport costs in the typical household budget has been rising dramatically, mobility costs are often underestimated or completely ignored in household relocation decisions (see Figure 1). Similarly, conventional housing affordability models also ignore transport costs (Mattingly & Morrissey 2014), whereas residential costs—e.g., the monthly mortgage—remain the main financial concern for households deciding where to relocate (Haller et al. 2012). The Munich region is a prominent example of how migration and especially the growth of labor can create a disconnect between residential location decisions and mobility costs.

Figure 1: Monetary factors in household relocation (MORECO 2014)

While population and employment levels are declining in many parts of Germany, the Munich region presents a conflicting case. Population forecasts project that the city of Munich will grow by 14.9% between 2011 and 2030 (an annual population growth of 0.73%). This growth will result in a total urban population of 1.65 million inhabitants. Both positive birth-to-death ratios and migration from other parts of Germany and Europe are contributing to this development (LHM 2012a).

Households migrating into the Munich region are confronted with a highly competitive housing market, with the current housing shortage resulting in sharp increases in residential costs. Munich has the most expensive housing market as a result of these increases in costs. Residences in the city are particularly high-priced, so new arrivals usually end up living in the outer suburbs or even in more remote and correspondingly more affordable locations (LHM

2012b). As a natural response to such a competitive housing market, remote municipalities are pushing for an allocation of new inhabitants that are in desperate search for affordable housing (MIMMO e.V. 2014).

Unfortunately, this relocation pattern is not sustainable. The remote locations often lack convenient access to a wide range of desired urban amenities and activities, and as a result, their residents must travel long distances to commute to work and for leisure, as well as to fulfill their basic needs. Sparsely distributed populations do not favor public or non-motorized transport; rather, this increasingly dispersed urban structure favors car use (Cervero & Guerra 2011; Scheiner 2006). For example, according to the Institute of Media Research and Urbanism (IMU), amidst this population growth in the less dense outskirts of Munich, the portion of trips traveled by non-motorized transport decreased from 12% to 6%, whereas public transport's share of trips dropped from 31% to 15% (IMU 2002).

This dispersed urban structure and the growing distances to daily mobility destinations exacerbate another problem: increased transport costs. Political instability in oil-producing countries, volatility in supply, increasing consumer demand, and peak oil have driven sharp and unpredictable increases in mobility costs (Wegener 2009). Between 2002 and 2012, gasoline prices in Germany nearly doubled from US$1.03 to $1.96 per liter (see Figure 2). Coupled with only minor increases in real income during the same period (Brenke 2009), the combination of longer travel distances and higher gas costs has forced households to spend a greater share of their budget on transport (Büttner et al. 2013). It is important to study sustainable transportation alternatives and strategies so that households can better adapt to increased mobility costs.

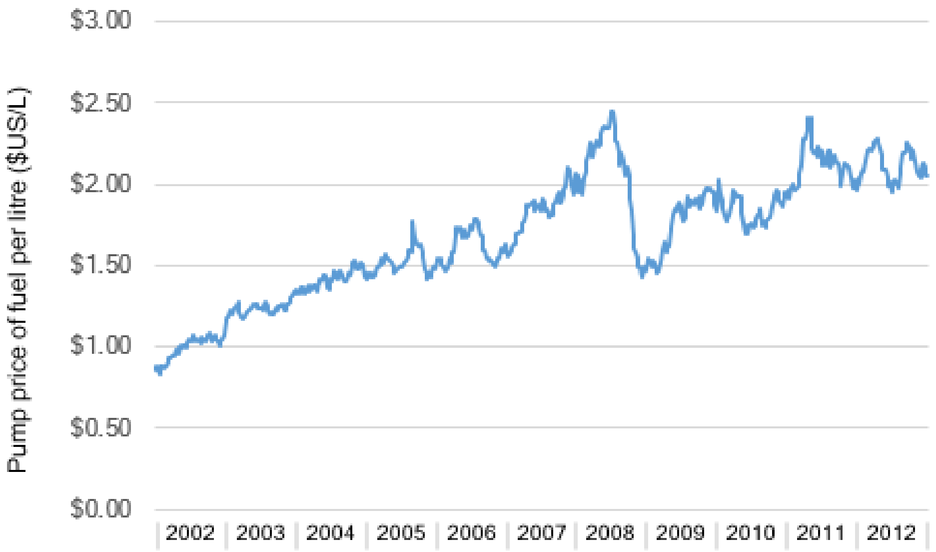

Figure 2: The price of fuel in Germany from 2002 to 2012 (U.S. Energy Information Administration 2015)

2. Methodological approaches

In line with the complexities of individuals' mobility behavior, a set of diverse approaches has been applied to examining the impact of increased transport costs on the mobility decisions of various user groups and stakeholders. To cope with the consequences of rising costs for people's mobility, the Scan-Explore-Prepare methodology was developed (see Figure 3). Its three steps can be described as follows:

Scan: An oil vulnerability assessment aims to scan and subsequently highlight which regions in Munich are at greatest risk due to increasing fuel costs (see Büttner et al. 2013).

Explore: An exploration of individual households is undertaken to develop a range of different storylines that portray real-life reactions to mobility cost shocks. These storylines form the basis for a common language between planners, decision makers, and households.

Prepare: Local stakeholders and decision makers are then given sustainable accessibility recommendations so that they can be better prepared to make key decisions at the regional level.

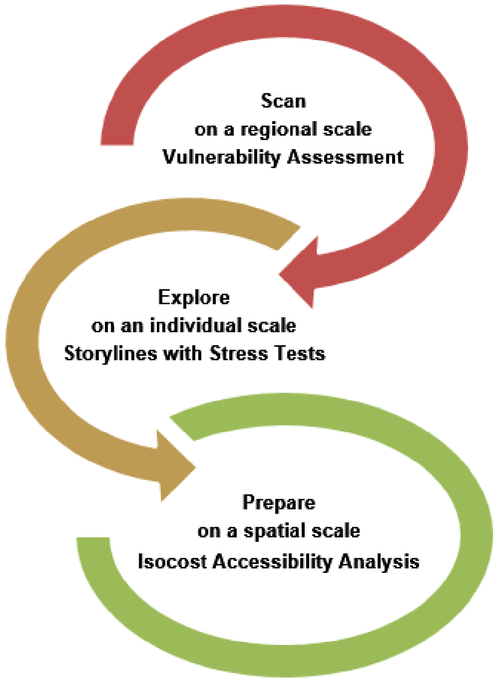

Figure 3: The Scan-Explore-Prepare methodology

2.1 Scan: Adapting the vulnerability assessment

As a first step, the resilience of the Munich study region was analyzed by means of an oil vulnerability assessment (see section 3 below), which identified those municipalities in the Munich area most threatened by increasing mobility costs. This vulnerability concept, which has previously been used to test susceptibility to famine and food security, hazards, and climate change (Adger 2006), is adapted here to examine regional vulnerability to drastic increases in mobility costs.

To adapt the vulnerability assessment to the issue of increasing fuel prices, appropriate indicators must be identified and data must be collected. Based on Kasperson et al. (2006), the three vulnerability indicators of exposure, sensitivity, and resilience are used. At the municipal level, these indicators can be described as follows:

- Who will be **exposed** by an increase in fuel prices?
  Answer: Those who have a high **fossil fuel consumption**
  Indicator: Municipal average of vehicle kilometers traveled per capita

- Who will be **sensitive** to rising fuel prices?
  Answer: Those who have relatively **low income**
  Indicator: Municipal average net income

- Who will be **resilient** in the case of increasing fuel prices?
  Answer: Those who have **alternatives to private cars**
  Indicator: Accessibility of jobs by public transport

- Who will be **vulnerable** to an increase in fuel prices?
  Answer: Those who are **highly exposed** and **highly sensitive** with **low resilience**
  Therefore, the vulnerability index was calculated as the sum of the listed indicators.

In general, this methodology can be transferred to other regions or thematic questions. However, for effective benchmarking, the framework and indicators must be adapted to such issues as data availability and index choice, as the current index demonstrates only one municipality's vulnerability relative to another's. To ensure a certain level of comparability, identical or at least similar and comparable data must be chosen. Another possibility is to combine indicators and weight them according to their perceived magnitude.

2.2 Explore: Developing individual storylines with shock scenarios

Following a determination of the characteristics of the Munich region, an exploration of individual households was undertaken (see section 4). The underlying premise was to analyze households' mobility behavior so as to develop a range of different storylines that portray real-life reactions to mobility price shocks (see Büttner & Wulfhorst 2012 for all storylines).

As a first step, synthetic households and their respective mobility behaviors were derived by analyzing a range of regional databases. Local communities also reviewed the qualities of the hypothetical households generated, including their individual mobility patterns, and confirmed their relevance and reasonableness.

