STRESS TESTS ON URBAN MOBILITY: LESSONS FOR PUBLIC POLICIES

Aurélie Mercier[1], Yves Crozet[1], Nicolas Ovtracht[1],Benjamin Buettner[2], Gebhard Wulfhorst[2]

(1) Laboratory of Transport Economics (LET) – University of Lyon (France)

(2) Chair of Urban Structure and Transport Planning – Technische Universität München - Munich (Germany)

Email for correspondance: aurelie.mercier@let.ish-lyon.cnrs.fr

Submission for track: F4

ABSTRACT

The paper is based on a French-German collaboration between the Laboratory of Transport Economics (LET) at the University of Lyon and the Department of Urban Structure and Transport Planning at the Technical University of Munich (TUM). This analysis evaluates the resilience of households to different mobility cost shocks including energy price increases and greenhouse gas emission budgets.
Through the application of three different stress test or shock scenarios, this paper compares and contrasts expected results and potential reactions depending on the type of mobility shock. If a fuel price based on $200 per barrel has only limited change on short-term mobility behaviours, tripling the price at the gas station is a drastic shock, especially for the most vulnerable households. Another severe shock would be a mandatory “cut by half” in oil consumption through the implementation of CO2-emission rationing to 500 kg CO2 per capita and per year. Such a shock requires new mobility behaviour combined with a change in or a reduction of activities to limit motorized mobility in private or public vehicles.

Keywords: stress-tests on mobility, vulnerability, fuel price, CO2 consumption constraint, mobility behaviours.

1. RESEARCH CONTEXT AND OBJECTIVE

This paper develops an outlook for the future of mobility using a stress test methodology. It is the second part of a series on the vulnerability approach to be presented at the WCTR 2013. A first paper entitled *The impact of sharp increases in mobility costs analysed by means of the Vulnerability Assessment* (Buettner et al., 2013) presents the methodolical approach of a vulnerability assessment performed with a combination of the three indicators

of 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.

Based on the vulnerability assessment results, this paper proposes to evaluate resilience of households to prospective shocks in mobility costs like mobility prices increase and greenhouse gas emission budgets. Studies on the Munich and Lyon regions indicate an increasing amount of the household budget is being spent on mobility (Buettner et al., 2013). While residential costs can be estimated easily and accurately (example of a monthly mortgage), mobility costs and travel times are often underestimated or even ignored in household location decisions (see Büttner et al. 2012). The disconnect between residential locations and transport costs can have serious impacts on a household budget.

In this context, it is important to research transportation alternatives and strategies so that households can adapt to these increases in mobility costs. The objective of this paper is to better understand how different changes in mobility constraints can impact daily activity schedules, mobility behaviour or residential and activities locations. To achieve this understanding, this paper's methodology consists of implementing stress tests. Stress testing is used to determine the stability of a given system or entity according to different sorts of hypothesis. Often applied in the financial sector, these tests ask the question "What happens for the bank if unemployment rate puts up by X% or if GDP decreases by X%?"

In this paper, stress-tests have been adapted to urban mobility to test effects of potential external shocks on accessibility and mobility. The next section will present data and methodology developed to implement the stress-test approach. Section 3 details stress-tests and section 4 analyses households' reactions to mobility shocks.

2. DATA AND METHODOLOGY

This section develops the methodology implemented to develop stress-tests on urban mobility. Stress-tests are based on a set of assumptions presented below.

Households identification

Eight categories of households are identified according to their vulnerability level (see Buettner etal., 2013). The four most representative households, based upon socio-economic features, are used for stress-tests implementation.
Various regional databases were analyzed to derive households and determine representativeness (WMU, SuM, MiDMUC, Household survey 2006).
For the Lyon stress tests analysis the vulnerable households' categories are the following:

- A four person family (two working parents with two children) living in a suburban area;
- A single student living in the city center;
- A retired couple living close to the city center;
- A couple living in a suburban area.

For the Munich stress tests analysis, the synthetic households and their mobility behavior were derived from analyzing regional databases. Spatial patterns of movement and the corresponding causes were considered based on the Wanderungsmotivuntersuchung II (WMU). The Study "Mobility in Germany on the level of the region of Munich" (MiDMUC) yielded socio-demographic characteristics of the population, trip chains and the corresponding mode of transport. Numerous data from the Bavaria department of data and statistics completed the population data on the municipality level. Also, the GIS-based accessibility atlas (TUM) helped with a first estimation of the community structures and was subsequently used for the implementation of the data and households. The communities reviewed the generated households including the individual mobility patterns in advance and judged whether they were relevant and reasonable.

For the German stress tests analysis the households' categories are the following:

- A four person family (two working parents with two children) living in a suburban area
- A middle aged couple living in the outerskirts
- A young man living in the south of the city

Housing

This stress tests methodology incorporates regional databases in the Lyon and Munich regions which provide data on type of housing (townhouse, detached home, apartment, etc.) and number of rooms. Sizes and rent levels are estimated according to type of housing and advertisements for flats to rent. Another assumption is that mortgage monthly payments for homeowners correspond to monthly rents. Monthly housing costs refer to fuel, water and electricity costs. Fuel costs are estimated at €16 per m², electricity consumption at € 0.11 per kWh (with a yearly consumption of 1200 kWh per inhabitant). Household income is also determined by local or national surveys.

Mobility and activity behavior

Housing and activities locations are mainly determined by activity programs detailed in Lyon and Munich databases. The origins and destinations are spatially referenced. MVV WoMo, Mappy and Multitud' calculators has been used to calculate car and public transport costs (time and distance) of individual trips. Note that the Multitud' tool, developed by the Rhône-Alpes region determines shortest travel time by choosing between all available public transport networks including the regional rail network, local interurban bus network and urban public network. It offers a full range of possible mobility options for users.

