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ALternative Pathways toward Sustainable development and climate stabilization (ALPS) Project

Final Report

RITE-IIASA Collaborative Study on

The potential for greenhouse gas mitigation through consumer choices on mobility

Activity 2

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The potential for greenhouse gas mitigation through consumer choices on mobility

Jens Borken-Kleefeld, Markus Amann

1. Introduction

Recent analyses, inter alia with IIASA's GAINS model, indicate that technological improvements can reduce greenhouse gas emissions in many economic sectors by 20% to 30% relative to baseline trends for 2020 at a marginal cost of less than 100€/tCO_2eq. However, the mitigation potential for reducing emissions from the road transport sector through technical means is far more limited and more costly. Trend scenarios suggest that in many countries future efficiency improvements of road vehicles could at best balance the future growth in transport volumes, depending on the economic performance.

Greenhouse gas emissions from the transport sector could also be reduced through changes in consumer's behavior through consumer choices induced by non-technical measures. This is particularly relevant for passenger travel. Fuel efficiency of light duty vehicles differs by up to a factor of two depending, inter alia, on vehicle size. Fuel consumption and emissions could also be reduced through fuel-sensitive driving behavior, increased occupancy of vehicles, and switch to public transport. Further potentials for lowering emissions emerge from changes in the demand for mobility, determined by the choice of locations and activities. Preliminary analysis indicates important differences within and between Annex I countries in terms of travel behavior and resulting GHG emissions per person.

Thus, if deep cuts in greenhouse gas emissions are to be achieved, technical measures need to be complemented by behavioral changes that would reduce the demand for travel. In this context, relevant research questions emerge:

- How much could future demographic change affect travel behavior of people?
- How much could various policies influence travel behavior?
- How different are the determinant factors and impacts between representative industrialized countries?
- Which policies appear most effective for influencing travel behavior?

In this paper we report an initial analysis that attempts quantifying the potential changes in transport behavior that could be achieved through dedicated policy interventions. We focus on travel behavior in the US, in Japan and in Germany. These three industrialized countries have a high standard of living and a maturely developed transport system, but very different travel behavior and strongly differing per capita greenhouse gas emissions from transport. Basic facts about the different travel behavior are summarized in Table 1.

Table 1: Summary characteristics for the travel behavior and transport system the US, Germany and Japan

	USA	Germany	Japan
Avg. travel per day	~75 km	~40-50 km	~25-30 km
Avg. trips per day	~4	3.5	2.3
Car share of trips	90%	70%	45%
Settlement density people/km2	~1100	~2500	~6700
Car operating cost ct(US)/km	4.3	9.5	19a)
Car fuel efficiency l/100 km	9	6-7	5-6

a) Notably due to high parking fees and road tolls.
Data sources: USA: National Household Travel Survey 2001 (Hu and Reuscher 2004)
Germany: Mobilitat in Deutschland 2002 (Follmer, Kunert et al. 2004)
Japan: Nationwide Person Travel Survey 2005 (MLIT 2007), (Buehler 2008)

This report is organized as follows: In Section 2 we describe a model of household travel behavior developed by Buehler (2008) that explains observed differences in travel behavior within the USA and in Germany. The model distinguishes 20 variables which can be linked with socio-economic conditions and dedicated transport and other policy interventions. Based on the coefficients derived by Buehler (2008) we employ this model for Japan (Section 3) to reproduce transport behavior as reported by the Nationwide Person Travel Survey for 2005 (MLIT 2007). These three countries make interesting test cases as their level of driving, the settlement structures and policies are very different. In Section 4, we develop a baseline scenario for the year 2030 that outlines changes in transport behavior in the USA, Germany and Japan for a business-as-usual development with current policies under the anticipated changes in socio-economic conditions. Subsequently, we explore the extent to which dedicated policy interventions could modify transport behavior and conclusions are drawn in Section 5. It should be mentioned that this analysis represents an initial attempt to develop a methodology for quantitative estimates of the greenhouse gas potential offered by behavioral changes. Further analysis will be required to refine this approach and derive robust findings.

2. Methodology

Travel behavior research is largely based on surveys and observed behavior, and numerous studies focus on individual aspects. Important aspects are elasticities between travel and fuel price, land use, settlement and population density, income, vehicle ownership, socio-demographic variables, various attributes of a mobility lifestyle, etc. Many quantitative studies address routine travel, typically commuting (i.e., home - work – home trips). These studies have revealed various characteristics of travel behavior, but up to now none has come up with a universal model. Also, only few studies have included a wide range of diverse factors, and even less studies have explored effects in an international context for different countries.

To answer the research questions outlined above we employ a model developed by Buehler (2008) that explains observed variations in transport behavior within different social groups within the USA and within Germany. Buehler (2008) represents one of the few studies which deal with comprehensive data that has been tested for the US and Germany. 20 variables, which are summarized in Table 1, were found relevant to describe the differences in daily travel behavior of the various groups of society.

About 50,000 respondents in each country answered the travel surveys in the US and Germany. Ordinary least square regression analysis was performed on the answers according to the following formula:

Equation 1: $$D_{country} = \sum_i \alpha_i * x_i + C_{country},$$

with D the distance traveled per person per day in the respective country, α_i the regression coefficients, x_i the variable, e.g., as response from the questionnaire, and C an adjustment variable. This regression identified the values for each coefficient.

Table 2: Parameters found relevant to describe daily car travel behavior (source: Buehler 2008)

Variable	**Unit**	**Theoretical background/comment**
Public transport variables		
Transit access <400m	1=yes	The better the supply with public transport, the more likely people use it. This is most pronounced in dense urban areas.
Transit access 400-1000m	1=yes	
Car variables		
Driver's License	1=yes	The higher the license rate, the more likely people drive with the car, both more frequently and further distances than without.
Car access/availability	Cars per person	The higher car access, the more likely people drive with the car, both more frequently and further distances than without.
Operating cost of car travel	US cts per km	The higher the operating costs, the lower the daily mileage.
Urban planning and land use variables		
Population density	1000 pep/skm	The higher population density, the lower the distance people travel with the car.
Mix of use	1=great mix	The higher the mix of different use, the lower the distance people travel with the car.
Socio-demographic variables		
Household income	$1000	The higher the income, the more people drive with the car.
Younger than 16/18	1=yes	People below driving age are accompanied in a car, but travel less than adults.
Single HH with job	1=yes	Adults with a job drive more than those without.
Couple HH with job	1=yes	
HH small children with job	1=yes	Adults with children drive more than those without.
HH school children with job	1=yes	
Retired HH	1=yes	Retired persons drive less than working adults.
Single HH without job	1=yes	Adults without a job drive less than those with a job.
Couple HH without job	1=yes	
HH small children without job	1=yes	
HH older children without job	1=yes	
Sex (Male=1)	1=yes	Men drive longer distances than women.
Macro		
Sunday	1=yes	The average driving distance is affected by holidays.

2.1 Relation between parameters and policies

The regression analysis of Equation 1 has assigned weights to the various variables that determine modal choice, daily travel, and car travel in particular. These elements can be influenced by policies in different ways as presented in Table 3.

Table 3: Variables affecting travel behavior and policy areas acting on them

Variable	**Associated policy**
Public transport policies	
Proximity to nearest public transport stop	Provision with and quality of public transport: • Accessibility and network density connectivity • Frequency and reliability of service • (Competitive) travel speed • Security, comfort, appearance • Fare structure & transferability of tickets • Accessibility and safety of walking
Car policy	
Driver's license	Legal driving age and requirements, e.g., for elderly • Attractiveness of walking, biking, public transport, car/ride sharing
Car access/availability	• Fees or limitations on car ownership • Parking space provision & fees • Road fees /city tolls • Travel speed / management / congestion
Operating costs	• Costs for fuel, insurance, maintenance, ownership, parking, road toll, fines, annuities, etc.
Urban planning and Land-use policies	
Mix of use Population density	• Integrated and coordinated spatial planning for cities and regions: Control/supply/incentives for infrastructure and services, such as water, electricity, transport, schools, health care, shopping, recreation, mixed land use • Provision/restriction of housing and parking space • Control of/influence on rent and housing
Socio-economic policies	
Household income	• Employment • Social security
Population …by age: younger than driving age, adult. …by household type: Single, couple; with/without small/larger children. …by employment: with/without job/retired.	• Migration policy • Job / social / economic policy • Attractiveness of city for various age groups and life phases
Holidays/leisure time	• Employment and social policies: How flexible are working and shopping schedules? How big is the available budget for leisure?