After the data were prepared, stress tests were established in line with studies predicting a rise in the crude oil price to US$200 per barrel (e.g., Institut für Mobilitätsforschung 2010). The first stress test aimed to demonstrate the effects of such an increase, which would cause the price of fuel at German gas stations to rise to 2.11 €/L—a 35% increase. The second stress test considered the scenario involving a tripling of fuel prices, forcing German households to spend 4.65 €/L for fuel.

By applying these stress-tests, the second approach aims to investigate the initial vulnerability assessment through exploring how changes in mobility constraints could impact daily activity schedules, mobility behavior, and selections of residential and activity locations. In line with a simplified economic approach, the research did not focus on the economic theory and variables related to gradual oil price increases; instead, it focused on how households would react to sudden drastic oil price shocks. It was assumed that a rise in oil prices would be directly translated into higher pump prices, thus directly affecting consumers each time they refueled.

2.3 Prepare: Including monetary budgets in accessibility analyses

In most cases, vulnerable households can change their mobility behavior only when they are offered more viable transport options or alternatives. Therefore, helping governments to recognize the interdependencies between land use and transport can enable vulnerable communities to prepare for and adapt to increases in mobility costs. Policies, intervention strategies, and recommendations should also be discussed in order to foster sustainable spatial development (Hull et al. 2012). This point is reinforced by Geurs et al. (2012), who state the importance of testing the current accessibility analysis in practice. For the implementation of accessibility planning, a strong collaboration between researchers and planning practitioners is needed.

With the help of the TUM Accessibility Atlas, different catchment areas and their respective potentials were calculated (see Büttner et al. 2011). Following this, the accessibility of the investigated areas was calculated based on each transport network. Using the Accessibility Atlas, mobility costs were implemented for both private motorized transport (PrT) and public transport (PuT). For a single journey (one-way), a budget of 2.50 € per trip was assumed. In 2010, private transport expenditures in Germany averaged 305 €; this value corresponds to 14% of total private consumption expenditures (Federal Statistical Office 2013).

3. Analysis within the study region

To tackle the issue of increasing mobility costs, the spatial scale of the analysis had to be adapted to the respective aims. We chose to delineate the region by the extent of its public transport network, which includes the city of Munich and eight neighboring districts. This area is served by most of the public transport services in the near vicinity of Munich (e.g., underground trains, suburban trains, trams, and inner-city and regional buses), all of which are managed by the regional public transport authority (the MVV).

3.1 Scan on a regional level by vulnerability assessment

As a first step, understanding the Munich region as a whole was of high importance. Therefore, as explained above, a vulnerability assessment based on Kasperson et al. (2006) was adapted to measure the entire region with regard to three indicators: exposure (fossil fuel consumption), sensitivity (income), and resilience (accessibility to jobs by public transport). Following the assessment, three municipalities representing different settlement structures (urban, sub-urban, and rural) were selected in order to better understand and characterize localized differences in vulnerability (see Büttner et al. 2013).

Exposure assessment

To measure exposure, two sources of data were used. The first, GENESIS online, is a national database of regional statistics that provides population data. The second source is the regional transport model, developed jointly by the city of Munich, the MVV, and the Munich public transport operating agency (MVG). This model allows for the calculation of vehicle kilometers traveled (VKTs) by the inhabitants of each municipality within the coverage area of the MVV network. This key indicator for measuring exposure was chosen because VKTs are directly related to fuel consumption.

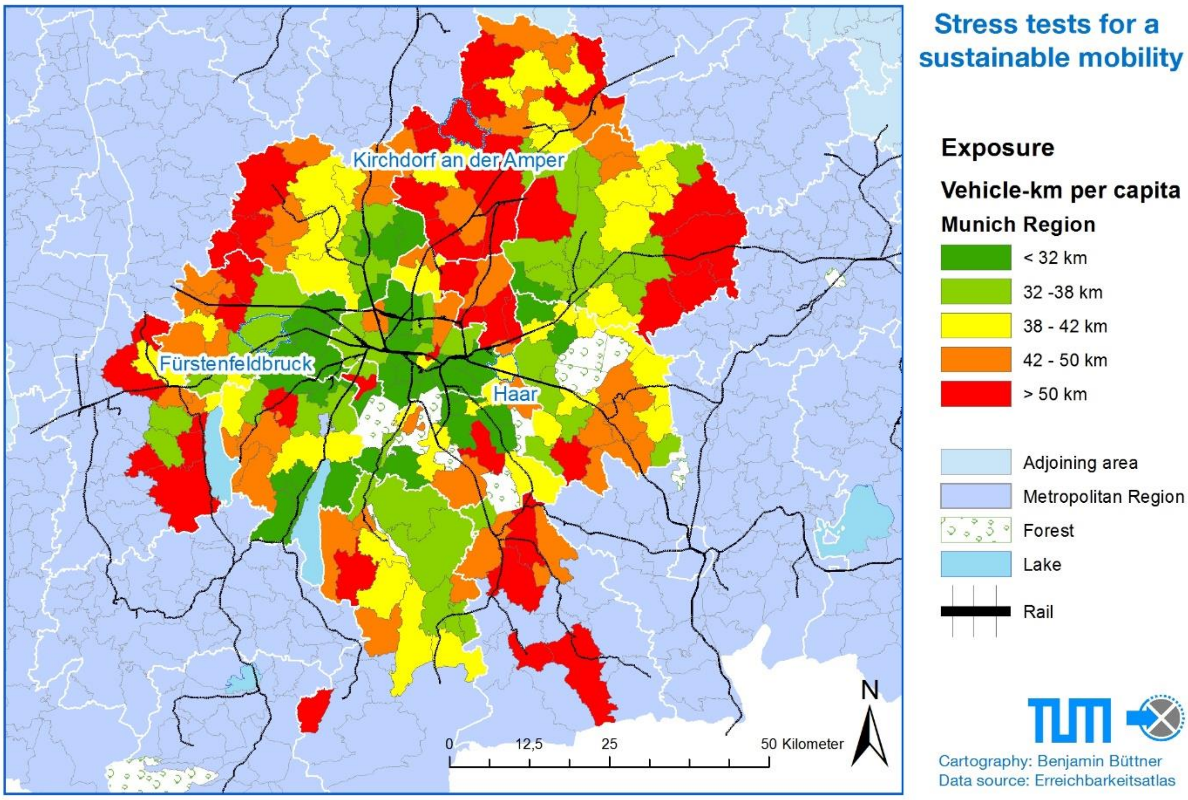

Figure 4: Municipal average of vehicle kilometers traveled per inhabitant in the Munich region

The red municipalities in Figure 4 show a very high exposure due to their high level of VKTs per inhabitant. On average, the inhabitants of these municipalities drive their car more than 50 kilometers each day on regular trips. Locations with higher exposure tend to be located on the periphery of Munich, with a cluster in the far north. The more exposed municipalities are generally located in rural regions, characterized by almost no public transport services. Individuals living within the red municipalities are very car-dependent.

Sensitivity assessment

The measurement of sensitivity relies on two indicators: unemployment rate and average monthly income. Both datasets, available on the municipal level, are drawn from the GENESIS online database provided by the Bavarian Department of Data and Statistics (2010).

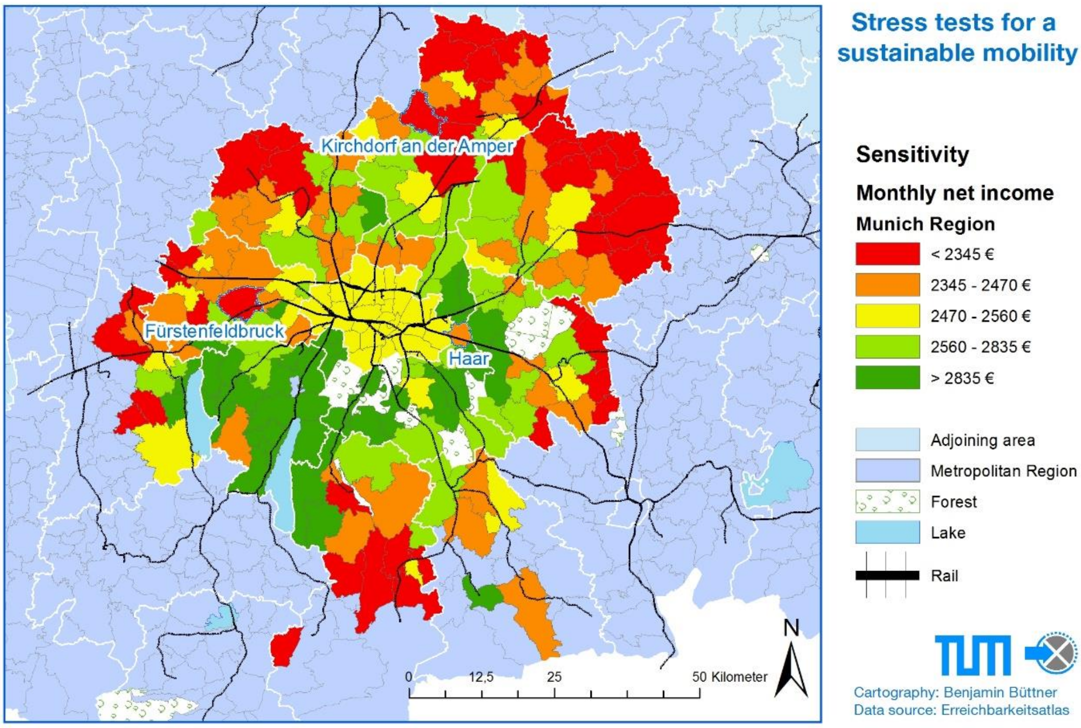

Figure 5: Monthly income in the Munich metropolitan region

The average monthly net income for employees is illustrated in Figure 5. Sensitive municipalities are located mainly on the outskirts of the Munich region. Many of these municipalities have both net monthly income of less than 2,345 € and high VKT levels, meaning that they would suffer severe consequences from an increase in mobility costs. On the other hand, the southwest municipalities have less sensitivity despite their large amounts of VKT, due to their relatively high net monthly income of more than 2,835 €.

