5. THE HELSINKI CASE CITY

5.1. Description of the Helsinki case city

The Helsinki model area is actually a large region that includes both urban and rural areas. At the heart of the region lies Helsinki, the capital of Finland, surrounded by three smaller cities. Together they form the Helsinki Metropolitan Area. Additionally, included in the model area is a relatively large surrounding region with smaller cities and towns lying within the Metropolitan Area's commutershed. The total land area is 13 827 km^2 of which the metropolitan region is 743 km^2.

Helsinki region accounts for about one third of Finland's GDP. In addition to its administrative status as the capital city and home for industry headquarters, the economy of the region is based on retail, wholesale and private services. The region, therefore, has a trade surplus with the rest of the country. While the traditional manufacturing industries have been declining, the share of high-technology industries and services has been growing. The large and concentrated traditional industries such as metal and paper are not typically located in the region. Consequently, foreign exports are not so dominant as for the rest of the country. Consistent with its high population density, the level of imports is high.

A sign of the structural change in the 1990s is the stratification of population and regions. The spread in income levels has increased along with the demand for the less educated labour force diminishing. The Helsinki Metropolitan area and its surroundings form a region that has been the most successful one in the country, but also within the region itself certain areas are prosperous while others are impoverished.

The Metropolitan Area faces a rapid population growth from the present 920.000 to 1.1 million inhabitants by the year 2020. This increases the pressures of urban sprawl as well as the use of natural and other green areas. It is expected that Helsinki can only accommodate less than one-fourth of the forecast growth, the rest being directed to the other cities of the Metropolitan Area.

It is predicted that mobility will increase faster than the population. One reason for this is the decentralising land use, but also the number of trips is expected to grow. The share of public transport has been dropping significantly during the past few decades, but this decline is now anticipated to have reached its low. If policies favouring public transport will be pursued, it is forecast that the share of collective transport will start slightly rising again. Traffic speed in the Metropolitan Area will continue its gradual downward trend unless the increase in the use of the private car can be curbed. The growing traffic will increase the noise nuisance experienced by the inhabitants. It has been estimated that the population living in areas where the daily average noise level exceeds 55 dB(A) will increase by about 15% to more than 200 000 people by 2020.

Currently, the concentrations of nitrogen dioxide and particulate matter exceed the guidelines annually. The levels of nitrogen dioxide are expected to fall because of the technical development of the vehicle fleet, but high particulate concentrations are still expected in the busiest traffic environments. The air quality in general is improved due to the sea environs. Acidic fallout exceeds the critical load because of trans-boundary emissions.

5.2. The Helsinki land use/transport model: the MEPLAN framework

The Helsinki region case study was carried out using the existing MEPLAN model application of the region (see Echenique et al 1995 and Moilanen, 2000). MEPLAN is a comprehensive land-use and transport interaction modelling package that can represent strategic multi-modal networks/services and estimate transport demand based on the spatial economic interactions between the households, employment and land use (see *e.g*. Echenique, 1994; Williams, 1994; Harris, 1996). The modelling process follows closely the TRANUS process (see the section on TRANUS).

The urban model applications of the MEPLAN framework follow a traditional four-step transport model supplemented with a land-use location model. The various overall phases (from demand to supply) the model predicts for a given period are as follows:

(i) The location of the households and firms (employment);

(ii) The generation of trips from the interactions between households and employment;

(iii) The distribution of the trips between zones in the area;

(iv) The mode split of the trips into car, public transport and slow modes trips;

(v) The assignment of the vehicles on the transport networks.

The process modelling the economic interactions and socio-economic characteristics of the region of step (i) is based on a spatial input-output framework for endogenous employment and population that also have elastic (Stone-Geary) consumption functions. The chain of production and consumption is started based on the exports and other exogenous employment and inactive (non-working) households. Various constraints (e.g. rents based on available floorspace) increasing the costs of location affect this process in addition to the accessibilities due to transport system demand and supply characteristics (steps ii-v above).

The econometric models utilised are of the stochastic discrete choice type with a nested logit formulation. The hierarchical structure is adopted extensively in the transport model from trip distribution to modal split and generation of trip matrices (see McFadden 1978). This gives a strong theoretical foundation of utility maximising and also leads to a consistent evaluation based on consumer surplus calculation considerations inherent in economic welfare theory (Williams 1977).

5.3. The design of the Helsinki land use/transport model

The land use/transport model for the Helsinki region has been developed in several phases. The current updated model is designed for carrying out practical tests of the transport and land-use policy proposals in the area. The structure follows a traditional (extended) four-step transport modelling approach described above. The transport sub-model simulates both peak and inter-peak travel conditions using all modes (car, public transport and low modes) for 15 separate trip types (purpose/period/SEG) that had different characteristics in the calibration of the model.

The trip generation is modelled in the demand model with a land-use generation and location process of the economic interactions in the region, which is affected by the characteristics of the transport conditions presenting a given modelled 5-year period. The demand model encompasses various types of households and employment sectors that are in economic interaction with each other (through an input-output framework), and the floorspace that they use for locating in a zone. The lack of floorspace will turn up as higher rents affecting in turn the location of the households and employment in addition to transport accessibilities and other consumption costs in a zone.

The study area consists of 81 zones, and covers an area of 14,400 square kilometres that includes not only the Helsinki Metropolitan Area but also the surrounding cities. The model area includes the cities of Helsinki, Espoo, Vantaa and Kauniainen, which form the Helsinki metropolitan area. In addition to the metropolitan area, also the surrounding region is included in the model (the provinces of Uusimaa and Itä-Uusimaa as well as major parts of the provinces of Kanta-Häme, Päijät-Häme and Pirkanmaa). The model has therefore some characteristics of an inter-urban model.

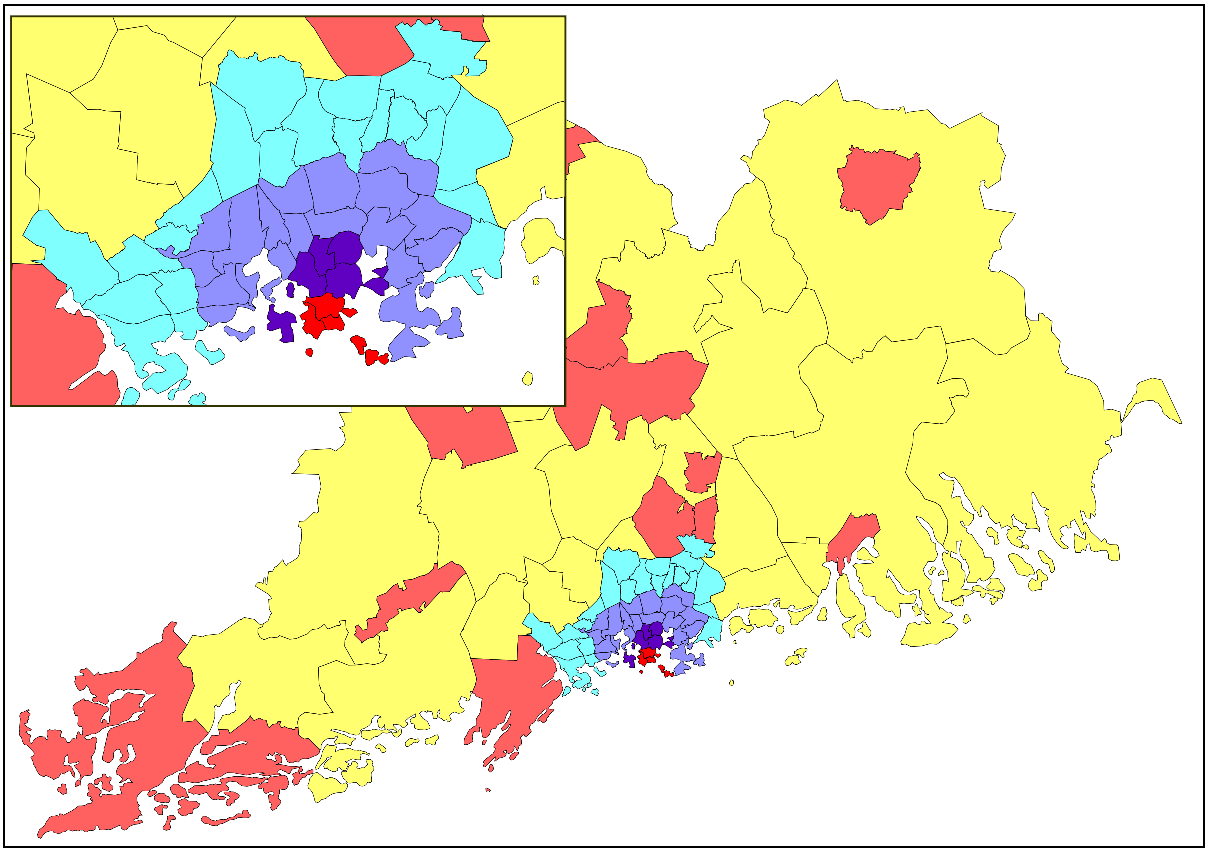


Figure 5.1: The study area and the super-zone definitions used in the analysis of sprawl : Helsinki centre (red), Inner Helsinki Metropolitan Area (HMA) (dark blue), outer HMA (mid-blue), HMA suburbs (light-blue), other urban conurbations outside HMA (orange) and rural municipalities (yellow).