Only few of these variables are subject to explicit *transport policies*, most notably the supply-oriented variables on provision of public transport and driving licenses on the one hand, and the demand-oriented variables car ownership and operating costs on the other hand. Of course many more transport variables can affect travel behavior, e.g., the quality of public transport, its frequency, connectivity and comfort, the relative speed between modes, congestion and reliability of the travel, parking availability and fees, etc. But either these parameters have not been measured in the surveys, or they have not been found relevant. *Car oriented policies* can first affect the legal requirements for obtaining or keeping a driving license (e.g., minimum driving age, frequency and requirements for repeating driving tests, etc.). Car ownership can be affected by both fiscal measures and direct and indirect restrictions, e.g., limitations on the number of vehicles or on parking space. Operating costs for cars as well as prices for competing public transport are directly affected by taxes on fuel, road use and parking space, and indirectly by law enforcement and fines. *Urban and regional planning* are key policies affecting settlement densities and the possible mix of different land uses, notably housing and jobs. This in turn directly affects the distances between various activities the individual undertakes over the course of a day or over the week. The *socio-economic* structure of society also determines the daily driving: The higher the household income, the more likely is car ownership and frequent car driving. Finally, also the *life cycle phase* of individuals plays a major role for the amount of travel. Most driving is observed for men with a job and for working women with children. On the contrary, people without jobs and/or without children tend to drive less than average. Finally, retired persons drive less than adults in working age. These parameters can be influenced by social and labor policies and, to some extent, by migration. In summary, many policies influence travel behavior. Transport policies in the direct sense can modulate travel demand, but other policies have larger impacts on travel behavior.

3. Travel behavior in the USA, Germany and Japan in the base year

3.1 Observational data

For our analysis we employ regression coefficients developed by (Buehler 2008) for the US and Germany. We define the reference household consisting of working adults with school children. Relative to the travel behavior of the average household, the other variables increase travel demand (if the sign of the coefficient is positive) or reduce it (if the sign of the coefficient is negative).
As mentioned before, the study conducted by Buehler (2008) addressed only USA and Germany. To apply the results to Japan, we adjusted the coefficients found for Germany in such a way that average travel behavior as reported by the Nationwide Person Travel Survey (MLIT 2007) could be reproduced.

When comparing the resulting coefficients for these countries, the same sign indicates the same qualitative behavior, and opposite signs a contrary behavior. The magnitude of the coefficient indicates the strength of the respective variable on the behavior.

Table 4: Coefficients and variable values for the base year for average driving behavior in the US, Germany and Japan

		USA		Germany		Japan	
Variable	**Unit**	α_i a)	**2001a)**	α_i b)	**2002 b)**	α_i e)	**2005f)**
Transit access <400m	1=yes	-6.8	32%	-2.1	54%	-2.1	60%
Transit access 400-1000m	1=yes	-5.7	11%	-2.0	35%	-2.0	30%
Driver's License	1=yes	6.6	90%	5.4	73%	5.4	62%
Car access/availability	cars per person	3.1	1.08	6.7	0.70	6.7	0.62
Operating cost per km of car travel	US cents per km	-2.8	4.3	-0.5	9.5	-0.5	19.0
Population density	1000 peop/km²	-2.7	1.094	-1.7	2.544	-1.7	6.700
Mix of use	1=great mix	-13.2	31%	-12.9	34%	-12.9	50%
Household income	$1000	0.1	57	0.1	47	0.1	41
Younger than 16/18	1=yes	-16.1	25%	-9.4	19%	-11.9	18%
Single HH with job	1=yes	-2.6	2.7%	5.2	1.7%	-1.0	7.7%
Couple HH with job	1=yes	-1.2	9.6%	1.7	8.8%	0.0	8.8%
HH small children with job	1=yes	2.4	12%	0.2	7%	1.0	12%
HH school children with job	1=yes	0.0	17%	0.0	16%	0.0	12%
Retired HH	1=yes	-9.2	20%	-1.2	25%	-5.2	25%
Single HH without job	1=yes	-9.8	2.5%	2.6	2.2%	-3.0	7.4%
Couple HH without job	1=yes	-5.7	9%	-3.8	11%	-3.8	7%
HH small children without job	1=yes	-4.7	11%	-2.6	9%	-2.6	10%
HH older children without job	1=yes	-6.5	16%	-3.5	20%	-3.5	10%
Sex (Male=1)	1=yes	3.8	47%	4.9	49%	7.0	49%
Sunday		-0.9	14%	4.0	14%	-0.4	14%
Constant	km	65.1	1	33.7	1	42.2	1
Average daily car travel	**km**		**50**		**32**		**24**

Data sources:
a) US: (Buehler 2008) and (Hu and Reuscher 2004)
b) DE: (Buehler 2008) and (Follmer, Kunert et al. 2004)
c) JPN: own assumptions and (MLIT 2007)

3.2 Travel behavior modeled for the base year

Applying Formula 1 with the data of Table 4 delivers the contributions of individual factors to total daily driving in the different countries (Figure 1). Note that the sign of the different parameters is the same in all three countries, except for the weekdays factor, where driving is slightly less on Sundays in the US and Japan, but not in Germany, and the marital status (singles drive more in Germany than average, but less in the US and Japan). Parameters that increase daily driving are higher income, higher share of driving license holders and higher car accessibility-ownership. The sensitivity to changes in these parameters is highest in Japan, and lowest for the US, reflecting the high ownership and driving habit in the country.

a) Absolute change in driving by variable **b) Change vs. mean daily distance driven**

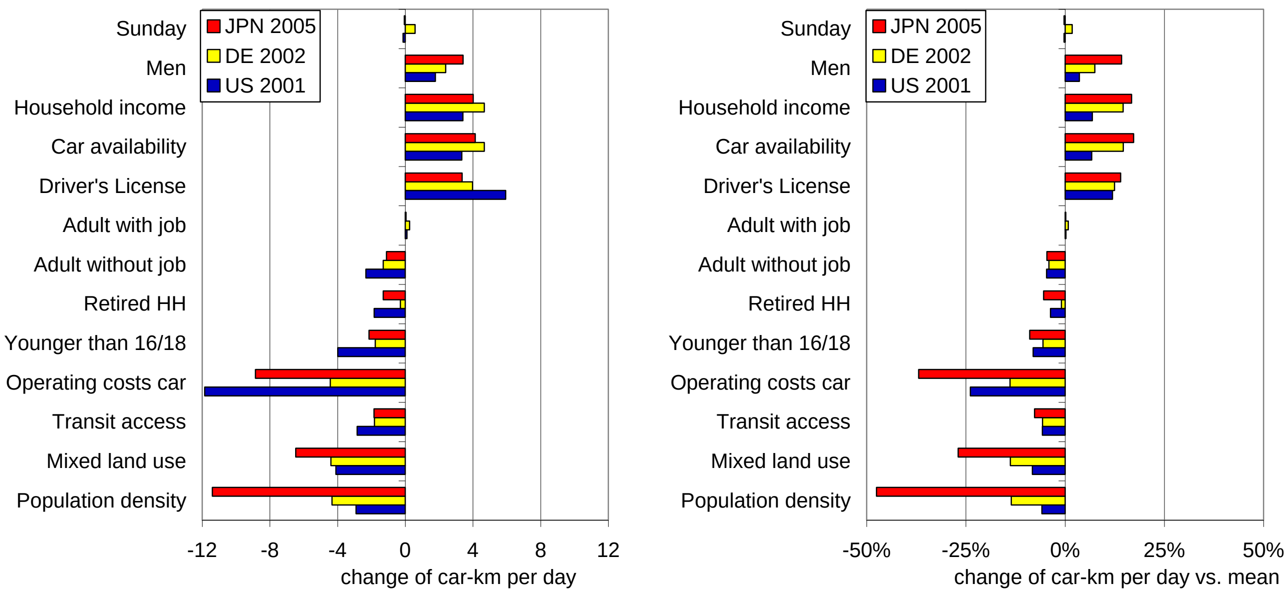


Figure 1: Change in car-km driven per person and day relative to mean driving distance as a function of the variables identified for the US, Germany and Japan in the base year. Left panel: Change in absolute terms. Right panel: Change in relative terms

Three variables are particularly important for reducing daily driving: dense settlements, mixed land use and higher operating costs for cars. The influence of population density is by far biggest in Japan and smallest in the US, in line with the grossly diverging settlement densities in these countries. Next, operating cost is the most important factor for the US and a strong lever in Japan. In addition, a denser supply with public transport reduces driving to some extent.

Household characteristics affect daily driving by less than 10%. Relative to the reference group (working adults with school children) daily driving is less for those without a job or the retired people, and notably less for teenagers without driving license.