Resilience assessment

The level of resilience is measured in terms of accessibility of jobs by means of public transportation. Accessibility can be defined as the ease of reaching various life opportunities from a given location using a particular transportation system (Morris et al. 1978). In this case, jobs are selected as the most relevant opportunities because of their high importance in generating traffic.

Access to jobs by public transport during the morning peak period serves as a key indicator of resilience. Figure 6 displays the total number of accessible jobs within one hour for every municipality.

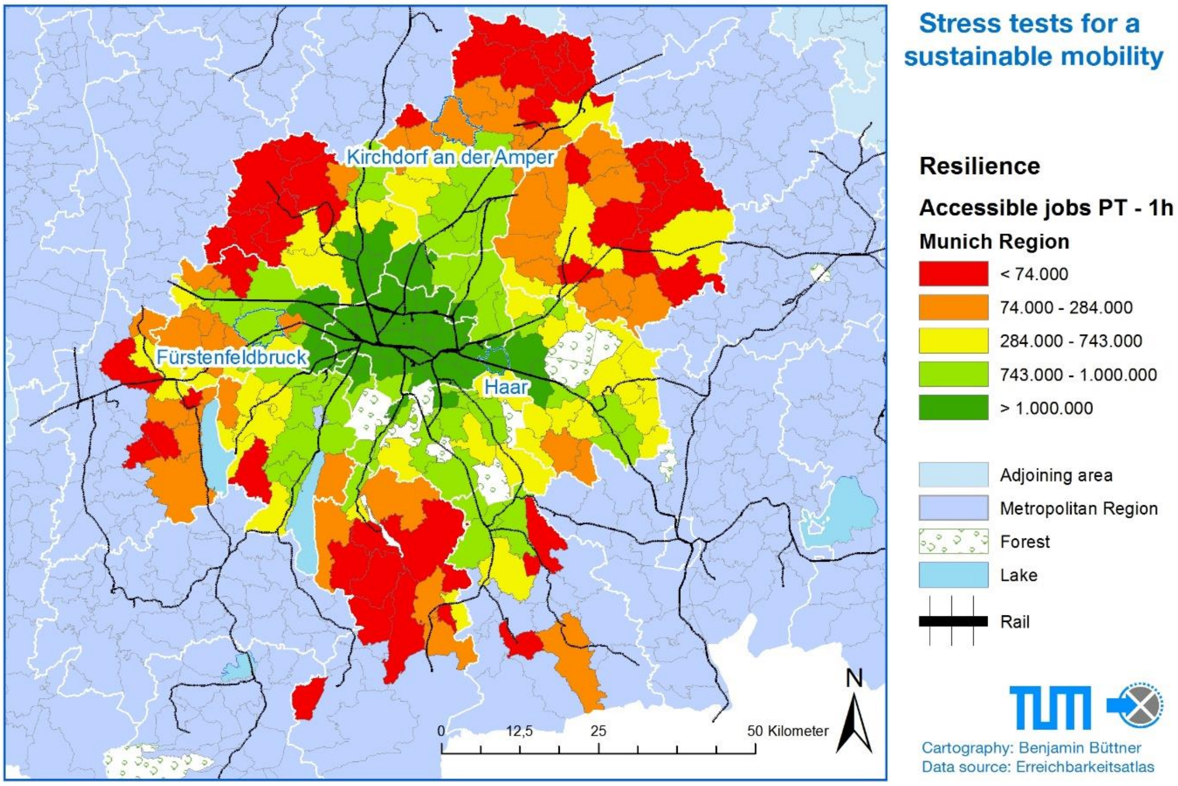

Figure 6: Accessibility to the number of jobs by public transport in the Munich region

From the green municipalities, more than one million jobs are accessible by public transport within one hour. Red municipalities lack adequate public transport and, in most cases, are not located in close proximity to jobs. Moreover, in less accessible municipalities, it is often impossible to shift from car to public transit for one's daily trips between home and work. Public transport is even less available for other trip purposes (e.g., leisure, shopping), and thus, people are less resilient with regard to these types of trips (see Büttner et al. 2012).

The inhabitants of these municipalities without convenient access to public transit also have limited ability to shift to non-fuel-powered modes of transport. Thus, these inhabitants are not resilient in the face of rising fuel prices.

Vulnerability assessment

A vulnerability index can be calculated based upon the indicators of exposure, sensitivity, and resilience as described in section 2. Due to the different methods of valuing the three indicators, the order of magnitude varies considerably: exposure ranges from 10 to 100 VKTs per day, sensitivity ranges from below 2,345 € to more than 2,835 € of net income, and resilience has a maximum of over a million jobs accessible by public transport. In order to make the three indicators qualitatively comparable to each other, a rank ranging from 1 to 100 was applied to each indicator.

The following assumptions were adopted when assigning the ranks: the more one drives (highly exposed), the more vulnerable he or she is; the less one earns (highly sensitive), the more vulnerable; and the better public transport accessibility one has (highly resilient), the less vulnerable. The scales were all constructed so that a score of 100 signifies the greatest vulnerability.

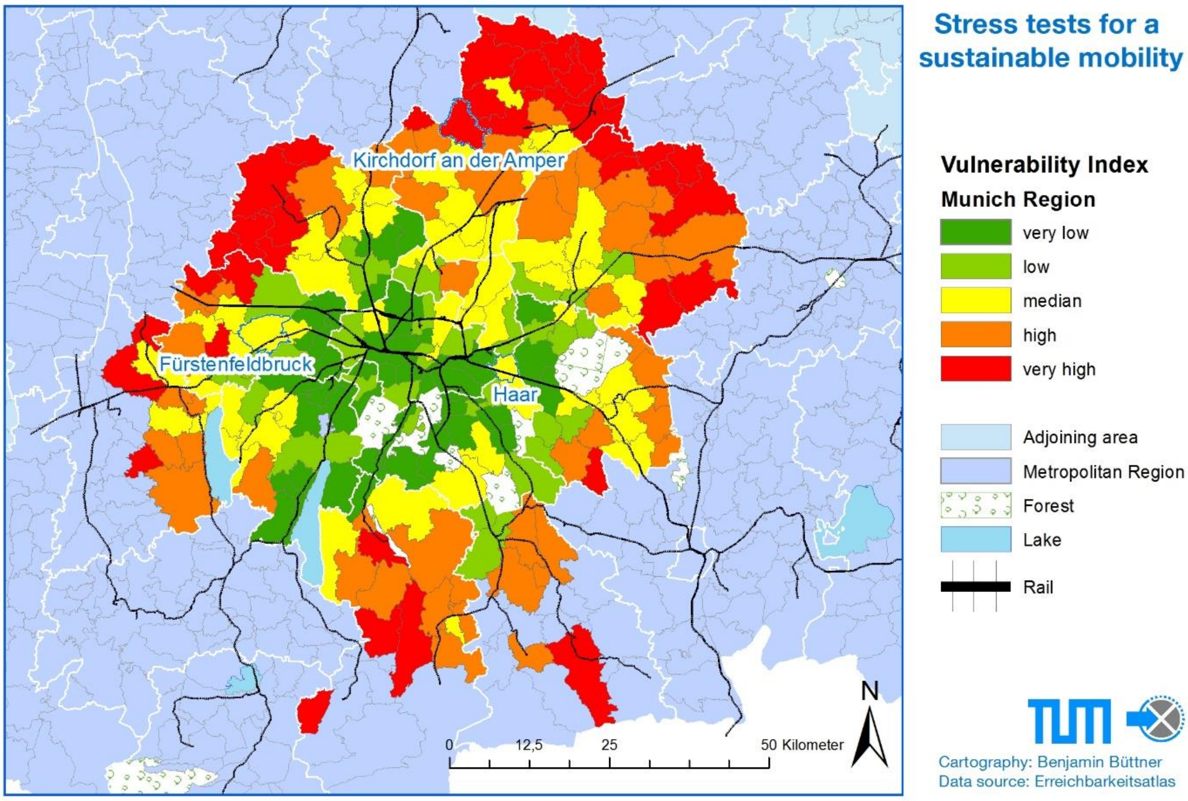

Figure 7: Vulnerability assessment concerning fuel price spikes in the Munich region

The green municipalities in Figure 7 show low vulnerability to rising fuel prices. These municipalities are able to cope with sharp increases in fuel costs. In contrast, the highly vulnerable red municipalities will suffer heavily due to high car dependency and low average income. Most of these vulnerable municipalities are located between the railway axes or in the outskirts of Munich. Therefore, to ensure resilient and sustainable regional development, transit-oriented development close to highly accessible public transport stations should be further fostered. At the same time, to maintain the quality of life within these vulnerable municipalities, it is urgently necessary to provide mobility alternatives (e.g., public transport) as well as convenient facilities to meet people’s daily needs (e.g., supermarkets, jobs, and schools).