Model factors are divided into three broad categories: employment factors (agriculture, industry, construction, wholesale, retail sale, private and public services), household categories (according to the social economic characteristics of the household head) and building stock (housing and employment floorspace) that is regulated in the land use model affecting the location of the new stock. Households in each income group are further divided into two types: active (i.e. working) and inactive (non-working). For inactive households, accessibility to work does not affect their location (like rents and other consumption costs).

5.4. Calibration of the Helsinki model

The calibration of the model is based on a wide set of census and other zone-based socio-economic and transport data supplied by the Finnish authorities. The household consumption (which determines for example the home based shopping trips) was modelled using a standard household expenditure survey by Statistics Finland as a source. The connection from employment to households was in turn developed based on a sample of anonymised records from the Finnish census. The design of the input-output framework in the model of Helsinki Region did benefit from a regional input-output table that was a constructed in a separate thesis study. It enabled the model to represent the whole economic structure of the modelled region with intermediate demand and good estimates of the exports and final consumption.

The network model of the multi-modal transport system is based on the Helsinki Metropolitan Area Council data. The road network includes the major arteries and the minor streets. The road network outside the Metropolitan area is a more coarse description of the connections between municipalities based on Finnish Road Administration data. The flow-delay functions have been calibrated to match the observed speed during periods of congestion. For public transport a 595-zone network of all bus and rail services within the Metropolitan area is used. The description of services includes the lines, stops, speeds/times, headways and the type of service (rail/metro/tram/bus). A simple distance-based (mostly intrazonal) network is used for slow modes.

For the region outside the Metropolitan area a coarser model is used based on the services between the municipalities and the Helsinki Metropolitan Area. The route assignment takes into account the in-vehicle, waiting, access and interchange times that are weighted according to the perceived time/inconvenience by the traveller. The disutility of travelling is also dependent on the type of service. The model has been calibrated to roughly match the observed ridership on the lines.

The assigned travel times and costs between origin and destination zones are used in the travel demand model that estimates the modal split of the trips generated by the land-use model according to the theory described above. The level of overall demand between zones is based on the input-output (e.g. working) relationships in the land use model.

The land-use model has been calibrated to model the location of the 1.6 million inhabitants (2000) in the area (out of approximately 5 million overall in Finland). The first stage has the objective to calibrate the model parameters in such a way as to reproduce the situation in the base year, whereas the following stages for each 5-year period following it aim at forecasting the interaction of transport demand and supply at the Master Plan until the final horizon year of 2020.

5.5. Definition of the simulated scenarios

Population in the study area is expected to grow significantly to nearly 2 million inhabitants by year 2020. Economic development in the region is estimated to grow annually by 2% in real terms. Household living space per capita is expected to grow from 39 m^2 in year 2000 to 50 m^2 in 2020. Over the same period, employment floor space is expected to contract from 46 m^2 to 44 m^2 due to structural changes in employment from traditional industry towards office work. The existing land use plans (of mid 90s) have been included in the forecast that affect the relocation of the new building stock. The strong growth due to the national migration towards the few urban agglomerations of high technology employment in the base forecast has created a crowding effect in the Helsinki region causing the sprawling effect towards the fringes of the Helsinki Metropolitan Area and outside it (see Figure 5.2 below).

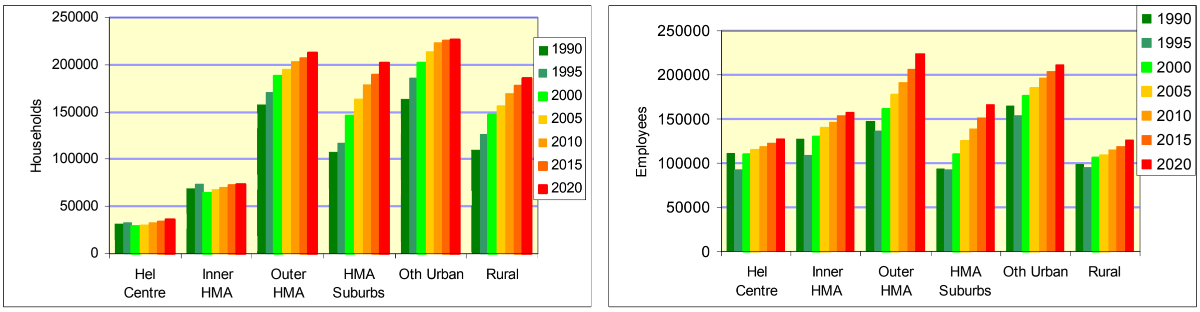


Figure 5.2: Observed development of the population and households 1990-2000 and as forecasted by the model for 2000-2020.

Transport prices (fuel, fares and parking) are expected to grow by 2% annually in real terms for household vehicles and public transport (1.3 %/year for parking), and to remain constant for freight transport. Car ownership is forecast to increase from 370 cars to 489 cars / 1000 inhabitants. The Helsinki Metropolitan Area Council has prepared a long-term transport plan illustrated in the figure below that is also included in the base forecast.

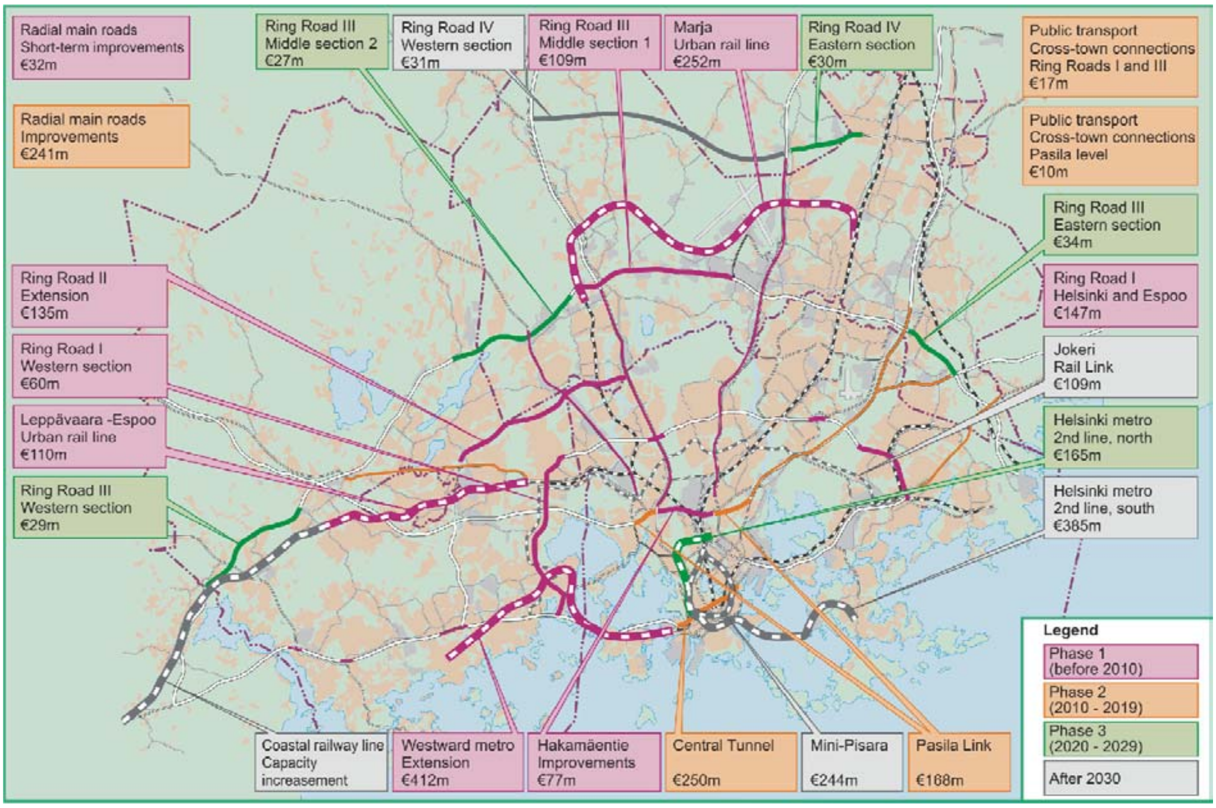
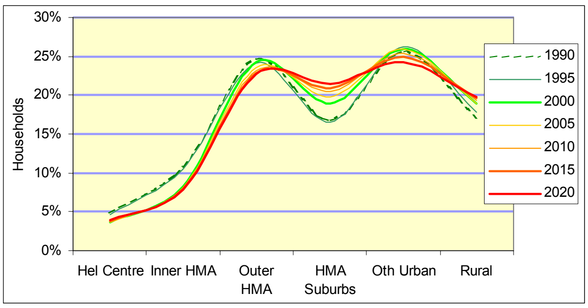


Figure5.3: Map of the projects included in the Helsinki reference solution including cost estimates

The simulated scenarios included the common scenarios and city-specific scenarios described in tables 2.1 and 2.2 above. For example, to assess the effect of strategic balance of road and public transport investment plans, the scenario tests 001H-004H were constructed from the base forecast (scenario 004H) including only the public transport (scenario 003H), road investments (scenario 002H) or no investments (scenario 001H) from the investment plan shown in Figure 5.3. The impacts of these general investment strategies are discussed below in section 5.6.2.