4. Scenarios of future transport demand

4.1 A baseline scenario of transport demand

To explore future changes in transport demand and how these could be influenced by dedicated policy intervention, we develop a baseline scenario for the year 2030 that serves as a reference case against which the impacts of policy inventions will be measured. This baseline scenario considers likely changes in socio-economic factors, the impacts of economic growth, and current policies on land use, public transport and car availability.

4.1.1 Socio-demographic assumptions

For the baseline scenario we base our assumptions on population development for Germany and the USA on the UN population projections (UN 2009), and for Japan on national projections by the Statistical Bureau (Stat JPN) (Table 5). These three countries span a wide range of development among industrialized countries:

- Over the next 30 years, total population expected to grow by more than 30% in the USA, to stay about constant for Germany, and to decline by 10% for Japan. This has strong impact on the total volume of travel.

- All countries will face a strong change in the age structure of society with a declining share of younger people. This will lead to a lower share of people without driving licenses, and a lower share of couples with children. On the other hand the share of elderly and consequently retired people will increase in all countries, by 30% in the USA and by as much as 50% in Germany. If elderly people will drive less than working adults[1] also in the future, then average driving per person would decline.

- Due to lack of data we assume that the share of employment stays constant in the US, but increases in Germany and Japan. As adult population shrinks, fewer children are raised and the participation of women in the work process will grow.

Table 5: Assumptions about the demographic development from the base year to 2030 in each country

	USA		Germany		Japan	
Variable	**2001**	**2030[a)]**	**2002**	**2030 [a)]**	**2005**	**2030[b)]**
Total population [mio.]	297	390 (+31%)	85	84 (-1%)	127	115 (-10%)
Share younger than 16/18	25%	22%	19%	14%	18%	13%
Share single HH	5%	5%	4%	4%	15%	22%
Couples without children	19%	17%	20%	18%	16%	15%
Couples with children	56%	52%	52%	41%	44%	30%
Retired HH	20%	26%	25%	38%	25%	32%
Employed persons	52%	52%	44%	50%	55%	63%
Share men	47%	48%	49%	48%	49%	48%

Note: The sum of shares over households is 100%, the share of people younger than legal driving age (16 years in the US and 18 years in Germany and Japan) is counted separately.
Data sources:
a) UN 2009
b) Stat JPN and own assumptions about household composition

[1] Yet, there is initial evidence that elderly in the future have a different driving behaviour than elderly in the past, notably keep driving.

4.1.2 Economic assumptions

Assumptions on the baseline development of the economy and of the global crude oil price are taken from the latest World Energy Outlook (IEA 2010) (cf.). Future household income is assumed change proportionally with GDP per capita; thus it is projected to increase by 34% in Germany and 41% in Japan over the period 2000 to 2030.

Table 6: Relative change in macro-economic parameters between 2000 and 2030 (2000=100). Assumptions from (IEA 2010)

	USA 2030	**Germany 2030**	**Japan 2030**
GDP (in PPP)	167	139	130
GDP/cap in PPP	137	134	141
Crude oil import price	234	234	234

We scale the fuel component of car operating costs with the change in crude oil price. The other two components of the operating costs, i.e., maintenance and parking fees, are scaled with the general increase in GDP in the respective country. On the other hand, fuel efficiency of vehicles is expected to increase as a result of technological progress, vehicle efficiency targets and consumer behavior. This will partly offset the increase in fuel related operating costs. In total, operating costs per kilometer would increase by 80 to 100% cover the period (Table 7).

With this assumed growth future costs will move outside the range of observations from which the regression coefficients have been originally derived, and it is questionable whether the elasticities that have been determined for the observed historical situations in each country would still apply.. In particular, average operating costs in the US in 2030 would reach the level of the German operating costs in 2002. Hypothesizing, that price elasticities are not only depending on the country, but also on the absolute price level, we employ the elasticities that have been derived for Germany for 2002, for the year 2030 also to the USA. In absence of observational evidence on even higher fuel prices, we keep the regression coefficients for Germany and Japan unchanged for even higher fuel prices in the future.[2]

[2] We note a need of more research on the dependence of the price elasticity of travel demand on the level of the operating costs.

Table 7: Assumptions about the development of car operating costs

	USA	Germany	Japan c)
Operating costs base year [US ct/km]	4.3	9.5	13.3
share fuel a)	35%	23%	19%
share tax a)	15%	47%	28%
share maintenance b)	45%	25%	18%
share parking and road fees b)	5%	5%	35%
change in vehicle efficiency d)	-35%	-22%	-20%
Operating costs in 2030 [US ct/km]	8.6	19.5	23.8

a) Scales with increase of crude oil price, assuming constant share of fuel tax in total fuel price.
b)Scales with increase of GDP.
c) Assumptions: Compared to Germany slightly lower fuel costs and same maintenance costs, but much higher parking fees and road tolls (Metschies 2001; Hays 2009).
d) Change in fuel consumption per km from 2002 to latest year of regulation over the same driving cycle (ICCT 2010).

4.1.3 Assumptions on policies on land use, transit and car availability

Given the expected demographic changes in Germany and Japan it is an open debate in both countries how urban areas could be adapted to the anticipated needs of a shrinking and older population. Changes would affect settlement densities, land use mix, and the supply with public transport. These factors are interrelated and act in the same direction with regard to transport demand: Increasing densities and mixing different land use will reduce the choice of car and increase walking, and decrease distances driven. The same is true for a denser and more frequent supply of public transport. For an economic operation of public transport sufficient densities are a prerequisite. Therefore, for authorities in both Germany and Japan it will be a challenge to increase or even maintain current settlement densities and the supply of public transport.

The situation is the opposite in the US: Settlement densities are low, and supply with public transport is poor. Suburbanization is increasing, and driving is the mode of choice for more than 90% of trips, even the shortest. Notable exceptions are only the big metropolitan areas. Given immigration trends and the absolute growth of the population, an increase in settlement densities can only be achieved with constraining the expansion of land use for housing. Indeed, some cities like San Francisco have announced that all future growth shall be contained within the current city boundaries. This would also improve the conditions for a higher supply with public transport.

In a similar way it is known that driving license, car ownership and car use are strongly correlated. The first to two factors can be addressed by various policies, e.g., affecting legal driving age, testing requirements, or costs of purchasing and owning a car. Past trends have seen an increase in driving licenses notably with elderly people also keeping their driving license for longer, and an increase in car ownership.

For the baseline scenario we assume the following (Table 8):

- USA: Historic trends continue, but at a slower rate. Population densities and land use mix decrease with slowing suburbanization, leading to shrinking access to public transit. At the same time, the number of driver's licenses grows as elderly keep their driving license and young people continue to desire them.

- Germany: Transit access and densities are kept at same level (as a result of recent policies), and driving licenses and car ownership increase.

- Japan: Decreasing total population results in decreasing densities and reduced access to public transport. Driving licenses and car availability are assumed to increase as elderly keep their driving license and young people continue to desire them.

Table 8: Baseline assumptions about the development of transit, car availability and densities

	USA		Germany		Japan	
Variable	**2001**	**2030 BAU**	**2002**	**2030 BAU**	**2005**	**2030 BAU**
Transit access <400m	32%	31%	54%	54%	60%	54%
Transit access 400-1000m	11%	11%	35%	35%	30%	27%
Driver's license	90%	95%	73%	80%	62%	68%
Car access/availability	1.08	1.13	0.70	77%	0.62	68%
Population density	1.094	0.985	2.544	2.544	6.700	6.030
Mix of uses	31%	0.28	34%	0.34	50%	0.45

4.2 Travel behavior in the baseline scenario

As a benchmark against which the impacts of policy interactions could be quantified we develop a baseline scenario for the year 2030 based on the assumptions listed above.

All factors together, i.e., demographic and economic changes as well as urban and transport policies, lead under business-as-usual assumptions to a decrease of average daily car driving by 5% in the US and Germany, and to stagnation in Japan (Figure 2a).