Monetary cost by car is considered as a marginal cost. It refers to fuel, maintenance and insurance costs with the following values for the various scenarios:

Costs (€ per Km)	Base scenario (1.55€/liter)	Stress-test n°1 : 2.1€/liter	Stress-test n°2 : 4.65 €/ liter
Fuel	0.12	0.24	0.37
Maintenance	0.06	0.06	0.06
Insurance	0.02	0.01	0.01
Total	0.19 (rounded up to 0.2)	0.31 (rounded up to 0.3)	0.44 (rounded up to 0.45)

Source: ADETEC déplacements, 2012 (base situation) and authors computations (stress-tests)

Table 1 : Car monetary costs

In the Lyon metropolitan area, monetary cost by public transport is considered using the following assumptions:

- In urban public transport network price of ticket is €1.60 (full price) and €1.25 (reduced price);
- A student making more than 20 trips per month takes a monthly seasonal ticket at €26.30;
- A working people making more than 30 trips per month takes a monthly seasonal ticket at €52.60 (if urban public transport only) or €65 (if coupled with interurban public transport);
- Trips by interurban bus services are offered at a single price of €2.00;
- A working people making more than 30 trips per month takes a monthly seasonal ticket at €52.60

For Munich the current costs for the synthetic households are based on their individual trip chains and spatially referenced activities were calculated using the WoMo calculator of the MVV. The residential costs were also considered in the case of relocation.
In order to avoid incorrect planning and wrong investments, drastic shock scenarios – assuming the gas price to triple – were implemented as well.

3. PRESENTATION OF STRESS-TESTS SCENARIOS

Stress-tests Assumptions

The research purpose is mainly to analyze impacts of oil shocks on daily mobility costs and travel behavior following a *ceteris paribus* approach.
Stress-test scenarios are implemented using the following assumptions:

- Shocks on mobility appear suddenly and therefore are not planed by households;
- Shocks alternatives depend only on households. Public authority cannot answer these shocks;
- No public measure such as a tax decrease or fuel voucher is implemented to absorb, even partially, the shocks;

- Proposed shocks only refer to daily mobility and long distance travels are not impacted by shocks.

It can be assumed that the rise in gas prices will appear in leaps, which will have an immediate effect on the price consumers pay at the pump. However, since public transportation costs are based less on market forces and more on political forces, it is assumed that public transport costs will rise more moderately and allow people more time to adapt.

Stress-test n°1: Crude oil price at a level of $200/barrel

Many studies predict a rise of the crude oil price to 200 $ per barrel, which would cause the prices at German gas stations to rise to 2.11 €/l. The jump from 1.55 €/l to 2.11 €/l is only a moderate shock. For France considering a mean price of $100 in 2011 the price increase generates a doubling of oil price.

Stress-test n°2: Fuel prices at the gas station triples

The second simulation represents a fuel price tripling where household must spend €4.50 per liter of fuel in France. At the same time Germans had to pay 1.55 €/l for fuel, which will result for shock scenario n°2 in 4.65 €/l.

Stress-test n°3: Oil shortage and rationing of fossil energy resources

Following the first two scenarios presenting a pricechange, the third stress-test proposes a quantity regulation. It rations fossil fuel resources by translating a limited fuel supply into a maximum number of kilometers traveled per month. It asks the following question: what would happen if a “monthly car travel distance of 42 km maximum” was imposed to each individual for daily mobility? Would households react to this situation by changing their daily activity program or mobility behavior?

In France, CO2 consumption is estimated to be between 8 and 9 tons per person per year (see ADEME). Among them 2 tons are used for mobility (Longuar et al., 2010). In this stress-test, the purpose is to reduce CO2 consumption to 500 kg per year, among them 200 kg for mobility. This yearly emission budget of 200kg corresponds to 120 liters of fuel per year, 500 kilometers (with a consumption of 5l per 100 km) and 42 monthly kilometers.

Potential reactions of users

Facing such shocks on mobility, we consider various potential reactions of users based on household features.

The research purpose is not to provide an exhaustive list of all the possible alternatives. It aims to show what alternatives households have in terms of adaptation to these shocks and what kinds of impacts shocks have on travel cost and time. Potential reactions are change of mode (walking/cycling, public transport, electric car, …) or car-pooling, eco-Driving, change of activities and/or destinations and change of residential location.

4. HOUSEHOLDS REACTIONS TO STRESS-TESTS

Household storyline 1: Four-person family living on a suburb area in the Lyon metropolitan region

Household presentation and base-situation

The first household is composed of two parents and two daughters (8 and 11 years old). They live in a small municipality (6500 inhabitants) 25 km from the city of Lyon, in a detached home. Two cars are available in the household.
The two parents are working and total household income amounts monthly to €3000.

Person	Age	Activity
Man	43	Full time worker
Woman	38	*Part time worker*
Daughter 1	11	High school student
Daughter 2	8	Primary school child

Adress	Housing		Rent (€/Month)	Income (€/Month)	Number of cars
Promenade des Tilleuls 01120 Montuel	dwelling-house	*90 m2*	*600*	3000	2

Table 1 : Household 1 presentation

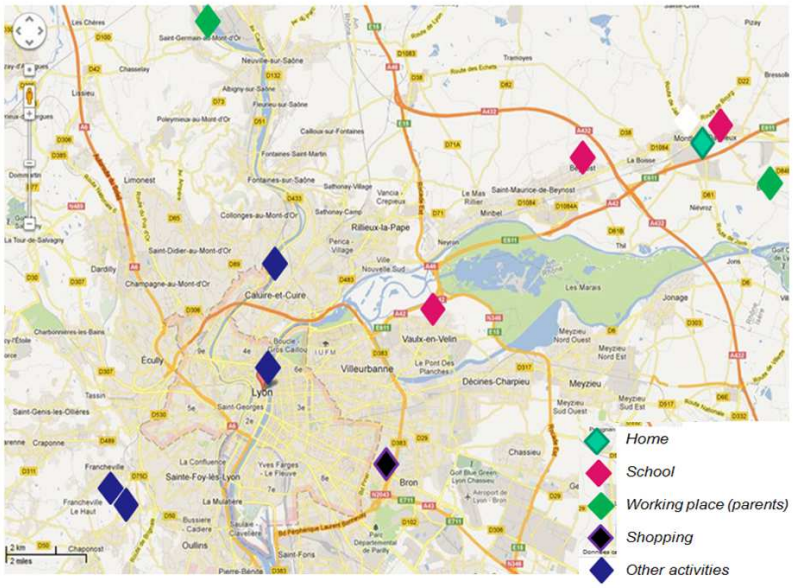

Figure 1: Household 1 activity location

Daily activities refer mainly to home to work trips for parents (even if the mother is a part-time worker 3 days a week) and to Home to school trips. Daughter 1 goes to school by foot while daughter 2 is accompanied by one parent within another trip like the morning Home-based work. Only the father leaves the suburbs of Montluel for his daily trips. Weekly activities generate high trip distances to Lyon or its suburbs (Caluire or Vaulx-en-Velin). Household member only make trips by car and spend monthly more than 43 hours in the cars to cover 2,500 kilometers. More than 60 percent of the household monthly travel time budget is spent by the father.