Scenarios were analysed in terms of sprawl as using the centrally concentric super-zone (shown in Figure 5.1) shares and their change over the period of 2000-2020. As Figure 5.4 shows, the employment and population in the central areas has declined and increased in the suburban and rural areas. This is a clear indication of sprawl in the region. To make the analysis of the future development of sprawl (and the effectiveness of the measures designed to reverse it) more sensitive, the simulation results are analysed as a relative development from the current state (year 2000) of matters as shown in Figure 5.5.



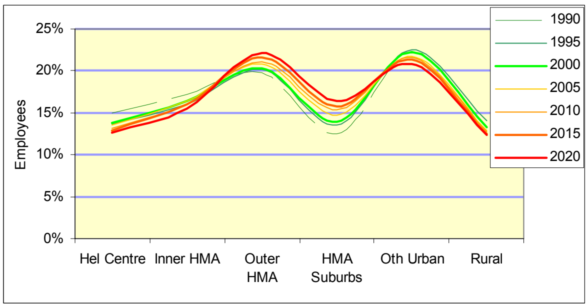


Figure5.4: Superzone shares with household and employment location 1990-2020 (observed and forecasted)

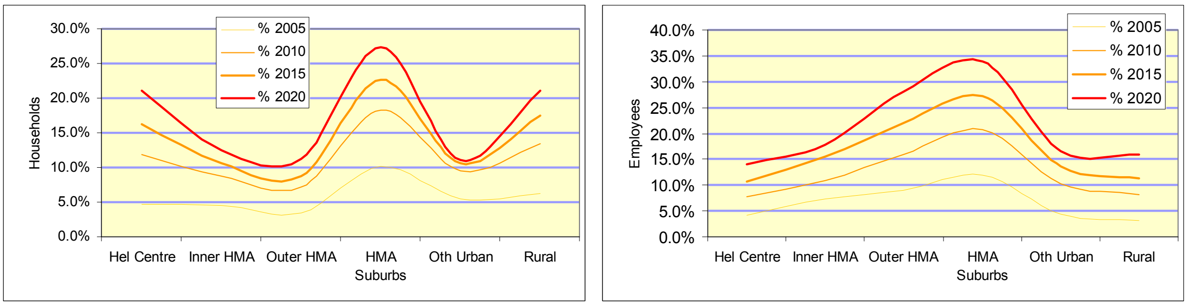


Figure 5.5: The relative development of household and employment from year 2000 in the base forecast

5.6. Simulation results in the Helsinki case city

5.6.1. General

The policies are analysed in the following groups:

- Investment policies
- New town alternatives
- Land use pricing policies
- Transport pricing
- Policy combinations

Both the city sprawl variables and the sustainability indicators are presented for these groups. An overview of the city sprawl variables and the sustainability evaluation of all policies is presented below (Table 5.1).

SCATTER		Base		Investment policies					New town alternatives					Land use (pricing) policies					Transport pricing			Combinations		
		PRESENT	Base 2021	Do not invest	Only car investments	Only PT investments	All reference investments	Develop orbital connections of PT	Vuosaari	Marja-Vantaa	Keski-Pasila	Espoon keskus	Matinkyl	DIF 670 euro/a	DIF 340 eur/a	DIF 1000 euro/a	ABC land use regulation for businesses	ABC land use pricing for businesses	Car operating cost +50%	Cordon (peak) pricing 2.55 euro	PT fare - 20%	Comb. 411+512+311	Comb. 411+512+331	Comb. 411+512+311+331
Helsinki case city		2001	000	001	002	003	004	121	211	212	213	214	215	311	312	313	321	331	411	412	512	811	812	813
Variable	**Unit**																							
Overall mobility																								
Average travel time (all modes)	minutes	29,8	29,2	-0,5%	0,0%	-0,3%	0,0%	-0,2%	0,2%	0,9%	2,8%	-0,4%	3,2%	-0,4%	-0,4%	-0,7%	-0,3%	-0,1%	-5,1%	-3,5%	5,1%	0,8%	1,1%	-0,2%
Public transport																								
Modal share of modes	%	44,1	42,3	-1,4	-1,4	0,2	0,0	0,1	-0,5	-0,2	0,7	-0,2	0,0	-0,1	0,1	-0,1	-0,2	0,0	0,8	3,4	4,5	6,1	12,3	12,2
Passenger-km by public modes	km/inhabitant/a	5232	5734	-5,1%	-4,2%	-0,6%	0,0%	0,3%	-1,4%	-0,9%	2,4%	-1,0%	0,1%	-0,6%	0,0%	-0,4%	-0,5%	-0,3%	-0,8%	6,2%	14,8%	16,8%	16,9%	16,2%
Road traffic																								
Private vehicle-km	km/inhabitant/a	2451	2930	-6,7%	-1,4%	-4,9%	0,0%	-0,7%	1,8%	1,2%	4,7%	-1,4%	6,0%	-1,1%	-0,2%	-0,9%	0,6%	-0,4%	-17,4%	-35,9%	0,9%	-16,1%	-15,9%	-17,6%
Greenhouse gases from transport	eq.ton/inhabitant/a	1,41	1,78	-1,6%	-0,9%	-0,5%	0,0%	-0,8%	2,6%	1,5%	4,1%	-0,4%	5,6%	-1,0%	-0,2%	-0,9%	0,7%	-0,4%	-11,8%	-25,1%	0,0%	-10,7%	-10,6%	-12,0%
Average road traffic speed	km/h	37,3	31,6	-1,6%	0,4%	-2,9%	0,0%	0,9%	-1,3%	0,6%	-1,4%	1,4%	-1,7%	0,8%	-0,1%	0,1%	-0,8%	-0,5%	-2,0%	20,0%	8,7%	1,8%	1,9%	2,6%
Land use																								
Households in urbanised zones	#	639565	772313	-0,1%	-0,2%	-0,1%	0,0%	-0,1%	0,0%	0,0%	-0,2%	-0,2%	-0,4%	0,7%	0,2%	1,0%	0,2%	0,0%	0,7%	0,1%	-1,0%	0,6%	-0,1%	0,6%
Households in core metropolitan area	#	265432	304320	0,1%	0,0%	0,1%	0,0%	-0,1%	0,0%	-0,9%	-0,4%	-0,2%	-0,6%	0,6%	0,3%	0,9%	0,5%	0,1%	1,7%	3,0%	-2,3%	0,1%	-0,5%	0,2%
Households in the city centre	#	28812	36485	0,0%	-0,2%	0,1%	0,0%	-0,1%	-0,4%	-1,2%	-0,5%	-0,4%	-1,1%	0,6%	0,3%	1,0%	-1,5%	0,0%	2,5%	5,4%	-4,0%	-0,7%	-1,4%	-0,6%
Employees in urbanised zones	#	698209	904015	0,0%	0,0%	0,0%	0,0%	-0,1%	0,4%	0,6%	0,0%	0,1%	0,0%	0,3%	0,1%	0,4%	0,8%	0,2%	0,2%	-0,4%	0,1%	0,6%	0,5%	0,7%
Employees in core metropolitan area	#	392807	499005	-0,2%	-0,2%	-0,2%	0,0%	-0,1%	-3,6%	-3,9%	0,5%	-1,6%	-2,4%	0,2%	0,1%	0,4%	1,8%	0,3%	0,0%	-1,9%	0,2%	0,9%	0,8%	1,2%
Employees in the city centre	#	109706	127650	-0,5%	-0,3%	-0,3%	0,0%	0,0%	-3,5%	-3,6%	-2,6%	-1,5%	-2,5%	0,1%	0,1%	0,2%	-2,9%	-0,2%	-0,1%	-1,2%	0,7%	2,3%	2,1%	2,5%
Accessibilities																								
Average home-work travel distance	kilometres	16,2	15,0	-0,7%	1,0%	-0,9%	0,0%	-0,3%	1,0%	0,8%	3,4%	0,1%	4,7%	-0,1%	-0,1%	-1,1%	0,5%	-0,2%	-13,8%	-3,9%	16,4%	0,5%	0,9%	-0,3%
Accessibility to city centre	minutes/trip	29,3	29,8	-0,9%	-0,6%	0,0%	0,0%	-0,3%	-0,4%	-0,6%	1,0%	-0,9%	0,6%	-0,7%	0,1%	-0,6%	0,0%	0,0%	-2,7%	-6,7%	-1,7%	-2,1%	-2,3%	-2,6%
Accessibility to services	minutes/trip	27,7	28,2	-1,6%	-1,2%	-0,4%	0,0%	0,3%	0,1%	0,7%	0,5%	0,0%	0,6%	-0,1%	0,0%	-0,2%	-0,5%	-0,1%	-2,3%	-3,2%	1,7%	0,0%	0,1%	-0,1%
Productivity gain from land use	%	0,0	0,0	-0,5	0,4	-1,1	0,0	0,2	-0,4	-0,2	-0,7	0,4	-0,7	0,2	-0,1	0,1	0,2	0,0	1,0	-0,6	0,4	0,3	0,4	0,7
	HMA	diff. in % units																						