Total: Absolute difference **Relative difference**

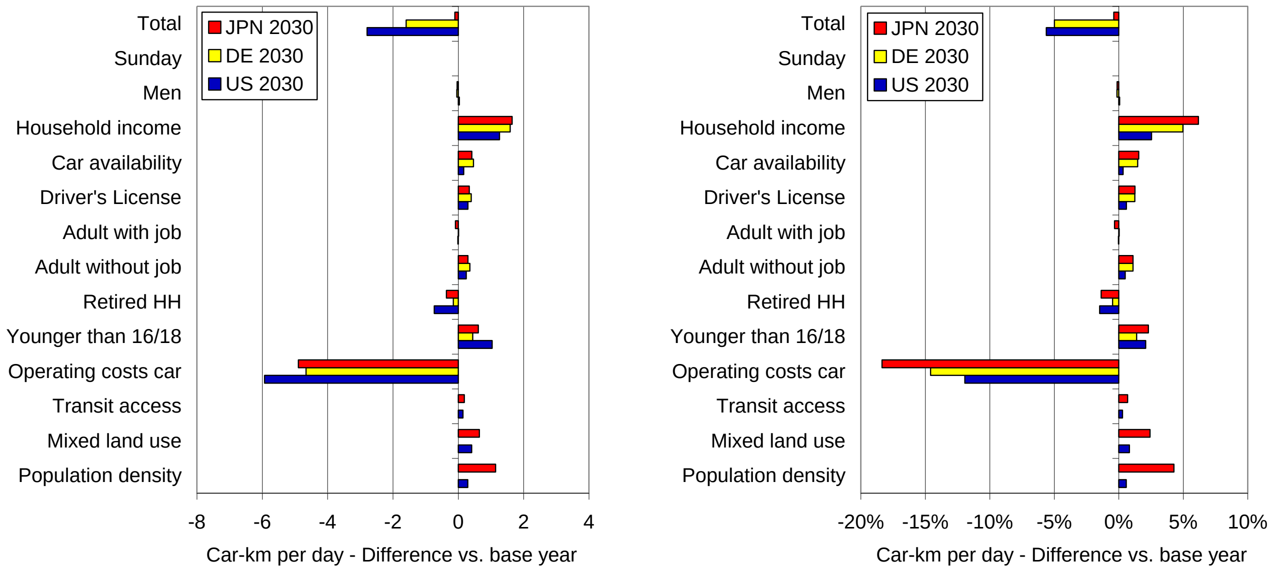


Figure 2a: Average daily car travel per person in the US, Germany and Japan in 2030 under business-as-usual assumptions (left panel). Absolute change relative and (right panel) relative change to the base year for each variable

We decompose the impacts of the different variables on the resulting transport demand:

- The combined changes in the *demographic compositions* are projected to increase daily car travel per person by 0.5 km or 1 to 2% (Figure 2b). The increase in average travel due to fewer younger people and more adult people is partly compensated by a significantly larger share of retired people, for which a lower driving demand is assumed. As a consequence, total travel volume will scale with the total population as the average travel behavior per person hardly changes.

Demographic change only **Relative difference**

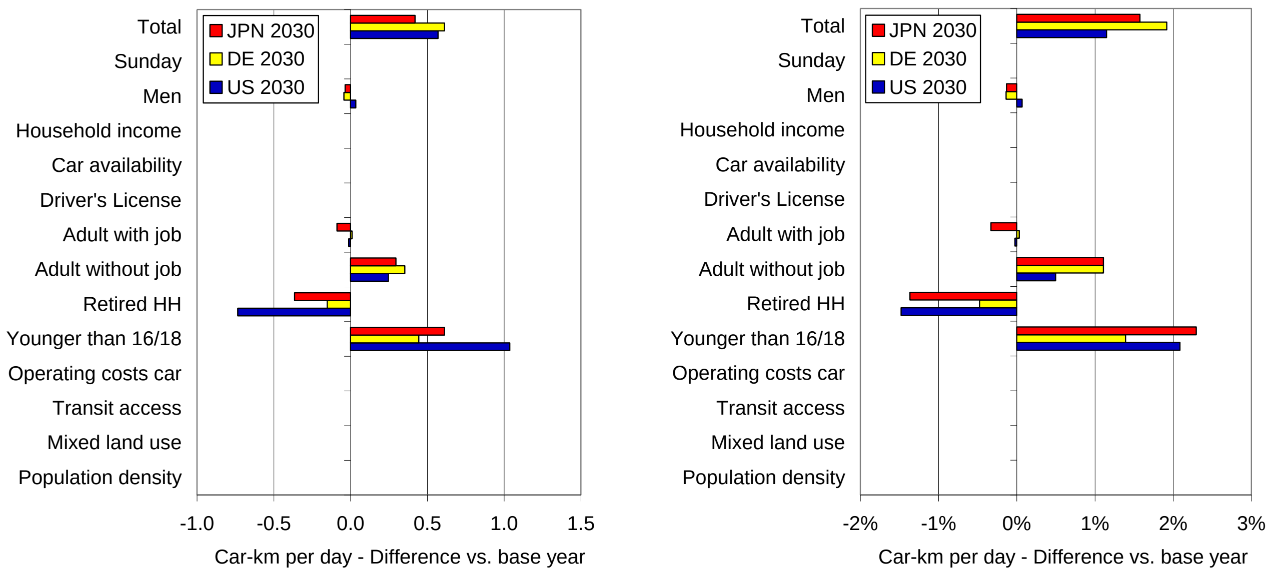
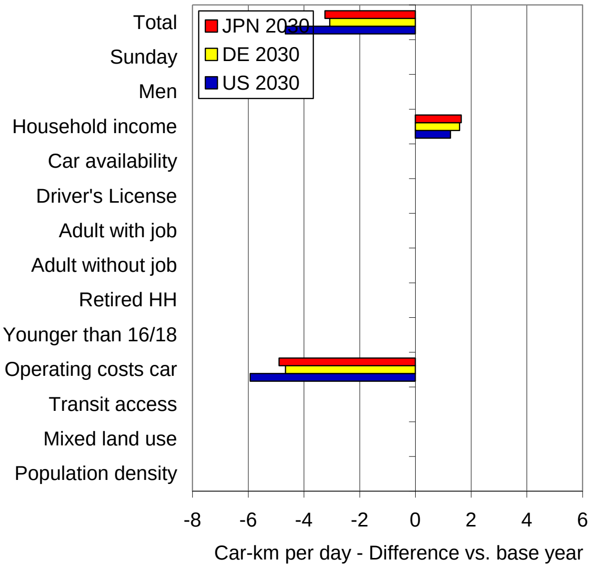


Figure 2b: Average daily car travel per person in the US, Germany and Japan in 2030 under business-as-usual assumptions. (left panel) Absolute change relative and (right panel) relative change to the base year for each variable

- In contrast, we see big impacts on daily travel from the projected *economic changes* (Figure 2c). In particular, the doubling of car operating costs in the period 2000 to 2030 would lead to a reduction of daily travel by 12, 15 and 20% in the US, Germany and Japan, respectively, based on the assumed price elasticity of about 0.2. However, this decrease will be partly offset by higher household income such that the net change will remain in the order of 10%. Further sensitivity analyses are required to explore the inherent uncertainties.

c) Economic changes only: Absolute difference



Relative difference

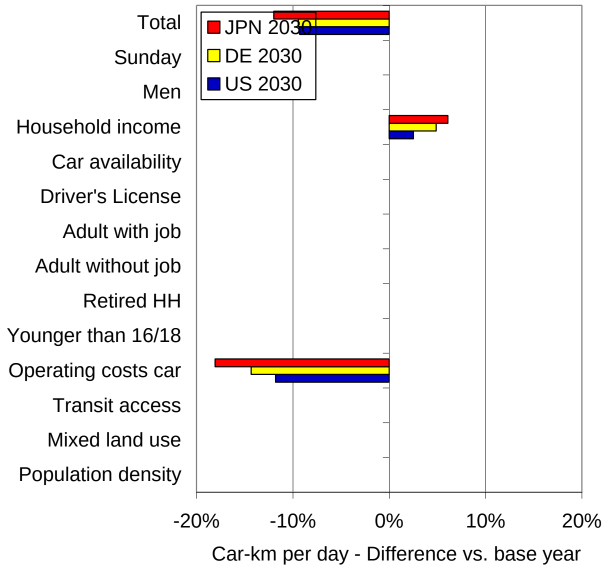


Figure 2c: Average daily car travel per person in the US, Germany and Japan in 2030 under business-as-usual assumptions. (left panel) Absolute change relative and (right panel) relative change to the base year for each variable

- The assumed changes of land use, spatial planning and car policies lead to a 3% increase of daily driving in the US and Germany, and a 10% increase in Japan (Figure 2d). As population densities and mixed land uses decline in Japan from a very high level, they have a much stronger impact than the same relative change in the US. In addition, car travel will increase in all countries due to see larger shares of drivers in the population and higher vehicle ownerships. Lastly, declining transit supply also leads to a small increase in car driving[3]. All these factors work in the same direction, i.e., they increase driving. As these variables are interlinked, policies addressing one variable could have multiplicative effects on various pathways, which could increase or decrease travel.