By adapting the vulnerability assessment methodology, regions (municipalities or zones) can be tested for their future viability in the case of sharp increases in mobility costs. Although dependent on data availability, it is highly important for proper analysis to select reasonable indicators. For benchmarking and comparing different case studies, the same regional scales as well as the same indicators need to be chosen.

Despite this, it is not advisable to transfer these municipal-based impacts to an individual basis. Therefore, an analysis of households has been performed within the same study region to point out the individual effects and differences people are facing to not only households but also decision makers in the region. As a result of drastic shock scenarios, individual strategies are formulated for maintaining social and economic participation.

4. Explore on an individual household level by storylines with stress tests

Having scanned the Munich region for municipalities in danger of increasing oil prices, subsequent analysis focuses on the effects felt by households due to sudden fuel price increases. This chapter aims to provide a common language for planners, decision makers, and households so that they can better understand the actual situation of households trying to maintain their mobility levels and their social and economic participation under financial strains.

This chapter is dedicated to just one household—“Household Y”—which represents a typical four-person family (see Table 1) unable to change their mobility behaviors suddenly. Within the MORECO project report (see Büttner & Wulfhorst 2013), other representative households (e.g., an elderly couple, a single mother, students, etc.) are included in different structural settings (urban, suburban, and rural).

Current mobility behavior

Table 1: Members of Household Y

Person	Age	Work / Education
Father	40	Full-time
Mother	39	Part-time
Son	9	Elementary school
Daughter	5	Kindergarten

Table 2: Household Y’s Residence

Address	Floor Space (m²)	Living Costs (€/month)	Income (€/month)	Number of Rooms	Number of Cars
Industriestrasse 61 Aubing	120	1,400	3,750	4	2

Table 3: Household Y's Activities

Person	Frequent Activities				Infrequent Activities (Monthly)	
	Work Days		Leisure (Weekly)			
Father	Full-time	Ottostrasse 13 (City center)	Soccer	Connollystrasse 32 (Olympic Park)	Barber	Innere Wiener Strasse 48 (Au-Haidhausen)
Mother	Part-time	Kapuzinerplatz 1 (Isarvorstadt)	Meeting friends/ dinner	Hohenzollern-strasse 25 (Schwabing)	-	
Son	School	Flurstrasse 8 (Au-Haidhausen)	Music academy	Flurstrasse 8 (Au-Haidhausen)	Doctor	Karl-Theodor-Strasse 97 (Schwabing)
Daughter	Kindergarten	Flurstrasse 8 (Au-Haidhausen)			Doctor	Karl-Theodor-Strasse 97 (Schwabing)
Together			Shopping /bowling/ movie theater	Thomas-Dehler-Strasse 12 (Neuperlach)	Visiting family/ hiking	Beccostrasse 12 (Pöcking)

Since the father has accepted a new job in Karlsfeld, and considering the commuting time from their existing residence in the center of Munich, the family has decided to move to a closer residence in Aubing. From here, Karlsfeld can be reached by car within 14 minutes via the A99 highway. The drive from the new residence to the mother's work takes 24 minutes, which is acceptable as well. Additionally, the new location is accessible by the suburban train, which provides direct service to the city center. The station is within one kilometer of the new house. Moving to the outskirts, in order to be closer to the father's new job, has also enabled the family to live in a green area where rent prices are lower than in the city center (see Table 2).

Since they want neither to lose contact with friends nor to dramatically change their habits, they continue to practice exactly the same activities as before (see Table 3). Leisure activities and meeting friends in Munich remain part of their weekly schedule. Overall, Aubing has high public transport accessibility, but the move will still influence the family's monthly transportation expenditures significantly.

Shock scenario: US$200/barrel (increase to 2.11 €/L)

An increase in fuel prices to 2.11 €/L (US$200/barrel) would not have a dramatic impact on the family's household budget. Only 78 € less would be available per month, compared with the pre-shock scenario (see Table 4). This slight increase would most likely cause no change in the family's mobility behavior. Nevertheless, some suggestions can be made concerning potential behavior changes so as to reduce total transport costs to the same level as before the price shock.

The mother could use park-and-ride (P+R) four times a week to go to work, instead of relying solely on her car. Only when she meets her friends in the city center would she need to use the car. Another simple alternative to save 30 € per month would be to change the weekly route to the music academy. In the pre-shock scenario, the mother drove her child to school via highway A99 (35 km); however, using a more direct route (22 km) would also save money.

But these changes in mobility behavior have significant time drawbacks, in that modifying mobility patterns as suggested would cause the household to spend an extra 477 minutes traveling per month.

Shock scenario: Tripling of oil price (increase to 4.65 €/L)

A spike in fuel prices to 4.65 €/L (a tripling of current prices) would have a drastic impact on the household budget. Each month, the family would spend an extra 429 € compared with the current situation. Such an increase would mean that 78% of the families' income is spent on mobility and living costs, compared with only 66% before the shock.

Assuming that the family wants to maintain the same budget as before the price shock, they will likely aim to travel in more cost-efficient ways. The mother will experience a longer travel time of 20 minutes each way on her commute to and from work. She will continue using the car for a series of connected trips on some days (combining leisure activities with work) as this requires a greater level of travel flexibility. The son will also go to music school by public transport, spending an extra 10 minutes per trip (each way). The husband will suffer the most from this new situation, as he will be forced to spend an extra 49 minutes traveling to work.

The husband's extra travel time is one major drawback of the chosen residential location, as the public transport connection to his workplace in Karlsfeld is very inconvenient compared with the car. For all remaining car trips, the shortest route will be chosen in order to minimize fuel consumption. Due to these changes in everyday mobility, the family's small second car will not be necessary any longer and can be sold. This saves 350 € of fixed car ownership costs per month.

Table and 5 summarize the differences between the status quo and the two shock scenarios. Further strategies for adopting more efficient mobility patterns in response to oil price spikes can be found in the MORECO project report (see Büttner & Wulfhorst 2013).

Table 4: Shock scenario expenditure summary for Household Y in Aubing

Type of Expenditure		Mobility Scenario Costs				
		1.55 €/L	2.11 €/L	2.11 €/L (incl. P+R change)	4.65 €/L	4.65 €/L (incl. PuT + Selling Car)
Living costs per month (€)	Net rent	1,100	1,100	1,100	1,100	1,100
	Additional living costs	300	300	300	300	300
	Total	1,400	1,400	1,400	1,400	1,400
Mobility costs per month (€)	Car ownership	800	800	800	800	450
	Car use	348	426	284	777	180
	Public transport	25	25	0	25	136
	Commuting allowance savings	91	91	91	91	91
	Total	1,082	1,159	1,059	1,511	674
Travel time (minutes/month)		2,572	2,572	3,049	2,572	5,569

Table 5: Shock scenario budget summary for Household Y in Aubing

Income and Expenditures	Mobility Scenario Total Costs				
	1.55 €/L	2.11 €/L	2.11 €/L (incl. P+R change)	4.65 €/L	4.65 €/L (incl. PuT + Selling Car)
Net income (€)	3,750	3,750	3,750	3,750	3,750
Mobility and living costs (€)	2,482	2,559	2,459	2,911	2,074
Ratio	66%	68%	66%	78%	55%
Disposable income (€)	1,268	1,191	1,291	839	1,676

Intermediate conclusions

A fuel price based on US$200 per barrel has a relatively minor impact on household activities and only a limited effect on short-term mobility behaviors. The tripling of gas prices, however, greatly affects the household budget, especially for the most vulnerable households—which are usually lower- or middle-class families living in suburban areas.