Table5.1:Urban sprawl variables in the tested policy alternatives

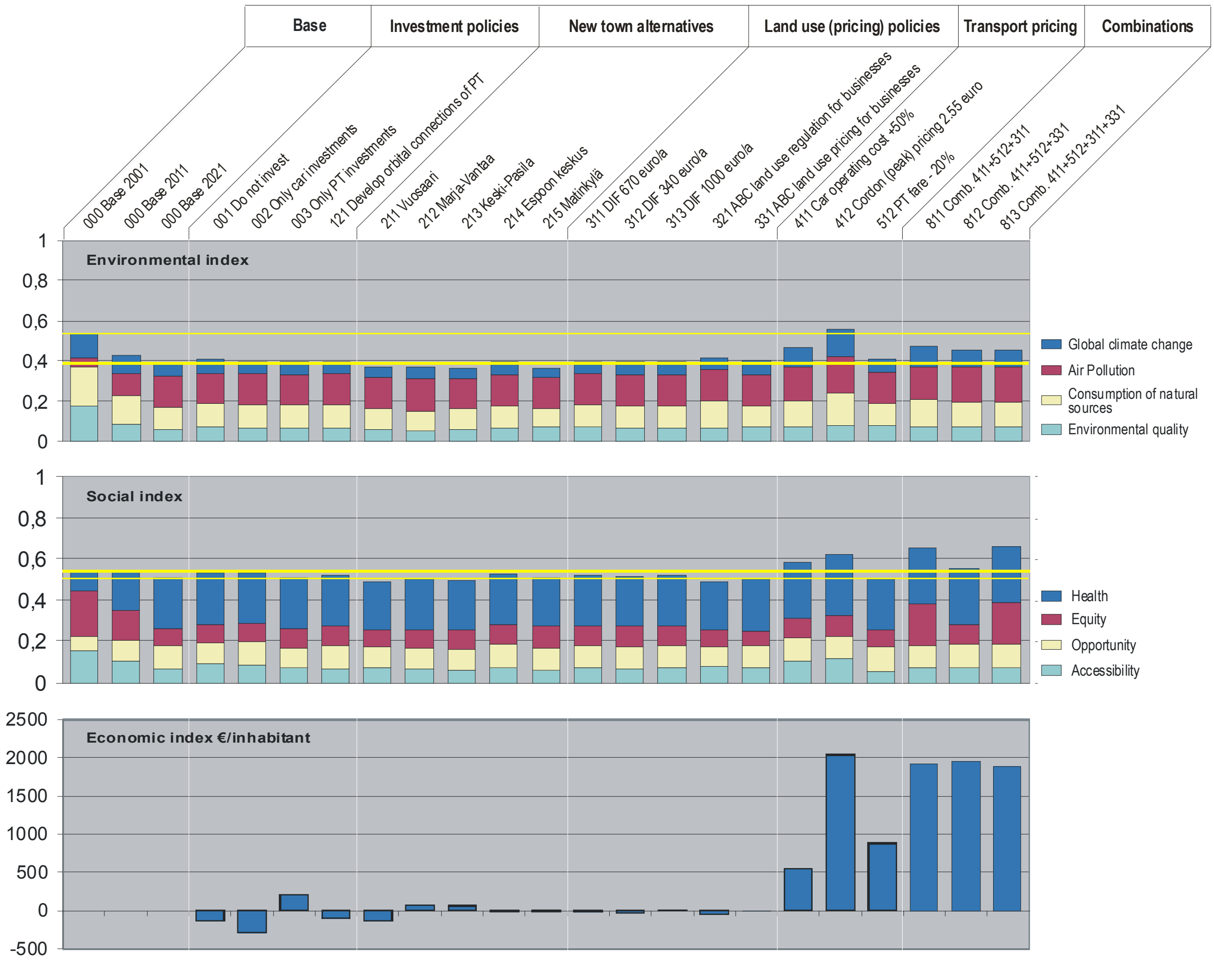


Figure 5.6: Sustainability indicators in the tested policy alternatives

5.6.2. Investment policies

The investment policies are local policies. The aim is to test the Helsinki Metropolitan Area Transportation Master Plan projects in large groups, namely PT investments on the one hand and road investments on the other hand. In addition, a project improving the orbital connections has been tested separately.

Table 5.2: Urban sprawl variables in Investment policies

SCATTER		Base		Investment policies				
		PRESENT	Base 2021	Do not invest	Only car investments	Only PT investments	All reference investments	Develop orbital connections of PT
Helsinki case city		2001	000	001	002	003	004	121
Variable	**Unit**							
Overall mobility								
Average travel time (all modes)	minutes	29,8	29,2	-0,5%	0,0%	-0,3%	0,0%	-0,2%
Public transport								
Modal share of modes	%	44,1	42,3	-1,4	-1,4	0,2	0,0	0,1
Passenger-km by public modes	km/inhabitant/a	5232	5734	-5,1%	-4,2%	-0,6%	0,0%	0,3%
Road traffic								
Private vehicle-km	km/inhabitant/a	2451	2930	-6,7%	-1,4%	-4,9%	0,0%	-0,7%
Greenhouse gases from transport	eq.ton/inhabitant/a	1,41	1,78	-1,6%	-0,9%	-0,5%	0,0%	-0,8%
Average road traffic speed	km/h	37,3	31,6	-1,6%	0,4%	-2,9%	0,0%	0,9%
Land use								
Households in urbanised zones	#	639565	772313	-0,1%	-0,2%	-0,1%	0,0%	-0,1%
Households in core metropolitan area	#	265432	304320	0,1%	0,0%	0,1%	0,0%	-0,1%
Households in the city centre	#	28812	36485	0,0%	-0,2%	0,1%	0,0%	-0,1%
Employees in urbanised zones	#	698209	904015	0,0%	0,0%	0,0%	0,0%	-0,1%
Employees in core metropolitan area	#	392807	499005	-0,2%	-0,2%	-0,2%	0,0%	-0,1%
Employees in the city centre	#	109706	127650	-0,5%	-0,3%	-0,3%	0,0%	0,0%
Accessibilities								
Average home-work travel distance	kilometres	16,2	15,0	-0,7%	1,0%	-0,9%	0,0%	-0,3%
Accessibility to city centre	minutes/trip	29,3	29,8	-0,9%	-0,6%	0,0%	0,0%	-0,3%
Accessibility to services	minutes/trip	27,7	28,2	-1,6%	-1,2%	-0,4%	0,0%	0,3%
Productivity gain from land use	%	0,0	0,0	-0,5	0,4	-1,1	0,0	0,2