[3] Note, as the elasticity is small an increase in supply would not lead to a major decrease in driving. This single measure alone cannot be a substitute for a comprehensive transport and urban policy.

d) Land use and car policy changes only **Relative difference**

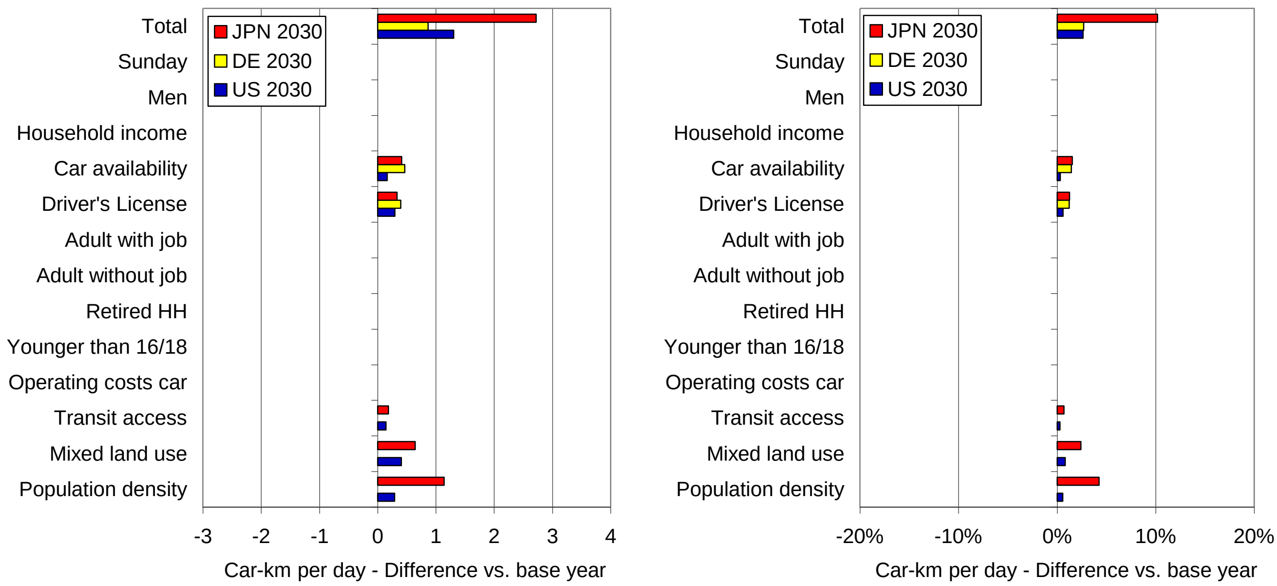


Figure 2d: Average daily car travel per person in the US, Germany and Japan in 2030 under business-as-usual assumptions. (left panel) Absolute change relative and (right panel) relative change to the base year for each variable

In summary, the increase in operating costs is the most important factor that *reduces* the demand for driving in the future, followed by a larger number of households with retired people. All other factors, e.g., increasing income and decreasing urban densities, cause *higher* demand. Nonetheless, the daily travel demand emerges as rather constant over the period, with several factors compensating each other.

Average daily car travel is expected to be about 47 km (29 miles) in the US, 30 km in Germany and almost 27 km in Japan. Thereby, in absence of targeted policy interventions, no significant changes in daily driving behavior can be expected in the future that would reduce greenhouse gas emissions from this interventions.

4.3 The scope for future policy interventions

The aim of this project is to determine the potential for greenhouse gas mitigation from changes in travel behavior. With the baseline scenario we established the reference for the comparison of the impacts of different policy measures. For these scenarios we leave the demographic and macro-economic assumptions of the baseline unchanged, but investigate the consequences of different policy interventions, e.g., those listed in .

Given the twenty different policy variables distinguished in this study and the wide range of their possible development in the future, an infinite number of combinations emerges for analysis. However, we restrict our initial analysis to two extreme cases that quantify the largest combined impacts of different policy interventions (Table 9):

- The ‘Low case’ scenario assumes that policies adopt all measures to reduce car travel in a coordinated way, i.e., that they result in largest driving reductions for every single variable. This should represent the lower margin that could be achieved by dedicated and harmonized policies.

- The 'High case' scenario combines all interventions that maximize demand for car travel beyond the baseline developments. This scenario can be considered an upper estimate on the assumption that the impact of policies on travel is neglected.

All other combinations of policies are assumed to fall in between these two cases. Thereby we explore the range that could be achieved by policy interventions, but we do not assess any likelihood of a specific policy to be implemented. In a first step we neglect potential feedbacks of such policy interventions on demographic and macro-economic drivers.

Table 9: Assumptions for different policies variables

	Scenario: Low case	**Scenario: High case**
Population density	US: Total population increases by 30% and settles only in urban areas. No new land is developed.	Suburbanization increases
	DE: Concentration of people in urban agglomerations, i.e. the center of jobs, services and health care (particularly relevant for the increasing share of elderly).	
	JPN: Already high settlement densities can still be increased despite declining population, e.g. as elderly people move from rural areas to cities.	
Mix of land uses	All: In parallel with the dedicated policies to increase urban densities mix of different land uses is increased.	Increasing segregation of uses with increasing suburbanization.
Transit supply	US: With the new population settling in urban areas, the share of people with transit access increases.	Strong decline of transit supply, notably due to declining densities and increasing suburbanization.
	DE/JPN: Increasing population densities. Assume 100% coverage with transit supply.	
Driving license	All: Declining shares as population in denser urban areas grows and transit supply increases.	Increase beyond baseline.
Car availability	All: Declining shares as population in denser urban areas grows and transit supply increases.	Increase beyond baseline.
Car operating costs	US: As part of a dedicated policy an increase in tax, road tolls and/or parking fees leads to a significant increase in operating costs. As the base level is low, there is significant space for an increase. DE/JPN: At an already high level some extra increase from tolls, parking and/or tax.	Compensation of costs by increase of vehicle fuel efficiency beyond baseline.

Because of very different starting levels and different traditions, the quantitative changes relative to the business-as-usual cases differ across countries (Table 10).

Table 10: Assumptions for the policy variables for the two extreme scenarios. Difference relative to the value for the 2030 baseline scenario

	USA		Germany		Japan	
Variable	**Low case**	**High case**	**Low case**	**High case**	**Low case**	**High case**
Population density	39%	-22%	20%	-20%	11%	-11%
Mix of use	39%	-22%	20%	-20%	11%	-11%
Transit access <400m	32%	-26%	15%	-20%	22%	-11%
Transit access 400-1000m	32%	-26%	10%	-20%	22%	-11%
Driver's License	-14%	5%	-14%	14%	-14%	14%
Car access/availability	-14%	5%	-14%	14%	-14%	14%
Operating cost car	50%	-15%	15%	-15%	9%	-9%

Our scenarios indicate that the assumed policies can significantly alter travel behavior.

For the USA the low scenario would reduce car travel by up to 27% below the baseline projection in 2030 (Figure 3a) and decline car travel per person to about 33 km per day, which corresponds to the average daily driving in Germany today. The largest change would emerge from higher car operating costs, and this change alone could offset increases from all other variables combined.

In contrast, in the high case daily car travel would increase by 5% relative to baseline, i.e., to 52 km per day. As in the US many important factors that are responsible for high car travel demand are close to the upper end of the plausible range, our analysis does not reveal a large potential for further increases. However, there is a much larger potential for reducing demand through dedicated policies.

a) USA 2030: Difference vs. base year **Relative change vs. base year's mean**

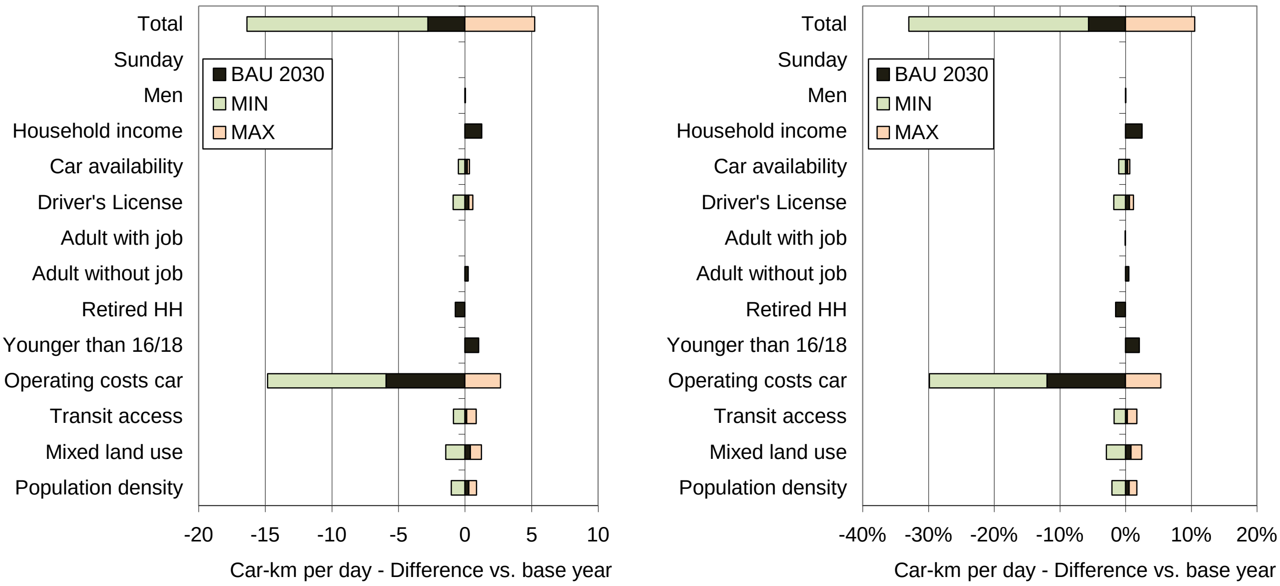


Figure 3a: Car-travel per person and day in the business-as-usual scenario, and range if active policies to reduce car travel were pursued ('Min'=Scenario 'Lower car travel) or if nothing is done to contain driving ('Max'=Scenario 'Higher car travel')