Almost 50 percent of the household income is devoted to transportation and housing costs, with housing costs representing 30 percent of the monthly income and mobility 17%. This household is just at the limit of the vulnerability level. For Vanco and Verry (2009), a household is vulnerable when more than 18 percent of the total income is spent for daily mobility - by way of comparison, in France 10 percent of household income is devoted for daily mobility. This household is car dependent mainly because of it residential location and faces the risk of easily becoming vulnerable because of an energetic crisis situation or a fuel price increase.

				Total
Coût(€)	Housing cost per month	Rent	600	**811**
		Housing costs	211	
	Mobility monthly costs	Km by car	2566	**513**
		Car marginal cost	0,2	
		PT seasonal ticket	0	**0**
		Savings using PT	0	
		Total cost by car	513	**513**
		Total cost by PT	0	
		TOTAL COST CAR+PT	513	
	Travel timeBY CAR		43h10	
	Travel timePT		0	
	Total travel time		43h10	

Net income(€/Month)	3000
Housing and mobility costs(€/Month)	**1324**
Ratio (cost/income)	**44%**
Available income(€/Month)	**1675,7**

Table 2 : Mobility and housing costs on base situation

Stress-test n°1: Crude oil price at a level of $200 / barrel

The crude oil price at a level of $200 per barrel increases mobility cost 50% above the base scenario. In this new situation the share of mobility budget compared to total income amounts to 25 percent and therefore the household becomes vulnerable. Only €1400 remains available for daily spending (taking out mobility and housing costs) and tax payment.

				Total
Cost(€)	Housing cost per month	Rent	600	811
		Housing costs	211	
	Monthly mobility mcosts	Km by car	2566	769
		Car marginal cost	0,3	
		PT seasonal ticket	0	0
		Savings using PT	0	
		Total cost by car	769	769
		Total cost by PT	0	
		TOTAL COST CAR+PT	769,8	

Net income(€/Month)	3000
Housing and mobility costs(€/Month)	**1580**
Ratio (cost/income)	**53%**
Available income(€/Month)	**1419**

Table 3 : Mobility and housing costs within shock 1

The first alternative refers to modal transfer. To keep a monthly mobility budget of €500, this household should reduce distance by car to 1,600 kilometers. The car travel cost decrease generated can allow financing public transport seasonal tickets. Modal transfer is only possible for the father. He can use public transportation for home to work trips. In this alternative, he has to take three different buses and the total travel time budget is increase is estimated to 30h per month! To avoid this travel time increase, another alternative could be to change modes for leisure purpose trips.

				Total
Cost(€)	Housing cost per month	Rent	600	811
		Housing costs	211	
	Monthly mobility costs	Km by car	1326	397,8
		Car marginal cost	0,3	
		PT seasonal ticket	90	90
		Savings using PT	282	
		Total cost by car	398	488
		Total cost by PT	90	
		TOTAL COST CAR+PT	488	
	Travel time by CAR		16h30	
	Travel time by PT		60h	
	Total travel time		76h30	

Net income(€/Month)	3000
Housing and mobility costs(€/Month)	**1298,9**
Ratio (cost/income)	**43%**
Available income(€/Month)	**1701**

Modal transfer for the father's home to work trips

				Total
Cost(€)	Housing cost per month	Rent	600	811
		Housing costs	211,08	
	Monthly mobility costs	Km by car	1840	552
		Car marginal cost	0,3	
		Tickets PTU	43	43
		Savings using PT	174	
		Total cost by car	552	595
		Total cost by PT	43	
		TOTAL COST CAR+PT	595	
	Travel timeBY CAR		30h	
	Travel timePT		34h10	
	Total travel time		64h10	

Net income(€/Month)	3000
Housing and mobility costs(€/Month)	**1406,1**
Ratio (cost/income)	**47%**
Available income(€/Month)	**1594**

Modal transfer for leisure activities

Table 4 : Household 1 reaction to shock 1

These two alternatives keep the mobility budget constant in spite a fuel price increase and highlight the difficulties in limiting trips by car. Household location is not well-served by public transport networks. Moreover the higher travel time increase is not compensated by the monetary cost decrease when the household uses public transportation. The main "disadvantage "of this family is thus its suburban location.

Stress-test n°2: Fuel price level triples at the gas station

A tripling of fuel price highly impacts household budget. In this scenario, the mobility budget grows to represents one third of total income. In this context, more than two thirds of total income is devoted to mobility and housing spending. In responding to this shock, simply changing modes is not sufficient and also not very realistic. Only a change of residential location can allow households to adapt to this change.

We consider that the new household location is chosen to minimise home to work trip distances for the father and should not be far from Montluel where the childrens' school and the mother's job are located. Under these constraints, the new location is in Rillieux-la-Pape, a city with 28,300 inhabitants, 16 km away from Montluel and 14 km away from the workplace of the father. We also assume that the younger daughter is driven by one of her parents unlike the older daughter who makes her way to school by herself.

				Total
Cost(€)	Housing cost per month	Rent	700	911
		Housing costs	211,08	
	Monthly mobility costs	Km by car	2432	1094
		Car marginal cost	0,45	
		PT seasonal ticket	0	0
		Savings using PT	0	
		Total cost by car	1094,4	1094
		Total cost by PT	0	
		TOTAL COST CAR+PT	1094,4	
	Travel timeBY CAR		49h30	
	Travel timePT		0	
	Total travel time		49h30	

Net income(€/Month)	3000
Housing and mobility costs(€/Month)	**2005,5**
Ratio (cost/income)	**67%**
Available income(€/Month)	**994,5**

Table 5 : Mobility and housing costs within shock 2

This new residential location equidistant from the job locations of both parents doesn't allow the household to reduce the cost/income ratio. First, monthly mobility cost reduction is very low (-5 percent). If distance covered by the father is divided by 2.3, the distance covered by the mother increases by 75 percent. Moreover, trips by car made for the older daughter rise exponentially (from 165 km to 800 km per month). The total distance increase of mother and

daughter trips costs €300 monthly. Avoiding special daughter trips by car (to go to school and other activities), combining with the home to work mother' trips, for example, the family could reduce the cost/income ratio to 56%. The rental price also increases by €100 for the same type of housing.