HMA diff. in % units

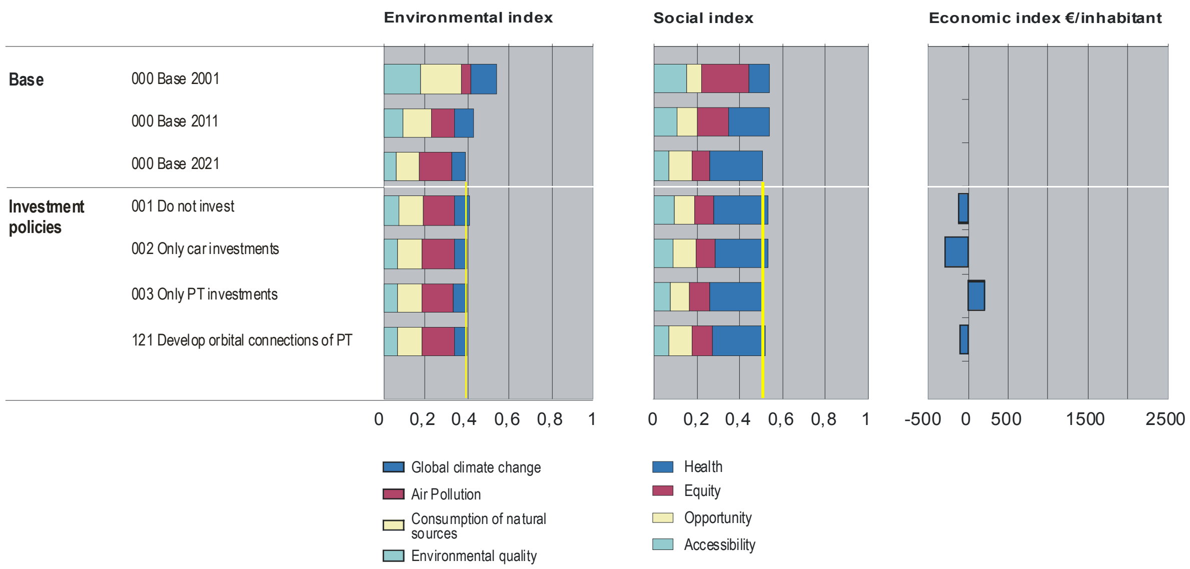


Figure5.7: Urban sustainability indicators in Investment policies

The urban sprawl variables show that both PT and road investments add to urban sprawl as vehicle kilometres travelled and CO2 emissions increase. Sprawl pattern in the Figure below confirm this. However, the impact of general investment strategies in the HMA (001H – 003H) on sprawl was rather small as they were orbital and were concentrated in the places where the growth resulted in congestion and therefore the investment only largely maintained the current level of accessibilities and did not result in much longer trips on average. The development of accessible rail corridors usually concentrates the population and employment along the corridors so while the urban pattern decentralises, the actual (harmful) sprawl towards rural areas may decrease slightly as shown in the Figure below. Individual right scale orbital investments (test 121H) did not seem to increase the threat of sprawl either.

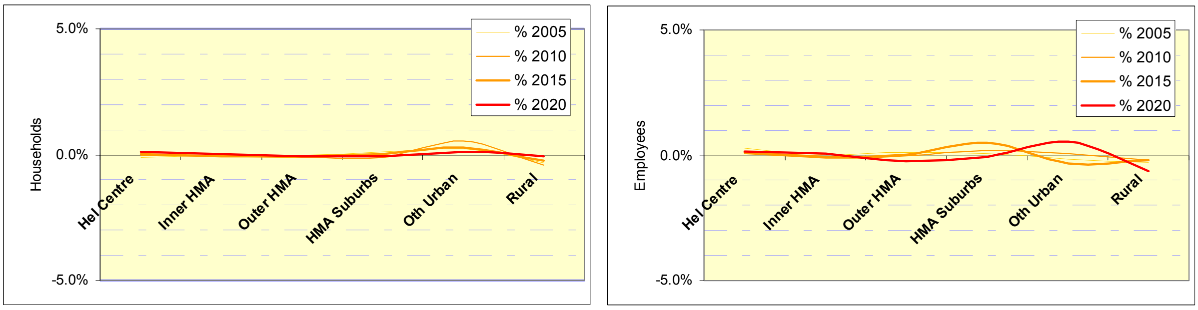


Figure 5.8: HMA plan's public transport rail investments compared with no investments

One can note that, although the traffic conditions are improved by investments in general, the city sprawl effect is stronger and as a result, the accessibilities to city centre and services may deteriorate as travellers utilise the speed increase by living further away. Large radial rail investments (test 116H or actions that otherwise increase the accessibilities away from the city centre, test 512H) can be shown to increase sprawl as households utilise the better access to space and therefore standard of living and lower housing prices in the fringes by moving there and still being able to work in the city. This situation is worsened by the current land use regulation in the HMA that constrain badly new construction (see discussion below).

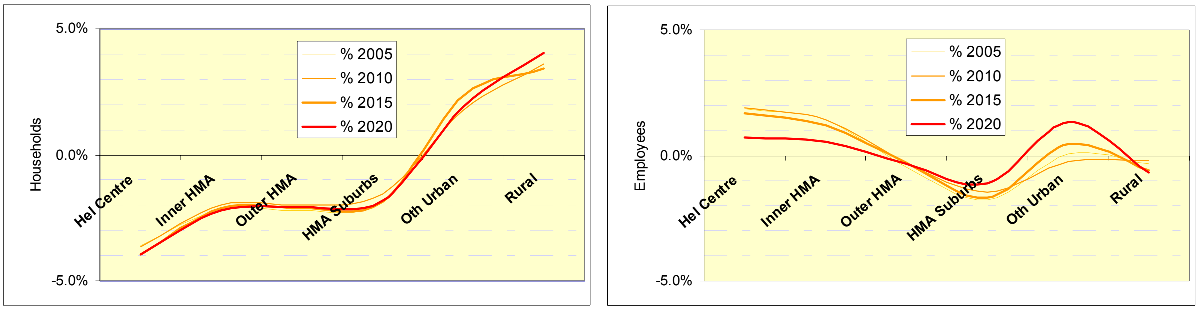


Figure 5.9: Test 512 H – Decrease public transport price by 20 %

The sustainability evaluation shows that the affect of investment policies on the environmental and social index is very small. The economic evaluation shows that the investment programme as a whole is viable. The set of PT investments is economically more feasible than the set of road investments.

5.6.3. New town alternatives

The aim of testing the “new town” alternatives is to theoretically study, from urban sustainability and city sprawl point of view, alternative locations for a large new concentration of workplaces.

Table 5.3: Urban sprawl variables in New town policies

SCATTER		Base		New town alternatives				
		PRESENT	Base 2021	Vuosaari	Marja-Vantaa	Keski-Pasila	Espoon keskus	Matinkylä
Helsinki case city		2001	000	211	212	213	214	215
Variable	**Unit**							
Overall mobility								
Average travel time (all modes)	minutes	29,8	29,2	0,2%	0,9%	2,8%	-0,4%	3,2%
Public transport								
Modal share of modes	%	44,1	42,3	-0,5	-0,2	0,7	-0,2	0,0
Passenger-km by public modes	km/inhabitant/a	5232	5734	-1,4%	-0,9%	2,4%	-1,0%	0,1%
Road traffic								
Private vehicle-km	km/inhabitant/a	2451	2930	1,8%	1,2%	4,7%	-1,4%	6,0%
Greenhouse gases from transport	eq.ton/inhabitant/a	1,41	1,78	2,6%	1,5%	4,1%	-0,4%	5,6%
Average road traffic speed	km/h	37,3	31,6	-1,3%	0,6%	-1,4%	1,4%	-1,7%
Land use								
Households in urbanised zones	#	639565	772313	0,0%	0,0%	-0,2%	-0,2%	-0,4%
Households in core metropolitan area	#	265432	304320	0,0%	-0,9%	-0,4%	-0,2%	-0,6%
Households in the city centre	#	28812	36485	-0,4%	-1,2%	-0,5%	-0,4%	-1,1%
Employees in urbanised zones	#	698209	904015	0,4%	0,6%	0,0%	0,1%	0,0%
Employees in core metropolitan area	#	392807	499005	-3,6%	-3,9%	0,5%	-1,6%	-2,4%
Employees in the city centre	#	109706	127650	-3,5%	-3,6%	-2,6%	-1,5%	-2,5%
Accessibilities								
Average home-work travel distance	kilometres	16,2	15,0	1,0%	0,8%	3,4%	0,1%	4,7%
Accessibility to city centre	minutes/trip	29,3	29,8	-0,4%	-0,6%	1,0%	-0,9%	0,6%
Accessibility to services	minutes/trip	27,7	28,2	0,1%	0,7%	0,5%	0,0%	0,6%
Productivity gain from land use	%	0,0	0,0	-0,4	-0,2	-0,7	0,4	-0,7