For Germany and Japan we identify a potential impact of these policies of ±15% compared to the baseline case (Figure 3b and c). Car operating costs are important policy interventions, but as they are already relatively high in international perspective, we do not assume a large additional potential increase beyond the business-as-usual projection. Policies affecting driving license holding and car ownership as well as settlement densities and mixed land uses appear equally important if car driving is to be reduced. Vice versa, neglecting these variables can lead to an equivalent increase in travel demand.

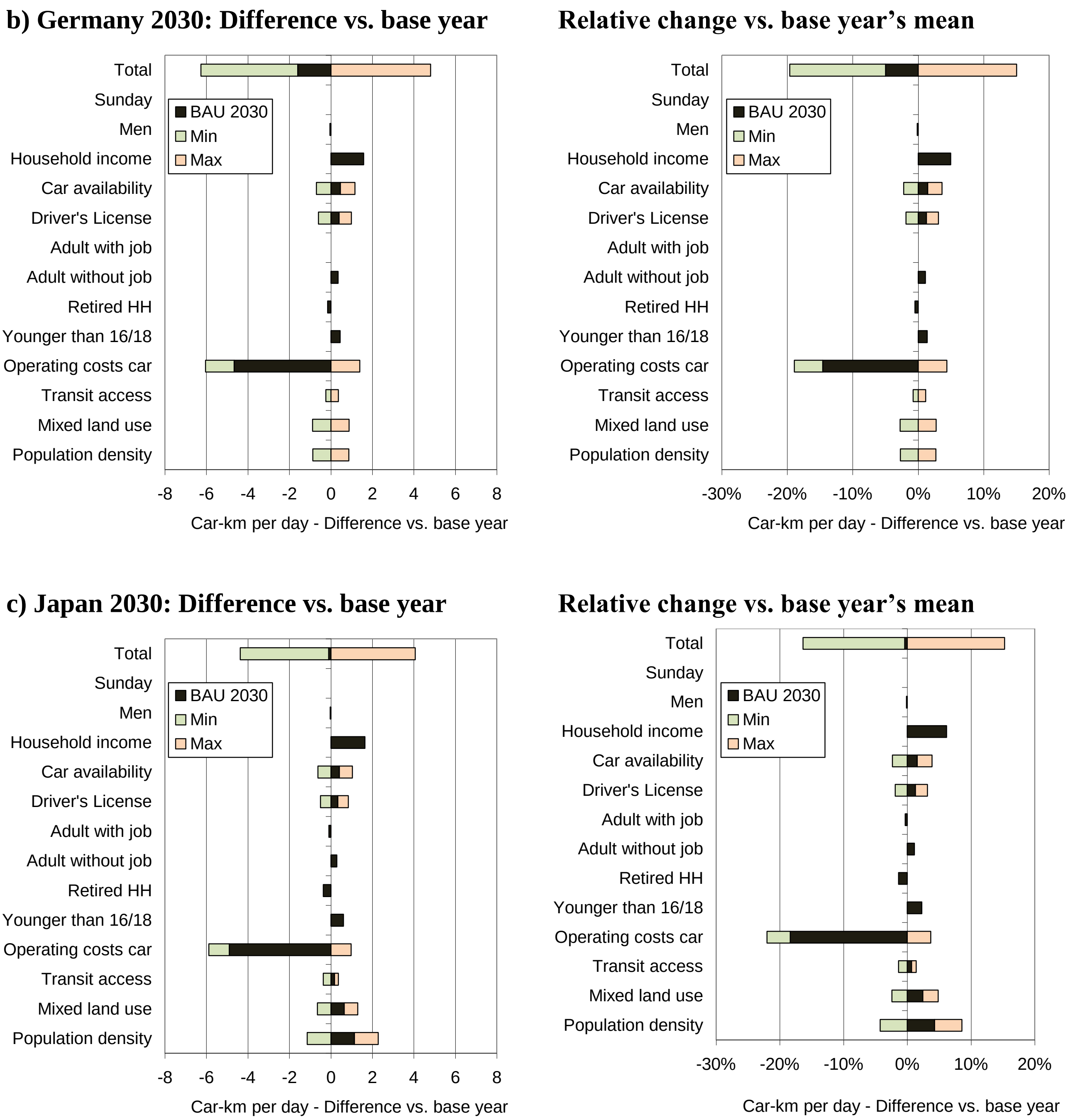


Figure 3b/c: Car-travel per person and day in the business-as-usual scenario, and range if active policies to reduce car travel were pursued ('Min'=Scenario 'Lower car travel) or if nothing is done to contain driving ('Max'=Scenario 'Higher car travel')

5. Conclusions

In contrast to other economic sector, there is only limited potential for reducing greenhouse gases from the transport sector through technical measures. Thus, if deep cuts in greenhouse gas emissions are to be achieved, technical measures need to be complemented by behavioral changes that would reduce the demand for travel. For this purpose we employed a model of household travel behavior developed by Buehler (2008) that explains observed differences in travel behavior within the USA and in Germany. The model distinguishes 20 variables which can be linked with socio-economic conditions and dedicated transport and other policy interventions.

Based on the coefficients derived by Buehler (2008) we applied this model to Japan to reproduce transport behavior as reported by the Nationwide Person Travel Survey for 2005 (MLIT 2007). These three countries make interesting test cases as their level of driving, the settlement structures and policies are very different.

In a further step we developed a baseline scenario for the year 2030 that outlines changes in transport behavior in the USA, Germany and Japan for a business-as-usual development with current policies under the anticipated changes in socio-economic conditions. In this baseline case, daily car travel per person in 2030 would decline by 5% in the US and Germany compared to the base year (2001/2002) and would remain at the same level as 2005 for Japan (Table 11).

Although these countries will face substantial demographic changes, they do not cause significant changes of driving behavior as different effects (larger share of retired population, less children, etc.) compensate each other to a large extent. However, total mileage will be affected following to change in total population. More important are the impacts of changes of settlement densities and land use mixes that can be considered as secondary impacts of population change. Observed trends in all three countries are conducive to more driving. The single most important factor that reduces driving is car operating costs. In our initial baseline scenario we assume that costs would double over the period in real terms (due to increasing crude oil prices), while income grows not more than 40%. In contrast, all other factors lead to increased driving demand such that the overall behavior will be only slightly affected.

Our model suggests that dedicated and harmonized policies can influence future travel behavior. The combined impact of the considered measures would reduce distances driven per person by as much as 25% in the US and by 15% in Germany and Japan. Though operating costs are an important means, policies also need to address urban planning (e.g., settlement densities, mixed land use, access to public transport, etc.) as well as car ownership and driving licenses. On the other hand, absence of a coherent set policies or economic incentives could increase daily car travel by 10% in the US and by 15% in Germany and Japan, above the levels projected for the baseline scenario.
Thus, given the set of variables quantified in our study, there is scope for policy interventions to average driving distances of the population by about ±15% in industrialized countries.

Table 11: Summary of results: Average daily car travel per person in the different scenarios

	USA		**Germany**		**Japan**	
Scenario	km	200x=100	km	200x=100	km	200x=100
Base year 200x	49.7	100%	31.9	100%	26.7	100%
Business-as-usual 2030	46.9	94%	30.3	95%	26.6	100%
Low case scenario 2030	33.3	67%	25.7	80%	22.3	84%
High case scenario 2030	52.1	105%	35.1	110%	30.6	115%

This research has advanced the quantitative understanding of the potential impacts of various policy interventions on driving behavior. At the same time it also highlighted a number of questions that are critical for a deeper understanding on the determinants of driving behavior. Further research, based on national surveys, could strengthen the statistical basis for the different countries and examine the extent to which results could be transferred to other countries, in particular to strongly growing economies like China or India.