To conclude, in a family with two parents working in two different places far from the residential location by several kilometers, the new housing location doesn't appear to be a realistic solution to a fuel price increase. It could be a source of savings only with a decreasing is the price of housing. To keep a monthly available budget close to €1600 with a residential place in Rillieux-la-Pape and the same activity locations, the rental price increase shouldn't be higher than €100.

Stress-test n°3: Oil shortage and rationing of fossil energy resources

The third shock rationing fossil energy resources highly impacts the family. With a reduction of the monthly car distance budget to 42 kilometers per person, the household needs to limit the total car travel distance to 168 kilometers per month. Facing this third shock, only a few alternatives are possible. A change of housing location or a reduction of activities for one or two family members is not sufficient. Combining new location schemes and activity programs is needed. We consider the following schemes:

1) Housing relocation close to the father's workplace so he can commute on foot from home to work. This new location needs a monthly rent increase of €200 but will save 1240 kilometres per month.

2) Use of public transportation for the mother's home to work trips, three times a week. Total travel time is estimated at 3 hours and 20 minutes. More than 540 kilometres are transferred from car to public transportation.

3) The housing relocation multiplied by 2 by a change of children school location. The new location is close to home. This change saves 540 kilometres by car per month.

4) All father's activities are made by public transportation.

5) Trips to supermarkets are replaced by online shopping. We assume that home delivery services are made by non-polluting vehicles.

6) Weekly activities are reduced to one time per week for the older daughter. Monthly activities are reduced to one for the mother and the younger daughter (instead of three).

				Total
Coût(€)	Housing cost per month	Rent	400	588
		Housing costs	188	
	Monthly mobility costs	Km by car	161	32,2
		Car marginal cost	0,2	
		PT seasonal ticket	145	145
		Savings using PT	335,8	
		Total cost by car	32	177
		Total cost by PT	145	
		TOTAL COST CAR+PT	177	
	Travel timeBY CAR		6h	
	Travel timePT		61h	
	Total travel time		67h	

Net income(€/Month)	3000
Housing and mobility costs(€/Month)	**765**
Ratio (cost/income)	**26%**
Available income(€/Month)	**2 235**

Table 6 : Household 1 reaction to shock 3

Through this combination of housing relocation and activity reduction, these alternatives increase monthly available income to €2200. But this budget comes as a result of drastic lifestyle changes with a high increase of travel time distance. This is particularly difficult for the mother who is spending more than 40 hours per month on public transportation.

Household storylines 2: a family living in the Munich metropolitan region

As a first step, the individual mobility behavior and trip chains of the synthetic households were geo-referenced and visualized. This was done with the GIS-based accessibility atlas using real address data.
The MVV WoMo calculator was used to calculate the current costs for the respective trips individually. Price shocks were applied and their possible effects were outlined. In addition, all trips were attributed CO2 emissions and travel times. The accessibility atlas therefore administers the households and the precise addresses of the corresponding origin and destination relationships of the calculated activities (work and education, supply, leisure).

Current Mobility Behavior

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

Table 7: Members of Household 1

Household 1 represents the average Munich household with four members as defined in the WMU survey.

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

Table 8: Household 1 in Munich

Work or Education

The husband 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 get 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 able to use PT as much because of the high flexibility required for her job and also due to other daily activities like taking the kids to school. 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 and kindergarten, respectively, are located close to their home (Flurstraße 8) and can be reached by foot.

Leisure

On Tuesday evenings the husband usually plays soccer with his friends in the Olympic Park (Connollystraße 32). Even though he could get there by PT he prefers to use the car.

The wife meets her friends in the city center once a week (Hohenzollernstraße 25). Most of the times she goes by PT, but also thinks about potential trip chains that could conveniently be done by car.

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

Infrequent trips in Munich

Possibilities for daily shopping are available nearby the family's house. On weekends, however, they use their car for going to a bigger shopping center in the outskirts and try to combine these trips with leisure activities like bowling or cinema (Thomas-Dehler-Straße 12).

Once a month, the entire family goes on an excursion outside Munich, for example hiking or visiting friends (Beccostraße 12, Pöcking). For this activity they usually take the car.

Other infrequent trips, like going to the barber (Innere Wiener Straße 48), special occasion dinners or meetings, are made by PT. On the other hand, the parents use the car to drive their kids to birthday parties or doctor's appointments (Karl-Theodor-Straße 97).

Person	Frequent Activities				Infrequent Activities (1x a month)	
	Work days		Leisure (1x a week)			
Husband	Full time	Ottostraße 13 (City center)	Soccer	Connollystraße 32 (Olympic Park)	Barber	Innere Wiener Straße 48 (Au-Haidhausen)
Wife	Part time	Kapuzinerplatz 1 (Isarvorstadt)	Meeting friends / dinner	Hohenzollernstraße 25 (Schwabing)	-	
Son	School	Flurstraße 8 (Au-Haidhausen)	Music academy	Flurstraße 8 (Au-Haidhausen)	Doctor / Birthday parties	Karl-Theodor-Straße 97 (Schwabing)
Daughter	Kindergarten	Flurstraße 8 (Au-Haidhausen)			Doctor / Birthday parties	Karl-Theodor-Straße 97 (Schwabing)
Together			Shopping / Bowling / Movie theater	Thomas-Dehler-Straße 12 (Neuperlach))	Visit family / Hiking	Beccostraße 12 (Pöcking)

Table 9: Activities of Household 1 in Munich

Since the husband has a new job in Karlsfeld, the family moves to Aubing, the westernmost district of Munich. From there, Karlsfeld can be reached by car within 14 minutes via the highway A99. 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 S-Bahn, which provides direct services to the city center. The stations are quite close to the new house, at just 1 to 1.5 km distance.

Moving to the outskirts to be closer to the husband's new job enables the family to live in a green area where rents are lower than in the city center.