HMA diff. in % units

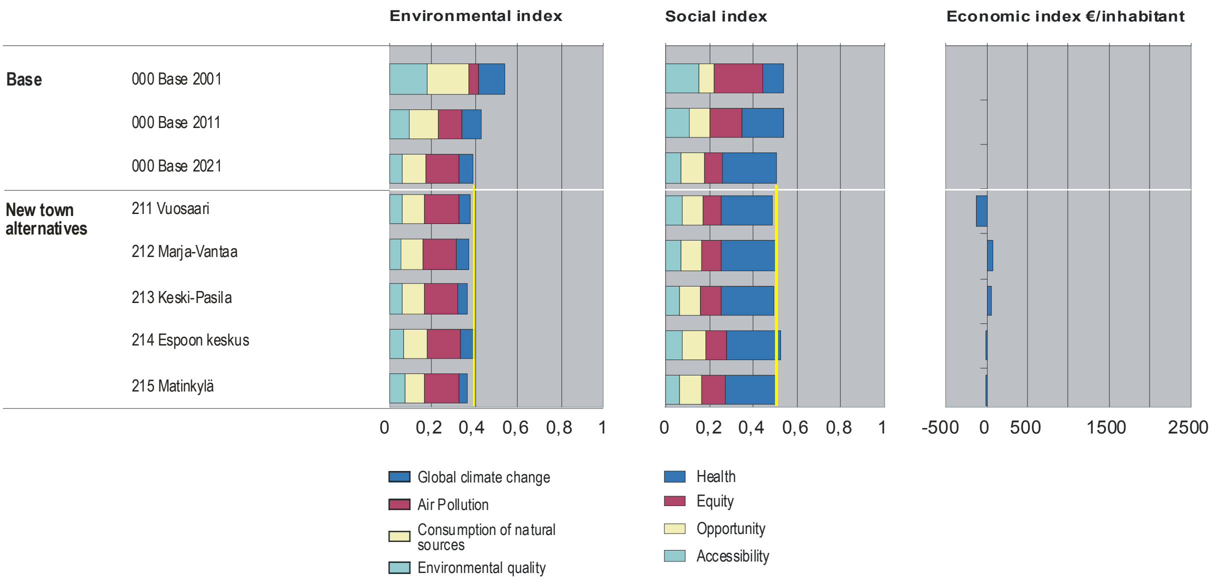


Figure5.10: Urban sustainability indicators in New town policies

Out of the new town alternatives tested locating in the West, North and East of the city centre the Pasila alternative is the most central one being very close to the main rail and road connections. The sustainability evaluation shows that in total the environmental, social and economic differences are very small between the alternatives. It would increase the PT share but also add to the overall mobility by both PT and private vehicles. The sprawl pattern is very similar in the Figures below in all cases. What is slightly worrying is the indication of population starting to increase in the rural areas, although the “gathering force” towards nearby locations of the new employment centre is what was intended.

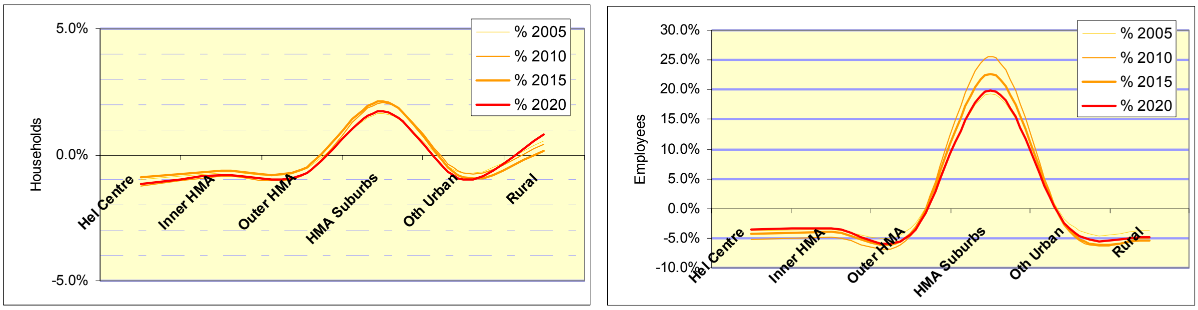


Figure 5.11: 212 H – New Centre in the North of Helsinki Centre (Marja-Vantaa)

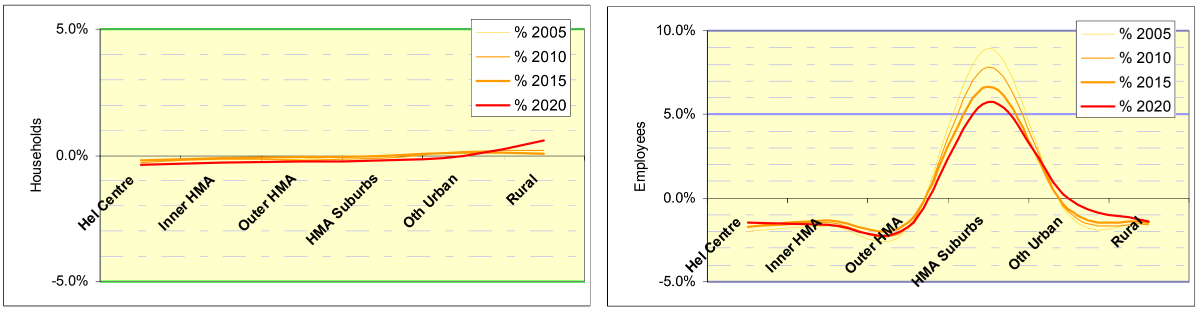


Figure 5.12: 214 H – New Centre in North-West (Espoon keskus)

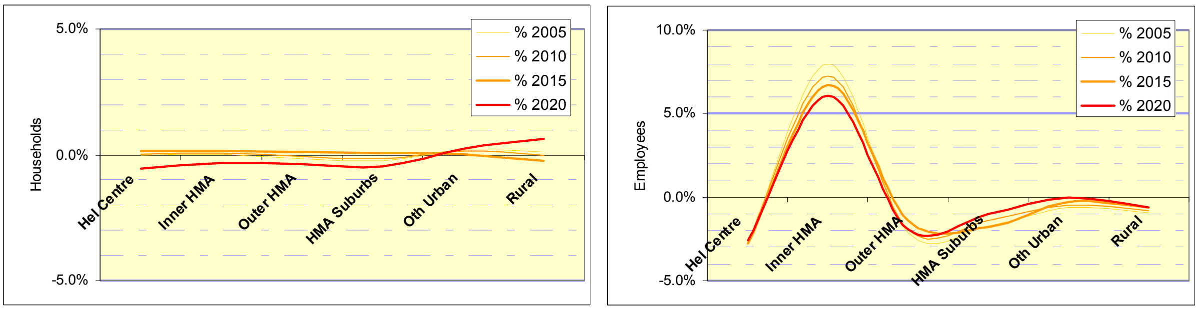


Figure 5.13: 213 H – New Centre next to City (Keski-Pasila)

5.6.4. Land use policies

Land use policies are common for all case cities. In Helsinki two additional alternatives for land pricing have been tested in order to find out sensitivities for different levels of land pricing.

Table 5.4: Urban sprawl variables in Land use policies

SCATTER		Base		Land use (pricing) policies				
		PRESENT	Base 2021	DIF 670 euro/a	DIF 340 eur/a	DIF 1000 euro/a	ABC land use regulation for businesses	ABC land use pricing for businesses
Helsinki case city		2001	000	311	312	313	321	331
Variable	**Unit**							
Overall mobility								
Average travel time (all modes)	minutes	29,8	29,2	-0,4%	-0,4%	-0,7%	-0,3%	-0,1%
Public transport								
Modal share of modes	%	44,1	42,3	-0,1	0,1	-0,1	-0,2	0,0
Passenger-km by public modes	km/inhabitant/a	5232	5734	-0,6%	0,0%	-0,4%	-0,5%	-0,3%
Road traffic								
Private vehicle-km	km/inhabitant/a	2451	2930	-1,1%	-0,2%	-0,9%	0,6%	-0,4%
Greenhouse gases from transport	eq.ton/inhabitant/a	1,41	1,78	-1,0%	-0,2%	-0,9%	0,7%	-0,4%
Average road traffic speed	km/h	37,3	31,6	0,8%	-0,1%	0,1%	-0,8%	-0,5%
Land use								
Households in urbanised zones	#	639565	772313	0,7%	0,2%	1,0%	0,2%	0,0%
Households in core metropolitan area	#	265432	304320	0,6%	0,3%	0,9%	0,5%	0,1%
Households in the city centre	#	28812	36485	0,6%	0,3%	1,0%	-1,5%	0,0%
Employees in urbanised zones	#	698209	904015	0,3%	0,1%	0,4%	0,8%	0,2%
Employees in core metropolitan area	#	392807	499005	0,2%	0,1%	0,4%	1,8%	0,3%
Employees in the city centre	#	109706	127650	0,1%	0,1%	0,2%	-2,9%	-0,2%
Accessibilities								
Average home-work travel distance	kilometres	16,2	15,0	-0,1%	-0,1%	-1,1%	0,5%	-0,2%
Accessibility to city centre	minutes/trip	29,3	29,8	-0,7%	0,1%	-0,6%	0,0%	0,0%
Accessibility to services	minutes/trip	27,7	28,2	-0,1%	0,0%	-0,2%	-0,5%	-0,1%
Productivity gain from land use	%	0,0	0,0	0,2	-0,1	0,1	0,2	0,0