Nevertheless, potential alternatives, such as using public transportation, carpooling, or changing activities or residential locations, can prevent this shock from highly impacting household budgets. Activities like working and shopping can be linked efficiently, and unnecessary trips can be avoided. Despite not always being possible, trip chains can offer enormous potential in terms of more sustainable travel behavior while also saving time and money. Choosing a more sustainable mode of transportation, if available, can also save money while reducing a household's vulnerability to mobility price shocks.

Daily private vehicle commutes can also be made more sustainable through ride sharing, which provides cost savings over operating one's own motor vehicle daily but with faster travel times when compared with public transport. Park and Ride (P+R) is another alternative as it combines the advantages of two modes. It offers flexibility and comfort in sparsely settled regions without any public transport services while still avoiding congestion in densely populated urban centers. In some instances, telecommuting can also allow households to save on mobility costs.

In most cases, households can change their mobility behavior only if they are offered other transport alternatives (which could range from public transit services to demand management incentives). Recommendations to stakeholders and decision makers should be based on detailed regional-level analyses that consider projected future residential and mobility costs. Regional decision makers, when discussing policies and strategies, should consult maps, like those presented in this paper, that display residents' degree of access to daily activities. Such an approach can help to foster sustainable spatial development.

5. Preparing decision makers by isocost accessibility analyses

Having first investigated oil vulnerability for the Munich region and subsequently the reality of oil price shocks for households, local stakeholders and decision-makers can now be prepared on the regional scale by means of isocost accessibility analyses. These analyses aim to show how different oil price shocks affect the accessibility of a range of activities (e.g., employment, health, and education). Analyses that consider public transport as well as walking accessibility are also offered.

This section examines the effects of severe oil price shocks on communities reflecting three different types of spatial development within the same region: the peripheral city of Fürstenfeldbruck (suburban), the town of Kirschdorf an der Amper (rural), and the inner-city suburb of Haar (urban). A detailed presentation on these municipalities and others is included in initial analyses and can be found in the report "MOR€CO: Investigation of future living and mobility costs for households in the Munich region" (see Büttner & Wulfhorst 2012).

Current situation and outcomes

Fürstenfeldbruck

Figure 8 details pedestrian access from the Fürstenfeldbruck suburban train station. The periphery of the station is distinguished by the lack of nearby activities accessible to pedestrians. Sparsely located shopping opportunities can be reached by a five-minute walk from the station; however, the main activity focal point is located more than 15 minutes away. Important educational institutions are located northeast of the suburban train station, but pedestrians need between 10 to 15 minutes to reach these areas even though they are only at a distance of 500 meters due to the lack of direct routes and the rail tracks serving as a barrier.

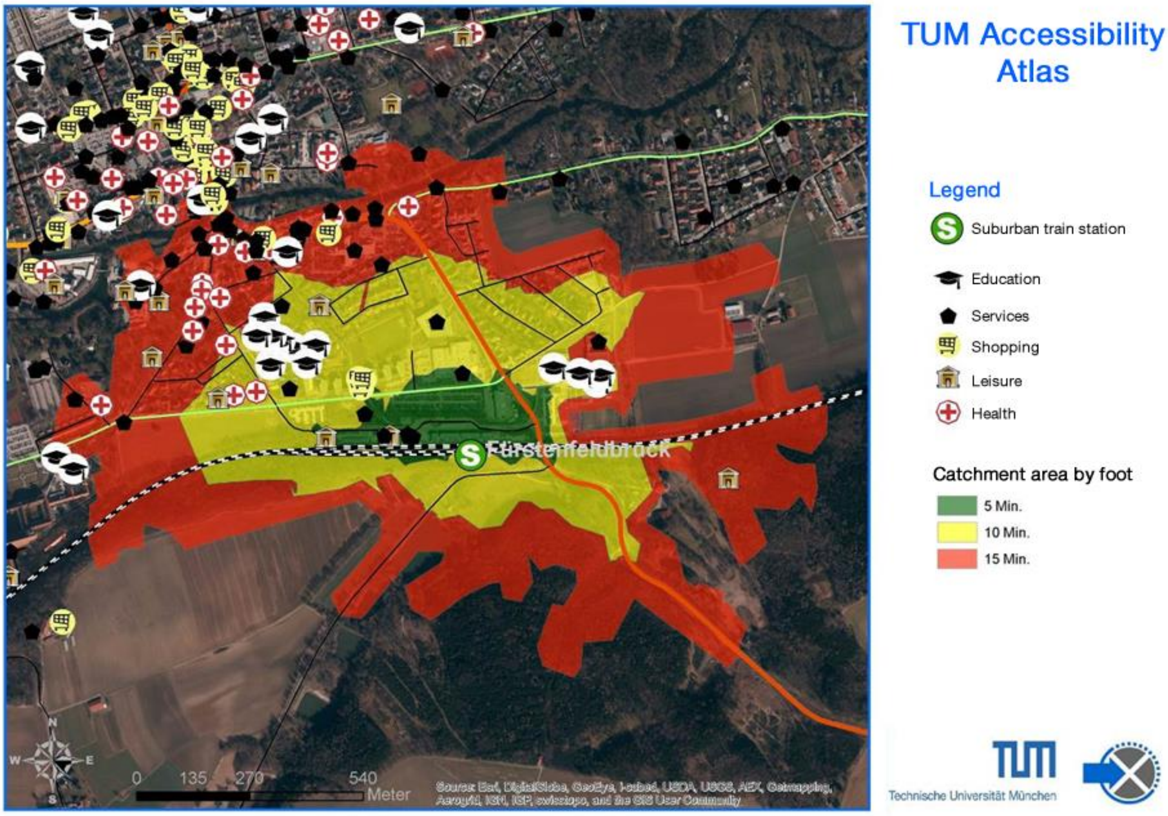

Figure 8: Pedestrian accessibility from the Fürstenfeldbruck train station

In the case of accessibility by private motorized and public transport, isocost analyses (shown in their entirety in the full MOR€CO II report; see Büttner, Ji & Wulfhorst 2014) demonstrate that private motorised transport can cover three times more area than public transport, assuming a travel budget of 2.50 € while conservatively taking into account solely operational costs (i.e., fuel costs at 1.55 €/L and a single-ticket train fare). For this scenario, twice the amount of population, jobs, and shopping opportunities can be accessed by car when compared with public transport, with the western areas of Munich also within reach.

Figure 9 highlights the car-based accessibility scenarios that involve fuel prices reaching US$200/barrel as well as the drastic tripling of prices. With a moderate fuel price increase to 2.11 €/L (US$200/barrel), less than half the previous number of jobs and residents would now be accessible by private car on a budget of 2.50 €/day, and the economic opportunities within. As a result, the potential of the city of Munich would no longer be accessible.

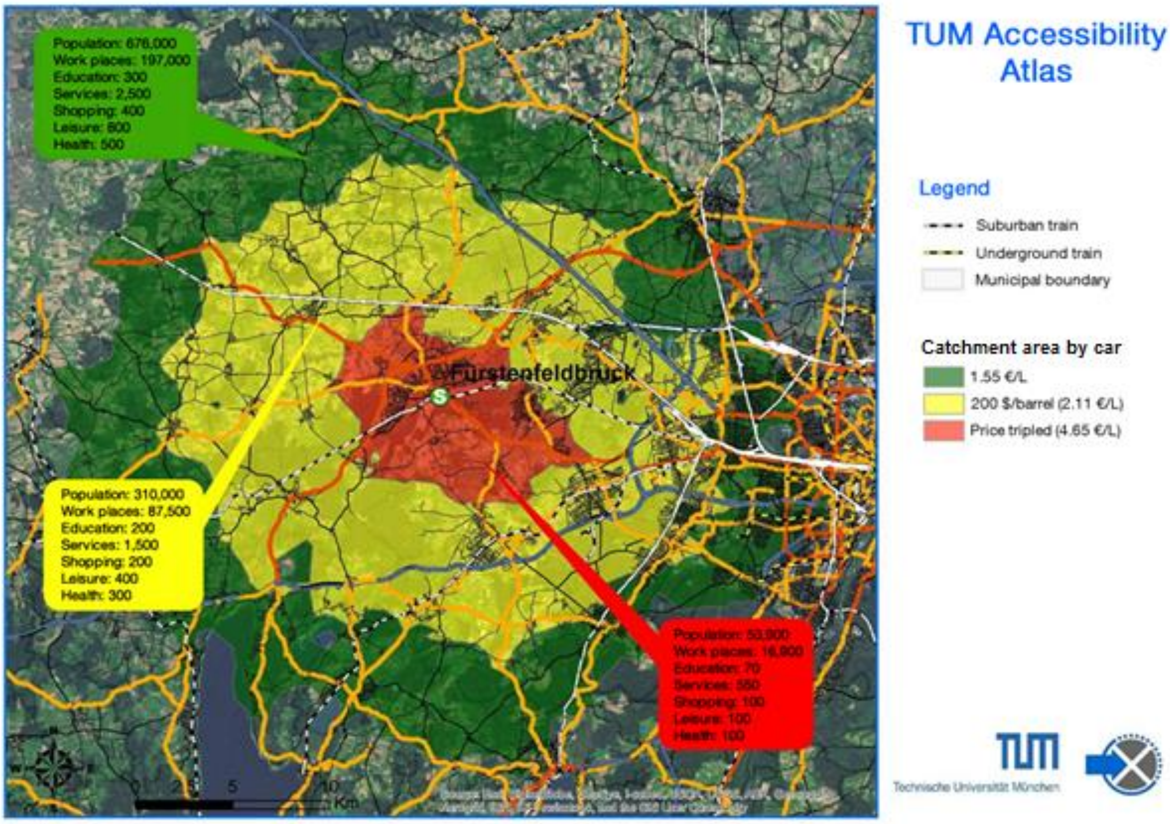

Figure 9: Access to opportunities by private car for different fuel price shock scenarios in Fürstenfeldbruck