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 10: Household 1 in Aubing

Since they do not want to lose contact with friends or dramatically change their habits, they keep practicing exactly the same activities as before. Leisure activities such as playing soccer or meeting friends in Munich are going to remain part of their weekly schedule.

Aubing has a high PT accessibility, but the move will still influence the family's monthly transportation expenditures significantly.

Initial Situation

Table 11: Initial situation: calculation of costs for Household 1 in Aubing

Activity	Workplace Husband	Workplace Wife	Workplace wife and trip chain for leisure	Leisure activities 1	Leisure activities 2
Transport mode	CAR	CAR	CAR	CAR	CAR
Travel time PT one way (min)	63	45	110*	112	156
Travel time car one way (min)	14	24	70*	59	102
Travel time P+R one way (min)	31	36	118*	74	110
Trips / week	x5	x4	x1	x1	x0.25

*way back home included

								Sum
Costs (€)	Living costs per month	Net rent	1100					**1100**
		Additional living costs	300					**300**
		Gross rent WMU	1300					**1300**
	Mobility costs per month	Car ownership	800					**800**
		Car use	100	98	39	88	23	**348**
		PT	25					**25**
		km car/month	495	612	241	436	115	**1899**
CO_2 Consumption	House		740					**740**
		Heat	567					**567**
		Appliances	75					**75**
		Hot water	98					**98**
	Transport		84	89	35	74	19	**300**
		PT						**0**
		Car	84	89	35	74	19	**300**
	Travel time (minutes/month)		630	864	315	531	232	**2572**

Shock Scenarios

Increase to 2.11 €

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

This slight increase in expenditures 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 P+R instead of her car four times a week to go to work. Only when she meets her friends in the city center she takes the car. Another simple way 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 kid to the school via highway A99 (35 km). Using a more direct route (22 km) would save some 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 12: Increase to 2.11 €: calculation of costs for Household 1 in Aubing

			1.55 €/l	2.11 €/l	2.11 €/l P+R mother	Sum		
						1.55 €/l	2.11 €/l	2.11 €/l + P+R mother
Costs (€)	Living costs per month	Net rent	1100	1100	1100	**1400**	**1400**	**1400**
		Additional living costs	300	300	300			
	Mobility costs per month	Car ownership	800	800	800	**1082**	**1159**	**1059**
		Car use	348	426	284			
		MVV season tickets	0	0	66			
		MVV additional tickets	25	25	0			
		Savings from commuting allowance	91	91	91			
	Travel time (minutes/month)					**2572**	**2572**	**3049**

Net income (€/month)	3750	3750	3750
Mobility and living costs (€/month)	**2482**	**2559**	**2459**
Ratio (costs/income)	**66%**	**68%**	**66%**
Remaining money (€/month)	**1268**	**1191**	**1291**

Increase to 4.65 €

A leap in fuel prices to 4.65 €/l (tripling the current prices) would have a drastic impact on the household budget. Each month, the family would spend 429 € more than in the current situation.

Assuming the household is aware of the importance of increasing transport efficiency, they will try to maintain the same budget as before the price shock by changing mobility patterns.

All family members have to contribute to this aim by using PT 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 activity) as this requires a certain level of flexibility. Also the son will go to music school by PT, losing 10 minutes per trip (one way). The husband suffers most from this new situation, because he has to spend 49 extra minutes on his way to work. This is a major drawback of the chosen residential location, as the PT 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 small car is not necessary anymore and could be sold. This saves 350 € of fixed car ownership costs per month.

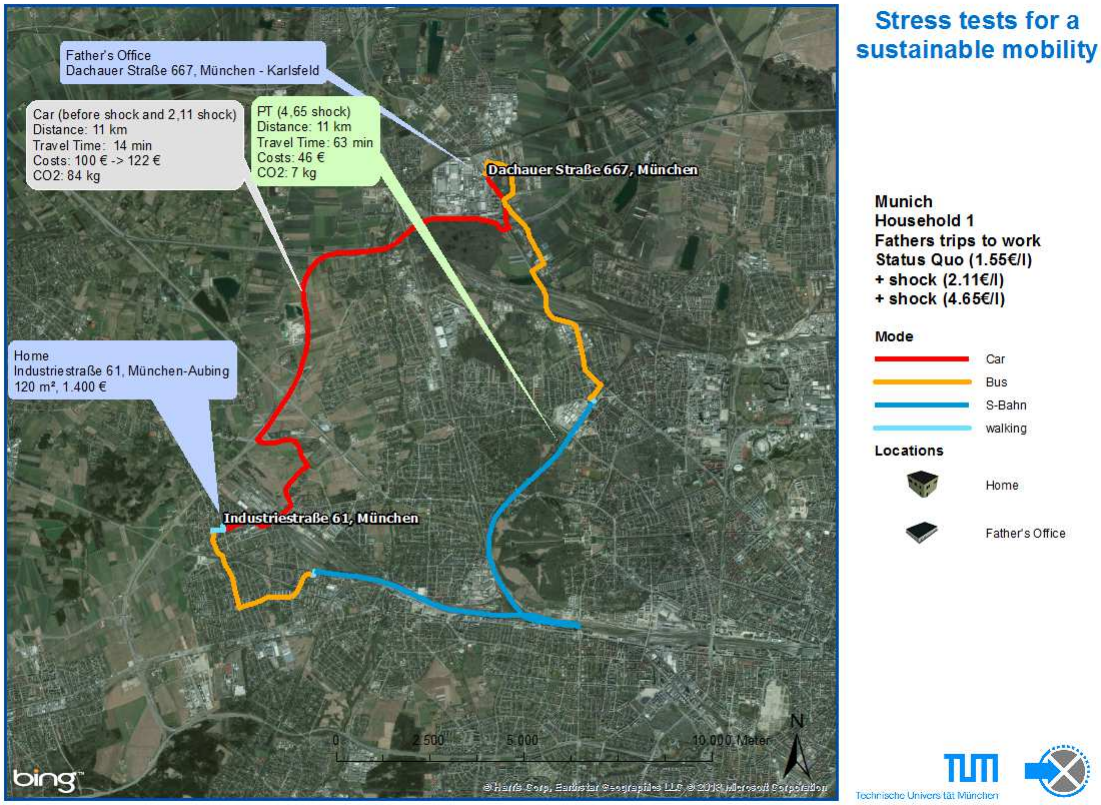

Figure 2: Household 1 shock scenarios and alternatives

As already stated, the negative consequences of changes in mobility behavior are increased time expenditures. 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 are leveled out by financial gains. Selling one car and adapting the trip behavior will even save 408 € compared to the pre-shock situation. A pure change in mobility patterns without selling the car would still increase the remaining amount of money by 74 €.