Obviously, this study is based on the assumption that behavior and preferences that have been observed in the past will prevail in the future. Changes in the historic preference structures could have substantial impact on future travel behavior. E.g., will future elderly really be less mobile than future adults? Will the marked difference of travel between men and women persist? Will younger generations all aspire driving and what is the potential for multi-modality?

While this study produced indications for significant potential impact on policy interventions on daily travel behavior that would allow substantial reductions of greenhouse gas emissions, further work will be necessary to substantiate this hypothesis and derive a more robust assessment of the resulting potential for emissions reductions.

6. Appendix

Summary input data for base year and business-as-usual projection in 2030

Table 12: Summary of input variables for the base year and for the business-as-usual scenario 2030 in the three countries

Variable	US 2001	US 2030	DE 2002	DE 2030	JPN 2005	JPN 2030
Transit access <400m	32.4%	30.8%	54.0%	54.0%	60.0%	54.0%
Transit access 400-1000m	11.1%	10.5%	35.0%	35.0%	30.0%	27.0%
Driver's License	90.0%	94.5%	73.0%	80.3%	61.7%	67.8%
Car access/availability	108.0 %	113.4%	70.0%	77.0%	62.0%	68.2%
Operating cost per km of car travel	4.3	8.6	9.5	19.5	13.3	23.8
Population density	1.094	0.985	2.544	2.544	6.700	6.030
Mix of use	31.0%	27.9%	34.0%	34.0%	50.0%	45.0%
Household income	57	78	47	63	41	57
Younger than 16/18	24.8%	18.4%	19.0%	14.3%	18.0%	12.9%
Single HH with job	2.7%	2.6%	1.7%	1.9%	7.7%	14.1%
Couple HH with job	9.6%	8.7%	8.8%	9.0%	8.8%	9.4%
HH small children with job	12.1%	11.0%	7.1%	6.4%	12.1%	9.7%
HH school children with job	16.8%	15.3%	15.6%	14.0%	12.1%	9.7%
Retired HH	20.0%	28.0%	24.6%	37.5%	25.0%	32.0%
Single HH without job	2.5%	2.4%	2.2%	1.9%	7.4%	8.3%
Couple HH without job	9.1%	8.0%	11.3%	9.0%	7.2%	5.5%
HH small children without job	11.3%	10.1%	9.0%	6.4%	9.9%	5.7%
HH older children without job	15.8%	14.1%	19.8%	14.0%	9.9%	5.7%
Sex (Male=1)	47.4%	48.3%	49.2%	48.3%	48.8%	48.3%
Sunday	14.3%	14.3%	14.3%	14.3%	14.3%	14.3%

Table 13: Change between 2030 business-as-usual scenario and base year value for each input variable in the three countries

Variable	USA	Germany	Japan
Transit access <400m	-5%	0%	-10%
Transit access 400-1000m	-5%	0%	-10%
Driver's License	5%	10%	10%
Car access/availability	5%	10%	10%
Operating cost per km of car travel	100%	105%	79%
Population density	-10%	0%	-10%
Mix of use	-10%	0%	-10%
Household income	37%	34%	41%
Younger than 16/18	-26%	-25%	-29%
Single HH with job	-4%	11%	84%
Couple HH with job	-10%	1%	7%
HH small children with job	-9%	-10%	-20%
HH school children with job	-9%	-10%	-20%
Retired HH	40%	52%	28%
Single HH without job	-6%	-13%	12%
Couple HH without job	-12%	-20%	-24%
HH small children without job	-11%	-29%	-42%
HH older children without job	-11%	-29%	-42%
Sex (Male=1)	2%	-2%	-1%
Sunday	0%	0%	0%

7. References

Buehler, R. (2008). Transport Policies, Travel Behavior, and Sustainability: A Comparison of Germany and the U.S. Graduate School-New Brunswick, Rutgers, The State University of New Jersey. PhD Thesis: 522.

Follmer, R., U. Kunert, et al. (2004). Mobilitat in Deutschland. Bundesministerium fuer Verkehr Bau- und Wohnungswesen. Bonn, Berlin, infas Institut fuer angewandte Sozialwissenschaften, DIW Deutsches Institut fuer Wirtschaftsforschung: 187.

Hays, J. (2009). "Facts and Details - Automobiles and Driving in Japan." Retrieved 2 Jan 2011, from http://factsanddetails.com/japan.php?itemid=851&catid=23&subcatid=153.

Hu, P. S. and T. R. Reuscher (2004). Summary of Travel Trends - 2001 National Household Travel Survey. Washington, D.C.

ICCT (2010). Global Passenger Car Fuel Economy and/or Greenhouse Gas Emissions Standards - April 2010 update, International Council on Clean Transportation.

IEA (2010). World Energy Outlook 2010. Paris/France, International Energy Agency (IEA).

Metschies, G. (2001). Fuel Prices and Vehicle Taxation. German Technical Cooperation (GTZ). Eschborn: 114 p.

MLIT (2007). Nationwide Person Trip Survey 2005, Urban Transportation Planning Office, Ministry of Land, Infrastructure and Transport of Japan (MLIT).

Stat JPN: Population in Japan 1920 – 2050. National Statistical Bureau Japan. http://www.stat.go.jp/english/index.htm

UN 2009: World Population Prospects: The 2008 Revision. POP/DB/WPP/Rev.2008/03/F01. United Nations, May 2009.

8. Extended bibliography

The following references were consulted for a parallel study, focusing on the travel behavior in US only (Ng, Borken-Kleefeld, forthcoming)[4].

Archibald, R. and R. Gillingham. (1980) An Analysis of the Short-Run Consumer Demand for Gasoline Using Household Survey Data. The Review of Economics and Statistics 62(4): 622-28.

Baltagi, B. H. and J. M. Griffin. (1983) Gasoline demand in the OECD: An application of pooling and testing procedures. European Economic Review 22(2): 117-137.

Bay Area Census. (2000) San Francisco Bay Area Census 2000. http://www.bayareacensus.ca.gov/bayarea.htm. Accessed: 6/6/2010.

Bento, A. M., M. L. Cropper, A. M. Mobarak, and K. Vinha. (2005) The effects of urban spatial structure on travel demand in the United States. The Review of Economic and Statistics 87(3): 466-478.

BTS. (2009) Transportation, Energy and the Environment. National Transportation Statistics 2009. U.S. Department of Transportation, Bureau of Transportation Statistics.

Calthorpe Associates. (2010) Vision California, Charting Our Future: Rapid Fire Model. Technical Summary, Model Version 1.5. Calthorpe Associates.

Cambridge Systematics, Inc. and Parsons Brinckerhoff Quade & Douglas, Inc. (1996) Analysis of Alternatives. Making the Land Use Transportation Air Quality Connections. 1000 Friends of Oregon, Portland, Oregon.

Cambridge Systematics, Inc. (2009) Moving Cooler: An Analysis of Transportation Strategies for Reducing Greenhouse Gas Emissions. Washington D.C.: Urban Land Institute.

[4] Achieving Low Carbon Transportation Systems: A Review of Passenger Transportation Demand and Elasticities in the San Francisco Bay Area. IIASA Interim Report, forthcoming.