In the case of a tripling of fuel prices, the close surrounding areas of Munich would not be accessible (see Figure 9) and therefore, only approximately 8% of the originally accessible population and job potential remain available. This shock scenario results in an expected increase in the price of a one-way train ticket from 2.50 € to 3.50 €. Consequently, public transportation is still not preferable to private motorized transport given this price increase, assuming that the PT tariff structure does not change. With a budget of 2.50 € (enough for short trips), only public transport from within Fürstenfeldbruck is accessible. With a budget of 3.50 €, more than double the workplaces, service providers, and educational and recreational facilities are accessible.

Kirchdorf an der Amper

The rural town of Kirchdorf an der Amper, approximately 50 km north of Munich, has no S-Bahn (rapid transit) connections within its periphery. Accordingly, the City Hall bus station is the most important public transport stop. Figure highlights pedestrian-accessible service areas within this small municipality, whereby it can be seen that all activities are accessible on foot within 15 minutes and that most are accessible within 10 minutes.

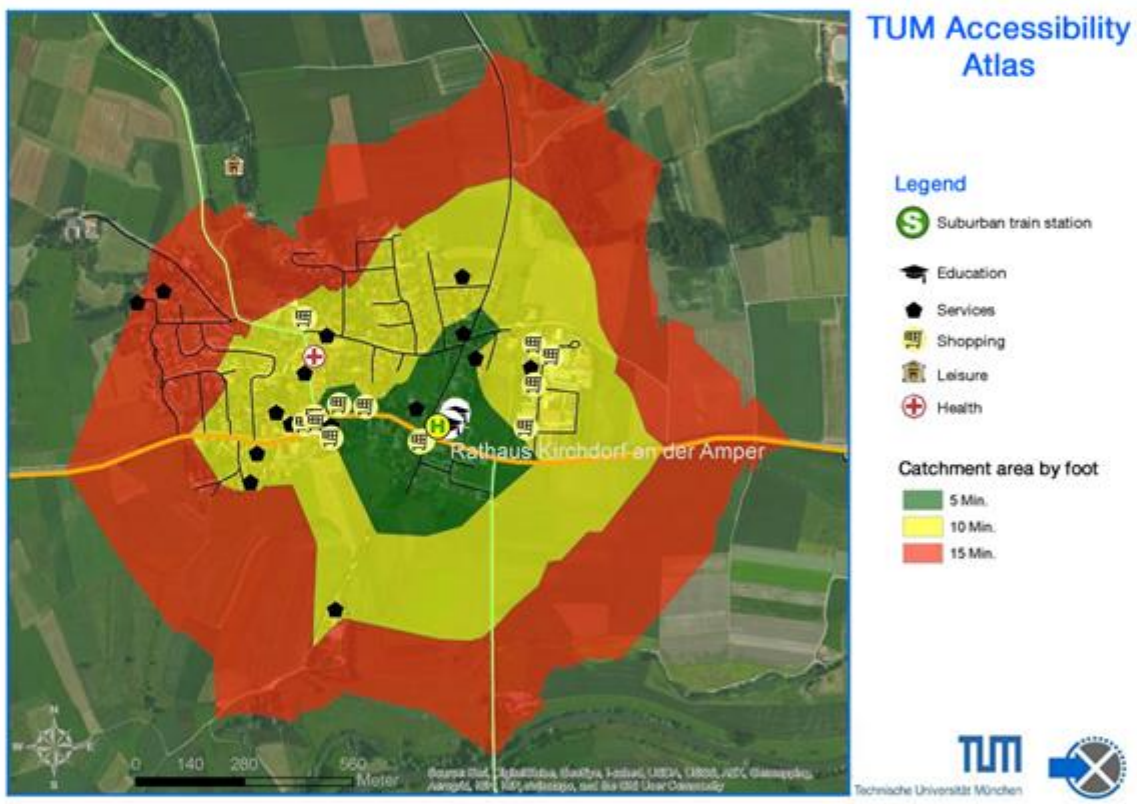

Figure 10: Pedestrian access from the Kirchdorf an der Amper S-Bahn station

A relatively larger area is accessible by using regional buses. Both Freising and Munich Airport can be reached with only a single-trip ticket of 2.50 €, but the frequency of these services is rather small and irregular. Accordingly, the realistic availability of public transport is highly dependent on the time of day and the day of the week. By car, the municipalities of Neufahrn, Hallbergmoos, and Eching, south of Kirchdorf an der Amper and north of Munich, are also accessible.

Figure 11 shows how a drastic fuel price increase in Kirchdorf an der Amper would affect the accessibility of activities. For the US$200 per barrel scenario, more than half of the previously reachable population, jobs, services, and shopping would become inaccessible. In this region, the Munich Airport specifically plays a supporting role with its variety of activities, which would no longer be accessible even with such a moderate increase. The accessibility within the airport region is at significant risk with an increase in mobility costs.

Should fuel costs triple, the cost of public transport is not affected as greatly as that of PrT. Accordingly, with a travel budget of 3.50 € by public transport, more than double the population, jobs, services, shopping, and leisure and health facilities are accessible (see the full MOR€CO II report for details).

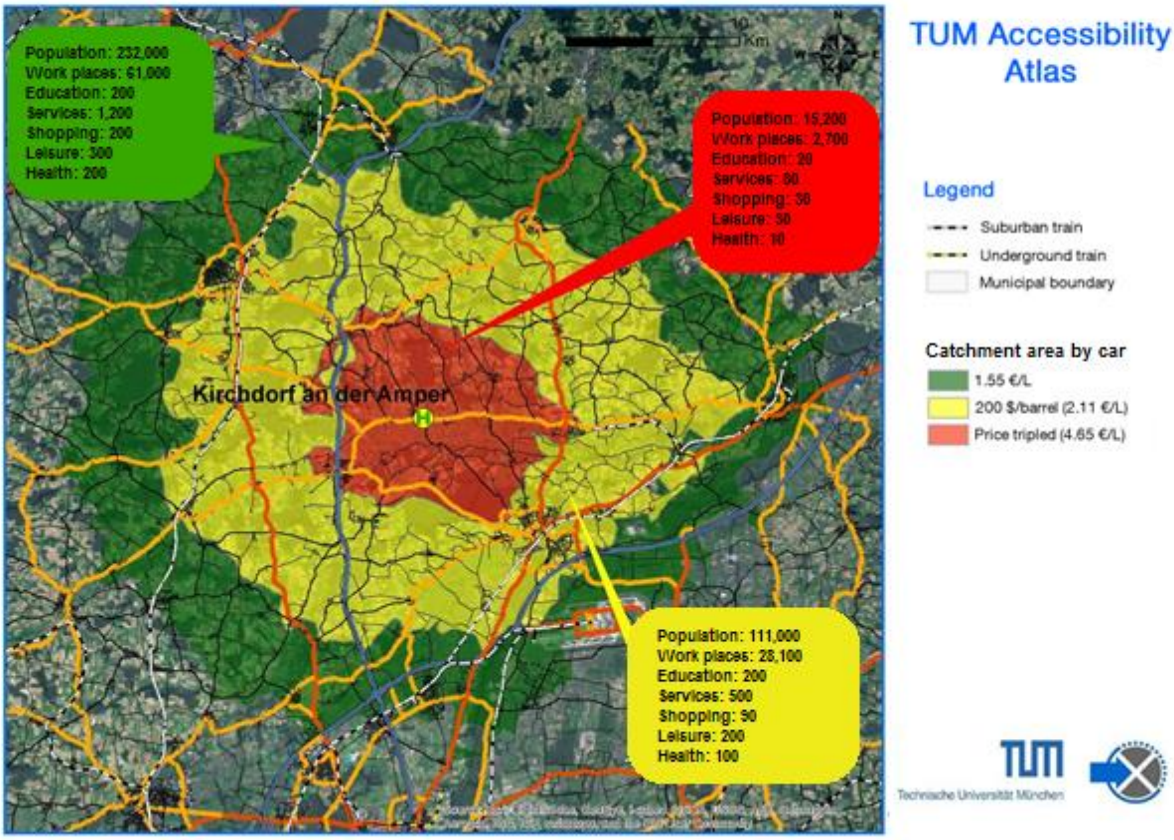

Figure 11: Access to locations by private car for different fuel price shock scenarios in Kirchdorf an der Amper

The development of attractive and reliable public transport connections between land use priorities and major workplaces, such as Munich Airport, is necessary to make this region more resilient in response to increasing mobility costs.