Table 13: Increase to 4.65 €: calculation of costs for Household 1 in Aubing

			1.55 €/l	4.65 €/l	4.65 €/l + PT	4.65 €/l + PT + Selling car	Sum			
							1.55 €/l	4.65 €/l	4.65 €/l + PT	4.65 €/l + PT + Selling car
Costs (€)	Living costs per month	Net rent	1100	1100	1100	1100	**1400**	**1400**	**1400**	**1400**
		Additional living costs	300	300	300	300				
	Mobility costs per month	Car ownership	800	800	800	450	**1082**	**1159**	**1008**	**674**
		Car use	348	777	164	180				
		MVV season tickets	0	0	113	113				
		MVV additional tickets	25	25	23	23				
		Savings from commuting allowance	91	91	91	91				
	Travel time (minutes/month)						**2572**	**2572**	**5569**	**5569**

Net income (€/month)	3750	3750	3750	3750
Mobility and living costs (€/month)	**2482**	**2911**	**2408**	**2074**
Ratio (costs/income)	**66%**	**78%**	**64%**	**55%**
Remaining money (€/month)	**1268**	**839**	**1342**	**1676**

Household storylines 3 : a young couple living in the outskirts of Munich

The second Munich household that will be analyzed is a young couple. While the man works as an electronic engineer for an aircraft industry company in the outskirts of Munich, the woman does a part time internship at a company located in Bogenhausen.

They are quite happy with their apartment in Milbertshofen that they rented when they were students. Due to the high demand for housing in Munich, it would be difficult to find a better one, which is why they decided to keep their current apartment.

Address	Floor space (m²)	Living costs (€/month)	Income (€/month)	Number of rooms	Number of cars
Frankfurter Ring 12 Milbertshofen	70	960	2,500	3	1

Table 14: Household 2 in Munich

Current Mobility Behavior

His salary allows the man to maintain a small car. It enables him to reach his work place within 35 minutes instead of 70 minutes by PT.

The woman, however, has to rely on PT to get to Bogenhausen. As the connection between their home and her internship is not very good, she has to accept spending around 35 minutes on the bus.

Table 15: Initial situation: calculation of costs for Household 2 in Munich

Activity	Workplace Man	Workplace Woman	Leisure activities
Transport mode	Car	PT	Car
Travel time PT one way (min)	70	37	60
Travel time Car one way (min)	33	15	31
Travel time P+R one way (min)		35	45
Trips / week	x5	x5	x1

						Sum
Costs (€)	Living costs per month	Net rent	762			**762**
		Additional living costs	198			**198**
	Mobility costs per month	Car ownership	350			**350**
		Car use	216	0	**51**	**266**
		PT	25			**25**
		km car/month	1350	0	318	**1668**
CO_2 Consumption	House		438			***438***
		Heat	339			**339**
		Appliances	75			**75**
		Hot water	24			**24**
	Transport		*196*	*13*	*46*	***255***
		PT	0	13	0	**13**
		Car	196	0	46	**242**
	Travel time (minutes/month)		1485	1665	279	**3429**

Shock Scenarios

Increase to 2.11 €

The increase in fuel prices to 2.11 €/l encourages the young man to finally realize his carpooling idea. Many of his colleagues at work do not own a car and have to travel from Munich to Weßling by PT. In order to cover the additional costs, he charges his coworkers half the fuel price and changes his route so he can pick them up in the city center (Neuhausen) on his way to the office. With the extra money earned, the household is able to get back to the same level of expenditures as before the price shock.

The remaining mobility patterns are not going to change in this scenario, as the couple can still afford using the car, for example when visiting their best friends in Freising.

Table 16: Increase to 2.11 €: calculation of costs for Household 2 in Munich

			1.55 €/l	2.11 €/l	2.11 €/l + car pooling	Sum		
						1.55 €/l	2.11 €/l	2.11 €/l + car pooling
Costs (€)	Living costs per month	Net rent	762	762	762	**960**	**960**	**960**
		Additional living costs	198	198	198			
	Mobility costs per month	Car ownership	350	350	350	**537**	**596**	**496**
		Car use	266	325	225			
		MVV season tickets	48	48	48			
		MVV additional tickets	0	0	0			
		Savings from commuting allowance	127	127	127			
	Travel time (minutes/month)					**3429**	**3429**	**3429**

Net income (€/month)	2500	2500	2500
Mobility and living costs (€/month)	**1497**	**1556**	**1456**
Ratio (costs/income)	**60%**	**62%**	**58%**
Remaining money (€/month)	**1003**	**944**	**1044**

Increase to 4.65 €

In case of a price jump to 4.65 €/l the mobility patterns of the household turn out to be unsustainable. The high costs for the daily car drive to the office in Weßling cannot be neglected and more drastic changes have to be made regarding everyday mobility.