Cambridge Systematics Inc. and Apogee Research. (1996) Measuring and Valuing Transit Benefits and Disbenefits: Summary. Transit Cooperative Research Program Report 20, Transportation Research Board (National Academy Press, Washington, DC).
Cervero, R. (2002) Built environments and mode choice: toward a normative framework. Transportation Research Part D 7: 265-284.
Cervero, R. and J. Landis. (1995) The Transportation-Land Use Connection Still Matters. Access 7: 2-10.
Cervero, R. and J. Murakami. (2010) Effects of built environments on vehicle miles traveled: evidence from 370 US urbanized areas. Environment and Planning A 42: 400-418.
Cervero, R. and Wu, K-L. (1997) Polycentrism, commuting, and residential location in the San Francisco Bay Area. Environment and Planning A 29(5): 865 – 886.
Dahl, C. A. (1995) Demand for transportation fuels: a survey of demand elasticities and their components. Journal of Energy Literature 1(2).
Dahl, C. A. and T. Sterner. (1991) Analyzing gasoline demand elasticities: a survey. Energy Economics 13(3): 203-210.
Deakin, E., G. Harvey, R. Pozdenza, and G. Yarema. (1996) Transportation Pricing Strategies for California: An Assessment of Congestion, Emissions, Energy, and Equity Impacts. California Air Resources Board.
Espey, M. (1996) Explaining the variation in elasticity estimates of gasoline demand in the United States: a meta-analysis. The Energy Journal 17(3): 49-60.
Evans, J. E. *et al*., (2004) Traveler Response to Transportation System Changes. Chapter 9, Transit Scheduling and Frequency. TCRP Report 95. Transportation Research Board. Washington D.C.
Ewing, R. and R. Cervero. (2010) Travel and the built environment. Journal of the American Planning Association 76(3): 265-294.
Fulton, L. M., R. B. Noland, D. J. Meszler, and J. V. Thomas. (2000) A statistical analysis of induced travel effects in the U.S. Mid-Atlantic region. Journal of Transportation and Statistics 3(1): 1-14.
Gómez-Ibáñez, J. A. (1999) Pricing, Chapter 4 in Gomez-Ibanez, J. A *et al*., (eds.), Essays in Transportation Economics and Policy. Brookings Institution Press, pp. 99-136.
Goodwin, P. B. (1992) A review of new demand elasticities with special reference to short and long run effects of price changes. Journal of Transport Economics and Policy 26(2): 155-169.
Goodwin, P., J. Dargay and M. Hanly. (2004) Elasticities of road traffic and fuel consumption with respect to price and income: a review. Transport Reviews 24(3): 275-292.
Graham, D. J. and S. Glaister. (2002) The demand for automobile fuel: a survey of elasticities. Journal of Transport Economics and Policy 36(1): 1-25.
Greene, D. (1996) Transportation and Energy. Eno Foundation. Washington, D.C.
Greene, D. and P. Hu. (1986) A Functional Form Analysis of the Short-Run Demand for Travel and Gasoline by One-Vehicle Households. Transportation Research Record 1092. Transportation Research Board, National Research Council, Washington, D.C., pp. 10–15.
Greening, L. *et al*., (1995) Use of region, life-cycle and role variables in the short-run estimation of the demand for gasoline and miles travelled. Applied Economics 27: 643–656.
Hankey, S. and J. D. Marshall. (2010) Impacts of urban form on future US passenger-vehicle greenhouse gas emissions. Energy Policy 38: 4880-4887.
Heanue, K. (1998). Harmonizing transportation and community values. ITE Journal 68(11): 32-35.
Hedges, L. V. and I. Olkin. (1985) Statistical Methods for Meta-Analysis. Orlando: Academic Press.
Hughes, J. E., C. R. Knittel and D. Sperling. (2007) Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand. Presented at the 86th Annual Meeting of the Transportation Research Board, National Research Council, January 21-25, Washington D.C.

Holmgren, J. (2007) Meta-analysis of public transport demand. Transportation Research Part A 41: 1021-1035.
Johnson, R. A., C. J. Rodier, M. Choy, and J. E. Abraham. (2000) Air Quality Impacts of Transit and Supporting Land Use and Pricing Policies. A Report for the U.S. Environmental Protection Agency.
Kain, J. F. (1999) The Urban Transportation Problem, Chapter 11 in Gomez-Ibanez *et al*., (eds) Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer. The Brookings Institution.
Lane, B. W. (2010) The relationship between recent gasoline price fluctuations and transit ridership in major US cities. Journal of Transport Geography 18: 214-225.
McCarthy, P. S. (2001) Regulation, Deregulation, and Efficiency in Transportation. Chapter 8 in Transportation Economics. Theory and Practice: A Case Study Approach. pp. 308-354. Blackwell Publishers.
McFadden, D. (1974) The measurement of urban travel demand. Journal of Public Economics 3: 303-328.
MTC. (2004) San Francisco Bay Area Travel Survey 2000. Regional Travel Characteristics Report. Volume 1. Metropolitan Transportation Commission.
MTC. (2007) Transportation 2035 Change in Motion. Travel Forecasts for the San Francisco Bay Area. 2009 Regional Transportation Plan. Vision 2035 Analysis. Data Summary. Metropolitan Transportation Commission.
MTC. (2008) Travel Forecasts Data Summary. Transportation 2035 Plan for the San Francisco Bay Area. Metropolitan Transportation Commission.
Nelson, P., K. Gillingham and E. Safirova. (2003) Revving up the Tax Engine: Gas Taxes and the DC Metro Area's Transportation Dilemma. Resources for the Future. Washington DC.
Oum, T. H., W. G. Waters II, and J-S. Yong. (1992) Concepts of price elasticities of transport demand and recent empirical estimates: an interpretative survey. Journal of Transport Economics and Policy 26(2): 139-154.
Pickrell, D. H. (1999) Transportation and Land Use. In Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer, edited by J. A. Gómez-Ibáñez, W. B. Tye and C. Winston. Chapter 12, pp. 403-435. Brookings Institution Press (Washington D.C.).
Pucher, J. and J. L. Renne. (2003) Socioeconomics of urban travel: evidence from the 2001 NHTS. Transportation Quarterly 57(3): 49-77.
Puller, S. L. and L. A. Greening. (1999) Household adjustment to gasoline price change: an analysis using 9 years of US survey data. Energy Economics 21: 37-52.
Quinet, E. (1997) Full social cost of transportation in Europe. In: The Full Costs and Benefits of Transportation. Contributions to Theory, Method and Measurement. D. Greene, D. Jones and M. Delucchi (eds.). Springer-Verlag.
Randall, C. (2000) The Influence of Urban Form on Travel: An Interpretive Review. Journal of Planning Literature 15 (1): 3-23.
Rodier, C. (2009) A Review of the International Modeling Literature: transit, land use, and auto pricing strategies to reduce vehicle miles traveled and greenhouse gas emissions. A Report for the California Air Resources Board and the California Department of Transportation. Submitted to the 2009 Transportation Research Board Annual Meeting.
Rose, G. (1986) Transit passenger response: short and long term elasticities using time series analysis. Transportation 13: 131-141.
SACOG. (2008) Metropolitan Transportation Plan 2025. Sacramento Area Council of Governments (SACOG). Sacramento, CA.
Safirova, E., S. Houde and W. Harrington. (2007) Spatial Development and Energy Consumption. Resources for the Future. Washington D.C.
Sarmiento, S. (2000) Household, Gender and Travel. Proceedings from the Second National Conference on Women's Travel Issues. Federal Highway Admininstration.

Schipper, L., C. Marie and R. Gorham. (2000) Flexing the Link: An Urban Transport CO_2 Strategy for the World Bank. Washington: World Bank and Paris, International Agency.
Shadish, W. R. and C. K. Haddock. (1994) Combining estimates of effect sizes. In: H. Cooper and L. V. Hedges (eds.), The Handbook of Research Synthesis. Russell Sage, New York, pp. 261-285.
Small, K. A. and K. Van Dender. (2007) Fuel efficiency and motor vehicle travel: the declining rebound effect. The Energy Journal 28(1): 25-51.
Souche, S. (2010) Measuring the structural determinants of urban travel demand. Transport Policy 17: 127-134.
Southworth, F. (2001) On the potential impacts of land use change policies on automobile vehicle miles of travel. Energy Policy 29: 1271-1283.
Sterner, T., C. Dahl and M. Franzen. (1992) Gasoline tax policy: carbon emissions and the global environment. Journal of Transport Economics and Policy 26: 109-119.
Su, Q. (2010) Travel demand in the US urban areas: a system dynamic panel data approach. Transportation Research Part A 44: 110-117.
Tietenberg, T. and L. Lewis. (2009) Regional and global air pollutants: acid rain and atmospheric modification. In D. Battista & N. Seibert (Eds.), Environmental & natural resource economics (8th ed.) pp. 425-437. Boston: Pearson Education, Inc.
U.S. Department of Energy (DOE). (2008) Annual Energy Review. Energy Information Administration, Washington DC: Annual issues.
U.S. Department of Energy (DOE). (2009) Annual Energy Review. Energy Information Administration, Washington DC: Annual issues.
Varian, H. R. (1999) Market Demand. Chapter 15 in Intermediate Microeconomics. A Modern Approach. Fifth Edition. W. W. Norton & Company.
Walls, M., A. Krupnick and C. Hood. (1993) Estimating the Demand for Vehicle-Miles-Traveled Using Household Survey Data: Results from the 1990 Nationwide Personal Transportation Survey. Resources for the Future Discussion Paper ENR 93-25, Washington DC.
Weissman, S. and J. Corbett. (1992) Land Use Strategies for More Livable Places. The Local Government Commission. Sacramento, CA.
Zhang, M. (2006) Travel choice with no alternative: can land use reduce automobile dependence? Journal of Planning Education and Research 25: 311-326.