Haar

The suburban municipality of Haar is distinguished by a high density of activities. The S-Bahn station is located northeast of the municipal center, and accordingly, some activities to the west cannot be reached by pedestrians within 15 minutes. In the immediate vicinity of the station, an urban upgrade involving a high utilization mix would bring about positive outcomes, especially north of the S-Bahn station where there are only a few restaurant options.

With such a large amount of activity potentially reachable by public transport, Haar benefits from its close proximity to the border of the city's inner and outer PuT tariff zones. With a single-trip ticket, a rider can access both tariff zones, whereas fuel consumption in dense urban settings is particularly high due to the stop-and-go traffic at intersections. Accordingly, the potential of all achievable activities reachable by PrT is already only half that of public transport (see Figure 12). This is particularly clear with regard to population and jobs.

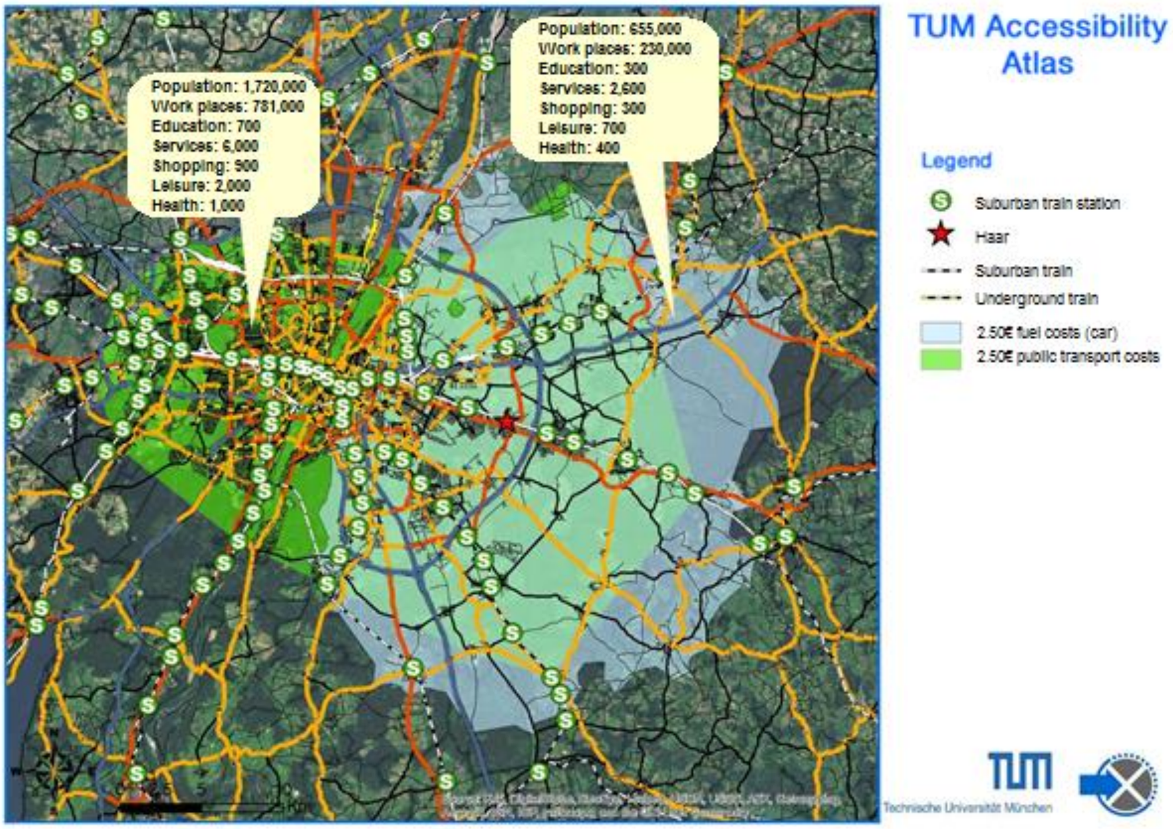

Figure 12: Private car and public transport accessibility in Haar

With the urban density of Munich acting as a mobility barrier, it is already almost impossible, with no fuel price spike and a budget of 2.50 €, to reach popular landmarks within the city (e.g., the Isar River) by car. Should fuel prices rise to 2.11 €/L, car trips would no longer reach activity concentrations on the city's outskirts; instead, they would be limited to Munich's closer suburban areas.

Haar benefits greatly from its very good public transport connections, specifically its two S-Bahn lines. Owing to its dense and mixed land-use structure, coupled with very good access to public transport, Haar is relatively resistant to mobility cost increases.

In the scenario of a tripling of fuel prices, public transport would be able to access almost six times as much population as private transport, seven times as many workplaces, nine times as much shopping, 10 times as many education and health facilities, and 20 times more recreational facilities.

6. Suggestions for local and regional development strategies

After the accessibility analysis was completed, the findings were presented at a stakeholder workshop setting (see Büttner et al. 2014), and the following recommendations were formulated for responding to increasing mobility costs in the Munich region. For each strategy, the different spatial scales and the main actors responsible are given.

6.1 Local level: municipalities

Promoting local areas

Local vulnerability to mobility cost increases can be reduced through targeted internal development and sustainable densification. Mixing of land uses (e.g., jobs and workplace activities) is an important strategy, which will contribute to sustainable mobility behavior. Local supply (both at home and around the workplace) of everyday goods also plays a major role. This supply can be both pedestrian- and bicycle-based so as to strengthen local mobility in the process. In the case of Household Y, proper spatial development within the family’s neighborhood might have allowed both parents to walk or cycle to work, decoupling the family’s mobility needs from the private car.

Convenient recreational open spaces as well as local activities can also support independence from mobility costs while increasing a neighborhood’s attractiveness. Accordingly, decentralized, small-scale supply structures should be encouraged, rather than economically driven concentration processes (i.e., economies of scale).

Support for citizen engagement, self-supply, and mobile supply

In rural municipalities, public participation can, to some extent, maintain a temporary supply. For example, the citizens of Oberbiberg (a suburb south of Munich) have organized their own citizen bus. As public transport in the Oberbiberg municipality is inadequate, 35 volunteers drive this citizen bus to the Deisenhofen suburban train station. In addition, municipalities can create online forums to facilitate carpooling. As seen in the storyline analysis of Household Y, carpooling or increasing car occupancy can reduce mobility costs.

Similar citizen engagement can be applied to village shops that frequently offer and even bundle a range of services, such as post offices, cafés, and pharmacies. Such arrangements develop community character through the creation of important social meeting places. In relatively dispersed locations, it is also helpful, for economic reasons, for part of the supply to be maintained by mobile services (mobile markets, pharmacies, banks, etc.).

6.2 Regional level: District and public transport authorities

Inter-municipal cooperation/balance management

In peripheral and vulnerable regions that cannot provide the required supply on their own, inter-municipal cooperation with neighboring municipalities is a possibility. For example, several municipalities could jointly operate a local school, possibly preventing the need for motorized transport. If the distances between participating communities are too great for pedestrians or cyclists, an adequate public transport system (possibly a citizen bus) linking the communities could be operated. Household Y’s children were required to switch to public transport for educational activities so as to maintain the same mobility budget; with no public transport available, this would not have been possible.

Public transport expansion, but only in line with spatial development policy

The expansion of public transport is necessary especially in a still-growing region. Such expansion should be undertaken only in conjunction with sophisticated spatial development. For this reason, information concerning the future development of settlement structures (i.e., the location not only of jobs and services but also of leisure) and their demands should be integrated. In addition, dense nodes can be connected in a polycentric network so as to enable an efficient public transport system. A sustainable public transport network should be linked not only radially to the regional centers but also tangentially between smaller nodes.

For sustainable development, especially in rural areas, it is necessary to focus on sub-spaces, clusters, and centers of different hierarchies. In particular, workplace nodes should focus on integrated, high-quality public transport from accessible locations. For this purpose, spatial planning instruments should be consistently employed to avoid further errors and oversights. This requires joint responsibility on the municipal level and thus a corresponding reform of business-related taxes.