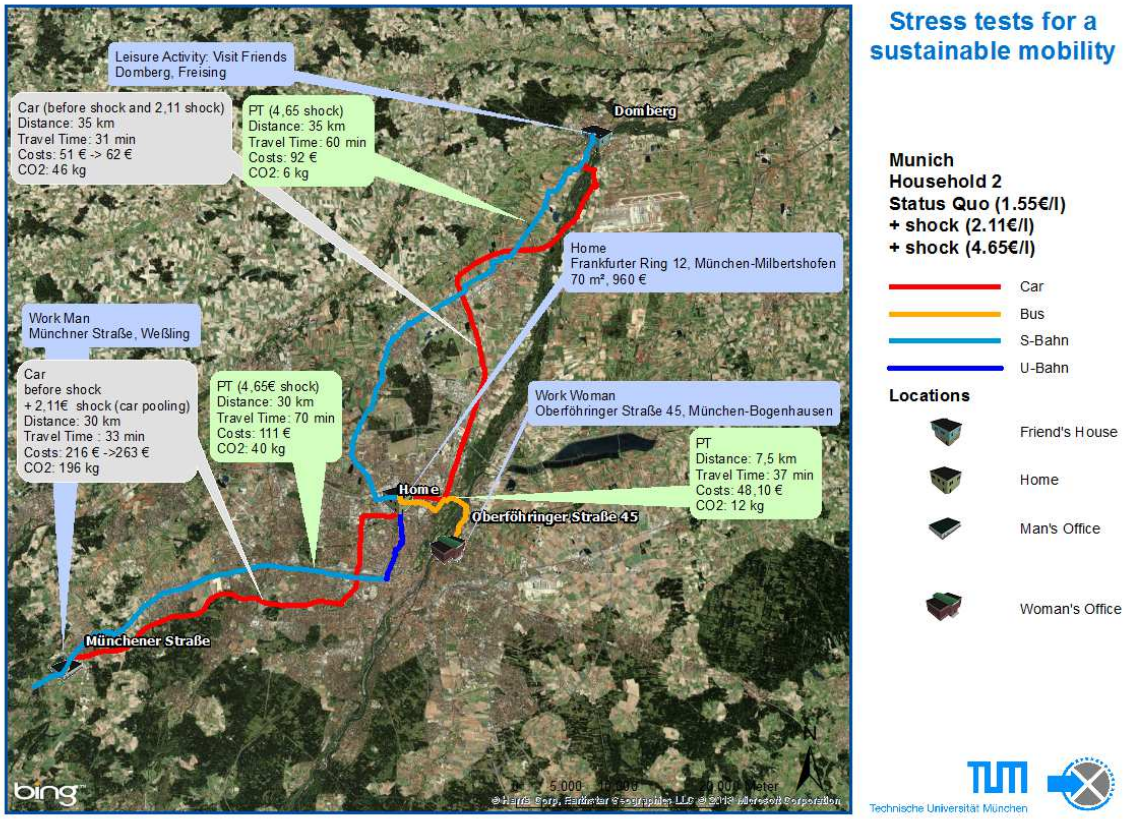

Figure 3: Household 2 shock scenarios and alternatives

A first possibility to reduce costs would be to stop going to Freising by car and use the S-Bahn instead. It takes 30 minutes longer per trip, but the couple accepts this as they have plenty of time on the weekends and thus value the financial savings higher than the loss of time.

Concerning the man's trips to the office, there are two possibilities for reducing his costs to the same level as before the fuel price triplication. One option would be to continue carpooling and charge his colleagues with half of the fuel price, which would now add up to around 300 €. However, it is unlikely that they are willing to accept these high costs. The second option would be to leave the car at home and use PT to go to work. This would take 70 minutes longer than by car, which sums up to almost 2000 extra minutes per month. A positive financial aspect of this option is that he could sell his car and thus save 350 € per month in insurance and maintenance costs.

Table 17: Increase to 4.65 €: calculation of costs for Household 2 in Munich

			1.55 €/l	4.65 €/l	4.65 €/l + more car pooling	4.65 €/l + PT + selling the car	Sum			
							1.55 €/l	4.65 €/l	4.65 €/l + PT	4.65 €/l + PT + Selling car
Costs (€)	Living costs per month	Net rent	762	762	762	762	**960**	**960**	**960**	**960**
		Additional living costs	198	198	198	198				
	Mobility costs per month	Car ownership	350	350	350	0	**537**	**863**	**642**	**124**
		Car use	266	592	279	0				
		MVV season tickets	48	48	48	159				
		MVV additional tickets	0	0	92	92				
		Savings from commuting allowance	127	127	127	127				
	Travel time (minutes/month)						**3429**	**3429**	**3690**	**5355**

Net income (€/month)	2500	2500	2500	2500
Mobility and living costs (€/month)	**1497**	**1823**	**1602**	**1084**
Ratio (costs/income)	**60%**	**73%**	**64%**	**43%**
Remaining money (€/month)	**1.003**	**677**	**898**	**1.416**

Household 4: a young man living in Munich

Household 3 consists of only one member, a young man who recently moved to Munich for his new job.

Current Mobility Behavior

The company's offices are located in Holzkirchen in the south of Munich, 30 km away from the house the man decided to rent. His home is close to the highway A8, which provides for a quite fast connection to his work place (28 minutes). Using PT would take a lot longer than driving by car (64 minutes).

He goes to the district of Sendling to play soccer and practice some other sports two times a week. He also uses his car for these trips as it saves time and seems more comfortable to him.

Table 18: Initial situation: calculation of costs for Household 3 in Munich

Activity	Workplace	Leisure activities
Transport mode	Car	Car
Travel time PT one way (min)	64	53
Travel time Car one way (min)	28	23
Travel time P+R one way (min)	41	37
Trips / week	x5	x2

					Sum
Costs (€)	Living costs per month	Net rent	698		**698**
		Additional living costs	181		**181**
	Mobility costs per month	Car ownership	350		**350**
		Car use	214	26	**240**
		PT			
		km car/month	1341	164	**1505**
CO_2 Consumption	House		397		***397***
		Heat	298		**298**
		Appliances	75		**75**
		Hot water	24		**24**
	Transport		*194*	*24*	***218***
		PT	0	0	**0**
		Car	194	24	**218**
	Travel time (minutes/month)		1260	414	**1674**

Shock Scenarios

Increase to 2.11 €

An increase to 2.11 €/l does not have a very strong effect on the mobility patterns of the household member.

Not changing his previous behavior will cost him 53 € more per month. Nevertheless, the fact that there is less money remaining every month makes him think about possible savings if he goes to the sports club by PT. However, this would only save him around 9 € per month as he has to buy a ticket.

Table 19: Increase to 2.11 €: calculation of costs for Household 3 in Munich

			1.55 €/l	2.11 €/l	2.11 €/l + PT for leisure	Sum 1.55 €/l	Sum 2.11 €/l	Sum 2.11 €/l + PT for leisure
Costs (€)	Living costs per month	Net rent	698	698	698	**879**	**879**	**879**
		Additional living costs	181	181	181			
	Mobility costs per month	Car ownership	350	350	350	**534**	**587**	**578**
		Car use	240	293	261			
		MVV season tickets	0,00	0,00	0,00			
		MVV additional tickets	0,00	0,00	23			
		Savings from commuting allowance	56	56	56			
	Travel time (minutes/month)					**1674**	**1674**	**2214**

Net income (€/month)	2000	2000	2000
Mobility and living costs (€/month)	**1413**	**1466**	**1457**
Ratio (costs/income)	**71%**	**73%**	**73%**
Remaining money (€/month)	**587**	**534**	**543**

Increase to 4.65 €

If fuel prices rise to 4.65 €/l the man will notice a huge impact on his household budget. The rather large distance to his workplace makes him very vulnerable to big leaps in oil prices.