HMA diff. in % units

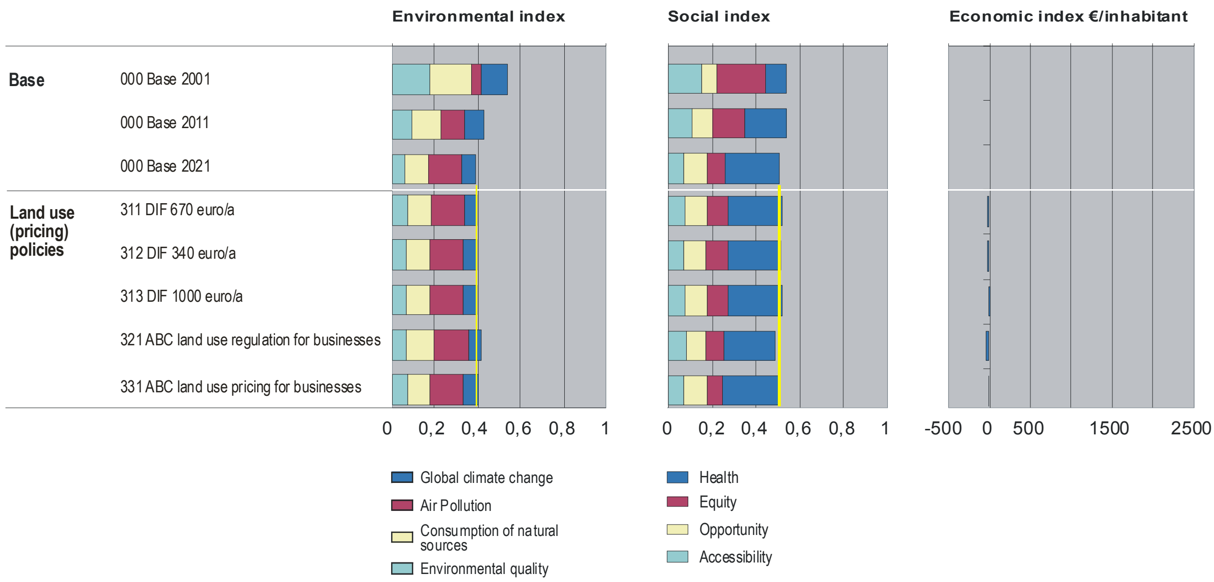


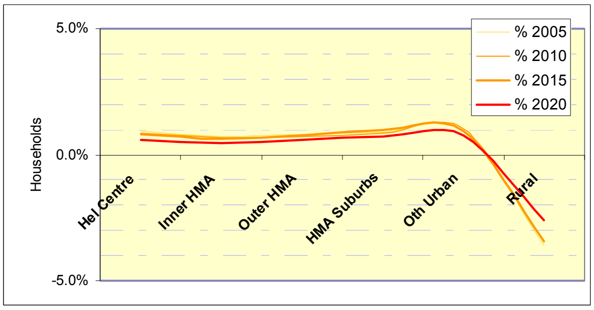
Figure 5.14: Urban sustainability indicators in Land use policies

The results indicate that the effects of the land pricing policies on the city sprawl variables are positive. The sustainability evaluation shows that the differences of the environmental, social and economic indices compared with the base scenario are also very small.

The sprawl patterns indicated that various regulatory actions (both land-use and transport) like ABC-policy as test 321H indicates could be efficient due to their pure nature of directly affecting the development of the region. However, this may not always be the case and the impact can remain small depending on the definition of the policy and existing current situation (test 331H), which is often difficult to identify beforehand. Also the modelling and assessing of these may prove difficult.

Another issue is how regulatory policies can be implemented in practise to reach the desired effects and how the various acceptability and institutional barriers can be overcome. Nevertheless the model reflecting the market-based economy and private preferences shows that all effects may also prove difficult to control especially if the measures are very crude. Secondary effects of specific targeted regulatory actions can remain unknown e.g. by surfacing elsewhere in the urban structure.

Pricing both land-use (policies 311H – 313H) and transport (policies 411H-412H, see the next section) are most effective to curb the sprawl especially if they can be more easily adjusted according to the observed problems (congestion, lengthening of trips and other externalities) whereas the regulatory actions are so called pull-policies that try to achieve the hoped-for effects that are in practise largely assumed and unknown in reality. But the intertwined acceptability, institutional and technological hurdles of the implementation of pricing are currently too high to get politicians or policymakers into this game in the complex administration of the Helsinki Metropolitan Area.



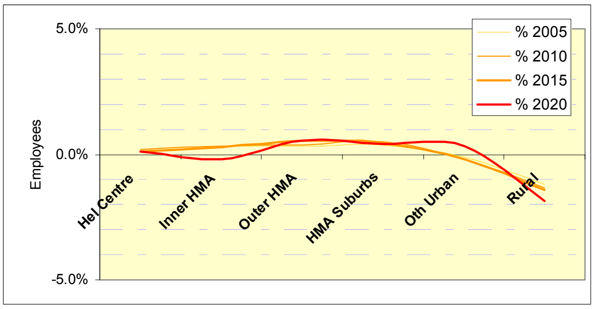


Figure 5.15: 311 H – Annual tax (development impact fee) in non urban zones + fiscal incentive (tax reduction) in urban zones

5.6.5. Transport pricing

Transport pricing policies consist of car operating cost increase policies and of a PT policy where the fare is assumed to be reduced by 20%.

Table 5.5: Urban sprawl variables in Transport pricing policies

SCATTER		Base		Transport pricing		
		PRESENT	Base 2021	Car operating cost +50%	Cordon (peak) pricing 2.55 euro	PT fare - 20%
Helsinki case city		2001	000	411	412	512
Variable	**Unit**					
Overall mobility						
Average travel time (all modes)	minutes	29,8	29,2	-5,1%	-3,5%	5,1%
Public transport						
Modal share of modes	%	44,1	42,3	0,8	3,4	4,5
Passenger-km by public modes	km/inhabitant/a	5232	5734	-0,8%	6,2%	14,8%
Road traffic						
Private vehicle-km	km/inhabitant/a	2451	2930	-17,4%	-35,9%	0,9%
Greenhouse gases from transport	eq.ton/inhabitant/a	1,41	1,78	-11,8%	-25,1%	0,0%
Average road traffic speed	km/h	37,3	31,6	-2,0%	20,0%	8,7%
Land use						
Households in urbanised zones	#	639565	772313	0,7%	0,1%	-1,0%
Households in core metropolitan area	#	265432	304320	1,7%	3,0%	-2,3%
Households in the city centre	#	28812	36485	2,5%	5,4%	-4,0%
Employees in urbanised zones	#	698209	904015	0,2%	-0,4%	0,1%
Employees in core metropolitan area	#	392807	499005	0,0%	-1,9%	0,2%
Employees in the city centre	#	109706	127650	-0,1%	-1,2%	0,7%
Accessibilities						
Average home-work travel distance	kilometres	16,2	15,0	-13,8%	-3,9%	16,4%
Accessibility to city centre	minutes/trip	29,3	29,8	-2,7%	-6,7%	-1,7%
Accessibility to services	minutes/trip	27,7	28,2	-2,3%	-3,2%	1,7%
Productivity gain from land use	%	0,0	0,0	1,0	-0,6	0,4

HMA diff. in % units

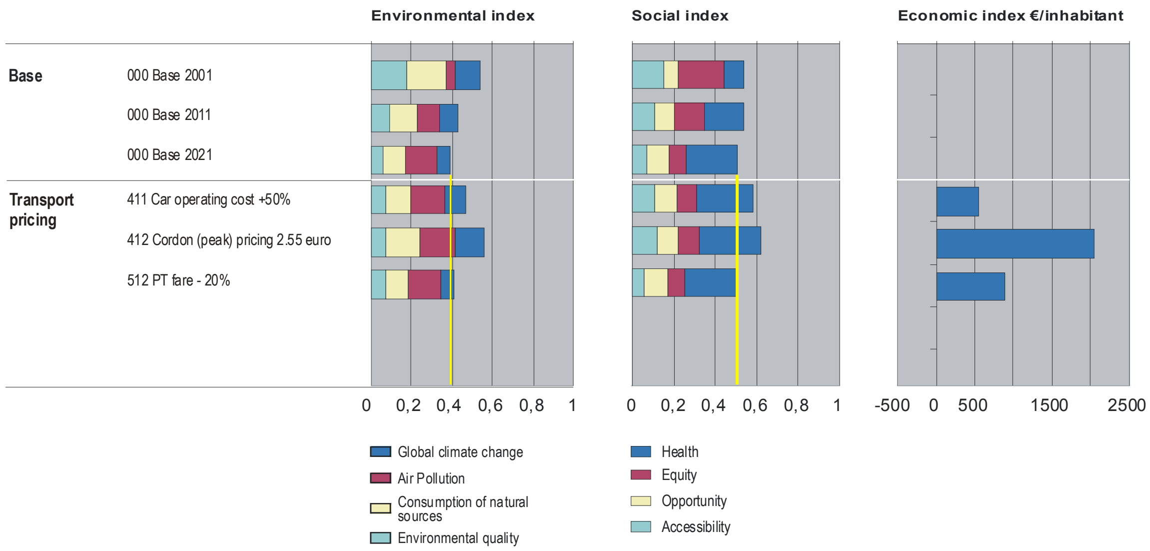


Figure 5.16: Urban sustainability indicators in Transport pricing policies

Compared with the previously presented policy alternatives the transport pricing policies have radical effects. Car pricing policies work strongly against urban sprawl increasing especially the number of inhabitants in central areas while at the same time reducing car kilometres and greenhouse emissions and improving the accessibility indicators. Reducing the PT fare has the opposite effect and this policy adds to urban sprawl.