Accessible places

The designation of green fields as areas for new business development often occurs without a prior assessment of traffic impacts. These peripheral and non-integrated sites are not sustainable in relation to rising mobility costs. In the future, public transport access for business areas will also be an important factor (as already seen in the case of one company in the Munich region that contributed financially toward establishing a bus line).

Promotion of “sharing economy” → Inter-modality → Establish networks / nodes

As seen in the case of Household Y, mobility chains that link different modes of transport can offer significant value. For example, bicycle stations can be implemented at public transport nodes, such as train stations. In this way, people can use bicycles to travel to the suburban train station and then again for their remaining distance to the workplace in order to solve the “last-mile problem.” In addition, innovative mobility models such as car sharing and carpooling can make individual mobility behavior more flexible.

Promote e-mobility, particularly in rural areas

With increasing mobility costs, electric mobility can also gain attractiveness if the price of energy (see energy turnaround) does not increase to a similar extent. E-mobility especially offers opportunities for dispersed rural municipalities where an efficient public transport system cannot be operated effectively and the distances for non-motorized mobility are too great.

6.3 Upper levels: State of Bavaria, Federal, EU

Many of the measures discussed above could be achieved only by the assistance of higher levels of government—i.e., the State of Bavaria, the federal government, and/or the European Union. Consequently, a sub-regional, cross-sectoral funding policy to implement such measures is needed.

These responsibilities are often not clearly defined. To take a parallel example, who is responsible for the widespread rollout of high-speed Internet access using broadband cable? If such a service were available, peripheral regions could be better served through e-shopping, e-learning, e-banking, and so on. However, nationwide broadband coverage is not attractive to the private sector and hardly affordable with public funds.

7. Discussion and further research

The volatility of oil prices poses a significant challenge to planners. The inability to predict sharp increases in travel costs and the prevalence of poor choices in both housing and transport development can present a significant danger to households in relatively hard-to-reach locations within the Munich region. To mitigate the effects of unwise housing and transport policies, governments and individuals in vulnerable regions must equip themselves to manage this threat.

Vulnerability assessments like the one presented in this study have proved to offer a very capable platform for identifying areas most vulnerable to severe oil price shocks. Whether this methodology can be transferred to other European regions is, however, still being questioned in terms of data availability. Recognizing the vulnerability of municipalities in terms of their exposure, sensitivity, and resilience has allowed for a more complete identification of long-term planning opportunities that can better prepare municipalities and their decision makers.

In terms of preparing municipalities for the possibility of increasing mobility costs, a range of recommendations, strategies, and policies can be developed that address this risk through sustainable methods of improving mobility, e.g., reshaping land use with an emphasis on multi-functionality and density and enabling non-motorized transport offer opportunities to increase vulnerable municipalities' sustainability and hence their citizens' quality of life.

At the same time, however, it is crucial for decision makers and practitioners to buy into the strategies and policies provided by researchers. Academics can facilitate this process by raising awareness of mobility issues through the use of bold, readily understandable maps and comprehensible storylines. The findings should then be presented, explained, and discussed with responsible practitioners (see Büttner et al. 2014). In this way, the usual gap between research-based findings and practical implementation can be substantially decreased (te Brömmelstroet et al. 2014).

References

Adger, W. (2006), Vulnerability. Global Environmental Change, 16(3), 268–281.

Brenke, K. (2009), Real wages in Germany: numerous years of decline. Weekly report, 5(28), 193–202.

Büttner, B., Franz, S., Reutter, U., Wulfhorst, G. (2012), MOR€CO–Mobility and Residential Costs: Improving the Settlement Development in the Transnational Alpine Space Region, Vienna.

Büttner, B., Ji, C., Wulfhorst, G. (2014), MOR€CO II - Handlungsempfehlungen für öffentliche Akteure zur Reaktion auf steigende Mobilitätskosten im MVV-Raum, Munich.

Büttner, B., & Wulfhorst, G. (2012), MOR€CO: Untersuchung der künftigen Wohn- und Mobilitätskosten für private Haushalte in der Region München, Munich.

Büttner, B., Wulfhorst, G., Crozet, Y., Mercier, A. (2013), The impact of sharp increases in mobility costs analysed by means of the Vulnerability Assessment, WCTR, Rio de Janeiro.

Büttner, B., Keller, J., Wulfhorst, G. (2011), Erreichbarkeitsatlas - Grundlagen für die Zukunft der Mobilität in der Metropolregion München, Munich.

Cervero, R., & Guerra, E. (2011), Urban densities and transit: A multi-dimensional perspective. Institute of Transportation Studies, University of California, Berkeley.

Dodson, J., Sipe, N., & Gavin, N. (2006), Shocking the suburbs: Urban location, housing debt and oil vulnerability in the Australian city. Urban Research Program, Griffith University.

Dodson, J., & Sipe, N. (2007), Oil vulnerability in the Australian city: Assessing socioeconomic risks from higher urban fuel prices. Urban studies, 44(1), 37–62.

Geurs, K., Krizek, K., Reggiani, A. (2012), Accessibility analysis and transport planning. Challenges for Europe and North America. Cheltenham, UK, Northampton, MA: Edward Elgar (NECTAR series on transportation and communications networks research).

Haller, M., Fink, B., Albrecht, M., Gutsche, J.M. (2012), Billiger wohnen im Umland? Mobilitätskosten von Wohnorten. MVV-WoMo - Der Wohn- und Mobilitätsrechner des MVV. Nahverkehr (1-2), 46–50.

Hull, A., Silva, C., Bertolini, L. (Ed.) (2012), Accessibility Instruments for Planning Practice. [S.l.]: COST Office.

IMU (2002), Raus aus der Stadt? Untersuchung der Motive für Fortzüge aus München in das Umland 1998–2002, München: IMU-Institut für Medienforschung

Institut für Mobilitätsforschung (ed.) (2010), Zukunft der Mobilität. Szenarien für das Jahr 2030. 1. Aufl. Berlin: Ifmo.

Kahn Ribeiro, S., Kobayashi, S., Beuthe, M., Gasca, J., Greene, D., Lee, D. S., … Sperling, D. (2007), Transport and its infrastructure. Climate Change, 323–385.

Kelly, P., & Adger, W. (2000), Theory and practice in assessing vulnerability to climate change and faciliting adaptation. Climatic Change 47, 325–352.

Landeshauptstadt München, Referat für Stadtplanung und Bauordnung (Hrsg.) (2012), Wanderungsmotivuntersuchung II. 2011. Unter Mitarbeit von Alexander Lang und Hubert Müller, Munich.

Landeshauptstadt München, Referat für Stadtplanung und Bauordnung (Hrsg.) (2010), Mobilität in Deutschland (MiD). Alltagsverkehr in München, im Münchner Umland und im MVV-Verbundraum, Munich.

Mattingly, K., Morrissey, J. (2014), Housing and transport expenditure: socio-spatial indicators of affordability in Auckland, 13(2), 91–109.

MIMMO e.V: Verein zur Förderung des Wirtschaftsstandorts Mühldorf a. Inn, Ich war ein Münchner, Retrieved December 20, 2014, from http://www.ich-war-ein-muenchner.de/

MOR€CO: Mobility and Residential Costs (2014), Press and illustrative material, Retrieved December 10, 2014, from http://www.moreco-project.eu/Results.php

Morris, J., Dumble, P., Wigan, M. (1979), Accessibility indicators for transport planning. Transportation Research Part A: General, 38, 69–83.

Scheiner, J. (2006), Does individualisation of travel behaviour exist? Determinants and determination of travel participation and mode choice in West Germany, 1976–2002. Die Erde, 137(4), 355–377.

U.S. EIA (2015), Retail premium gasoline prices, selected countries, Retrieved March 10, 2015, from http://www.eia.gov/countries/prices/gasolinewithtax.cfm

U.S. EPA (2015), Global Greenhouse Gas Emissions Data, Retrieved March 10, 2015, from http://www.epa.gov/climatechange/ghgemissions/global.html

Wegener, M. (2009), Energie, Raum und Verkehr. Auswirkungen hoher Energiepreise auf Stadtentwicklung und Mobilität. Wissenschaft & Umwelt INTERDISZIPLINÄR (12).

Te Brömmelstroet, M., Silva, C., Bertolini, L. (2014): Assessing Usability of Accessibility Instruments. [S.l.]: COST Office.

Imprint

Publisher:

Univ.-Prof. Dr.-Ing. Gebhard Wulfhorst

Chair of Urban Structure and Transport Planning

Technische Universität München

Germany

Edited by:

Benjamin Büttner

Printed by:

TypeSet GmbH, Kirchheim bei München

Place and year of publication:

München, 2017

ISBN 978-3-9814676-5-9

ISSN 2192-9459

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