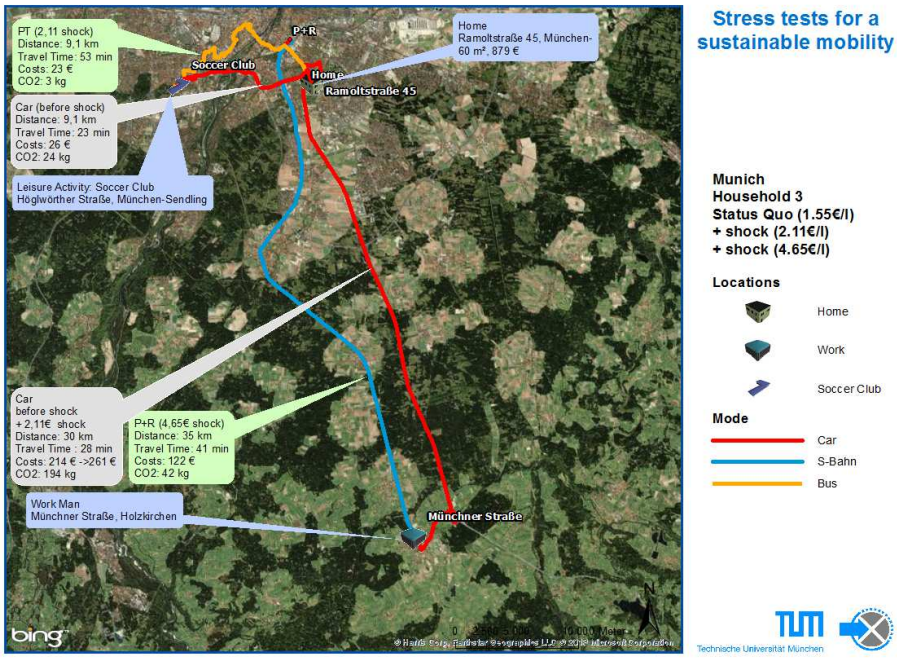

Figure 4: Household 3 shock scenarios and alternatives

Instead of driving the entire way to work, he goes to the closest P+R facility and uses the S-Bahn from there. Even though he has to buy an MVV ticket for 122 € each month, he saves around 400 € in terms of fuel consumption, making the effect of using PT visible. These savings allow him to use his car twice a week for going to the sports club.

The downside of this change in behavior is that he has to spend 13 more minutes to reach his job location, which sums up to 600 minutes of additional travel time per month.

Table 20: Increase to 4.65 €: calculation of costs for Household 3 in Munich

			1.55 €/l	4.65 €/l	4.65 €/l + PT for leisure	Sum		
						1.55 €/l	4.65 €/l	4.65 €/l + PT for leisure
Costs (€)	Living costs per month	Net rent	698	698	698	**879**	**879**	**879**
		Additional living costs	181	181	181			
	Mobility costs per month	Car ownership	350	350	350	**534**	**828**	**521**
		Car use	240	534	104			
		MVV season tickets	0	0	122			
		MVV additional tickets	0	0	0			
		Savings from commuting allowance	56	56	56			
	Travel time (minutes/month)					**1674**	**1674**	**2259**

Net income (€/month)	2000	2000	2000
Mobility and living costs (€/month)	**1413**	**1432**	**1400**
Ratio (costs/income)	**71%**	**72%**	**70%**
Remaining money (€/month)	**587**	**568**	**600**

5. CONCLUSION

This paper compares and contrasts the results of three different fuel shock scenarios applied to mobility. These three scenarios include a fuel price based on $200 a barrel, a tripling of fuel prices at the pump (4.65€ per liter), and a reduction in CO2 emissions by one half (restricting distances traveled by car to 42 km per month per person).

A fuel price based on $200 per barrel has a limited impact on household activities and only limited effect on short-term mobility behaviors.

The shock tripling the price at the gas station begins to really affect the household budget, especially for the most vulnerable households - often lower or medium class households living in suburban areas. Nevertheless, potential alternatives such as using public transportation, car-pooling or changing activities or residential locations can prevent this shock from highly impacting the household budget.

The most dramatic shock would be to cut oil consumption by half through CO2-emission rationing to 500 kg CO2/capita per year. Such a shock requires new mobility behaviour without car as a personal vehicle but used in a car-pooling or car sharing strategy. Simply changing modes is not sufficient under this scenario and must be combined with a change or a reduction of activities to limit motorized mobility in private or public vehicles.

Although the price at the pump is going up, 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. Therefore intelligent location choices are required. However, this is not always possible, as some activity locations cannot be changed easily. Still, trip chains 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 settlement structure. Daily private vehicle commutes can be made more sustainable through sharing a ride with other people. Car pooling is an effective strategy to save costs of commuting trips over driving alone and usually it enables faster travel times than public transport.
Park and Ride is another alternative, as it combines the advantages of two modes. It offers flexibility and comfort in sparsely settled regions without any PT services. At the same time congestion and time losses in densely populated urban centers can be avoided. In some cases teleworking might be another possibility to save mobility costs.

In most cases, households are only able to change their mobility behavior if they are offered other options or alternatives. 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.

LITERATURE

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.

Buettner, 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.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.

IAU, 2009, La facture énergétique des ménages franciliens, Note rapide Habitat n°485, août 2009. http://www.iau-idf.fr/fileadmin/Etudes/etude_614/NR_485_web.pdf

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.

Longuar, Z., Nicolas, J-P. , Very D., 2010, Chaque Français émet en moyenne deux tonnes de CO2 par an pour effectuer ses déplacements, RevueCGDD. Online:
http://www.statistiques.developpement-durable.gouv.fr/fileadmin/documents/_shared/pdf/9_RevueCGDD-ENTD-article_9_CO2_-_13_12_10_cle67215c.pdf

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.