All policies, including the PT fare reduction policy, are economically viable. The sustainability indicators show that the car pricing policies have simultaneous positive effect on all the dimensions of sustainability. This is due to the very effective counteractive force against the general increase of transport mobility due economic growth that adds to incomes and thus evens out the centralising effect of real cost increase of petrol price and fares. However, employment tends to decentralise but in urban areas outside HMA.

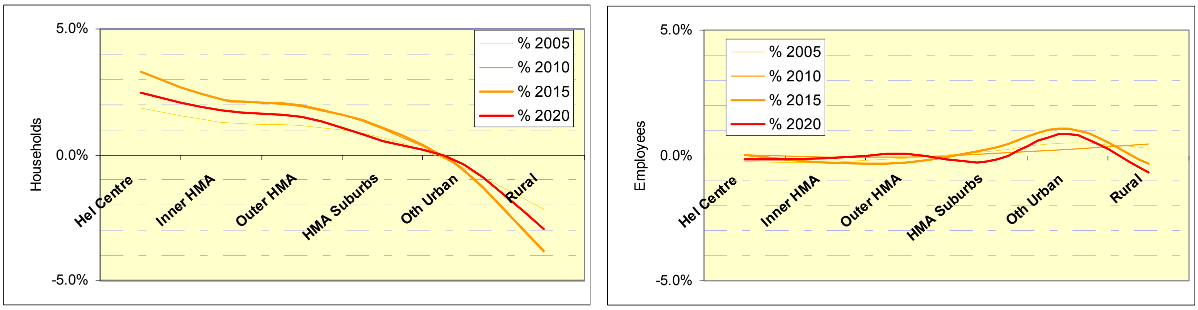


Figure 5.17: 411 H – Car operating costs +50%

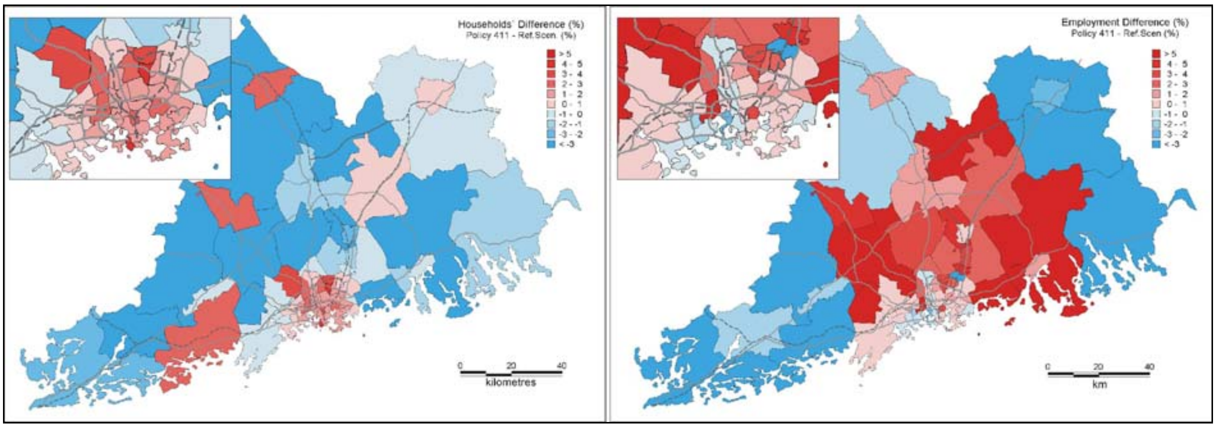


Figure 5.18 : 411 H – Car operating costs +50%, household and employment changes

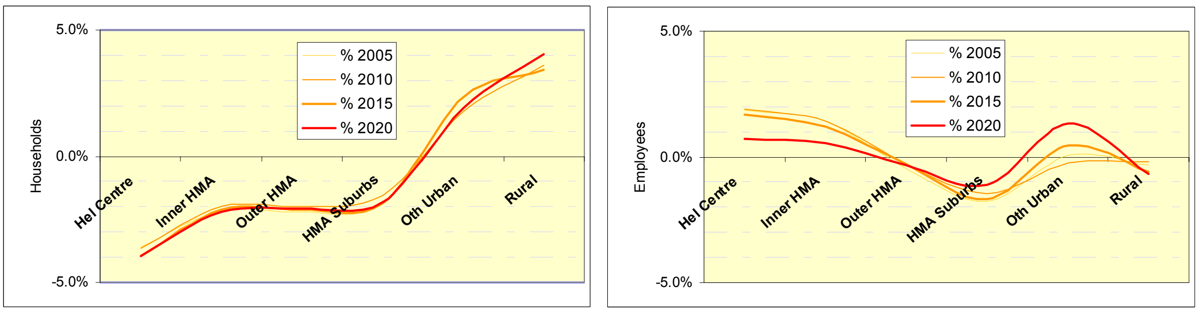


Figure5.19 : 512H – Public transport fare reduction –20%

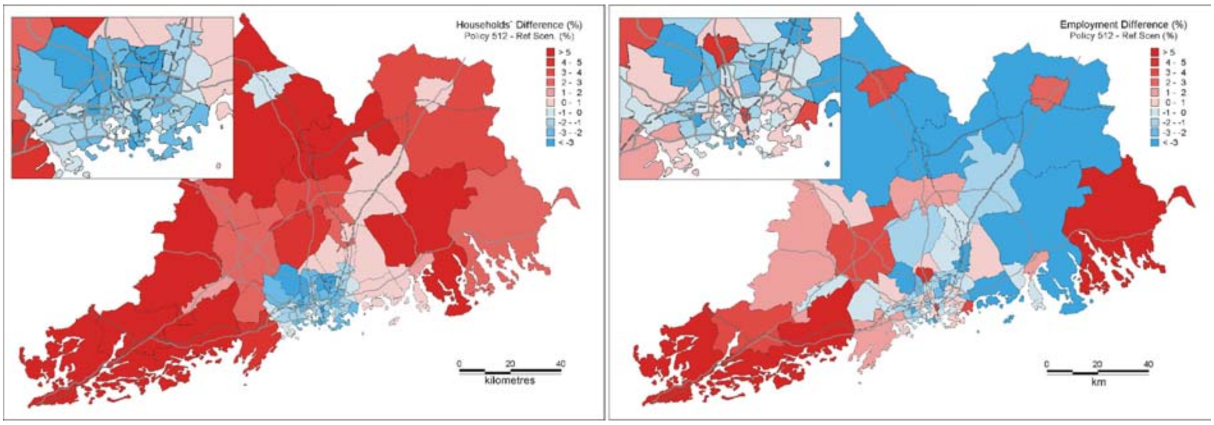


Figure 5.20: 512H – Public transport fare reduction –20%, household and employment changes

5.6.6. Policy combinations

The policy combinations consist of car operating cost increase and PT fare reduction combined with alternative land (pricing) policies.

Table 5.6: Urban sprawl variables in Combinations policies

SCATTER		Base		Combinations		
		PRESENT	Base 2021	Comb. 411+512+311	Comb. 411+512+331	Comb. 411+512+311+331
Helsinki case city		2001	000	811	812	813
Variable	**Unit**					
Overall mobility						
Average travel time (all modes)	minutes	29,8	29,2	0,8%	1,1%	-0,2%
Public transport						
Modal share of modes	%	44,1	42,3	6,1	12,3	12,2
Passenger-km by public modes	km/inhabitant/a	5232	5734	16,8%	16,9%	16,2%
Road traffic						
Private vehicle-km	km/inhabitant/a	2451	2930	-16,1%	-15,9%	-17,6%
Greenhouse gases from transport	eq.ton/inhabitant/a	1,41	1,78	-10,7%	-10,6%	-12,0%
Average road traffic speed	km/h	37,3	31,6	1,8%	1,9%	2,6%
Land use						
Households in urbanised zones	#	639565	772313	0,6%	-0,1%	0,6%
Households in core metropolitan area	#	265432	304320	0,1%	-0,5%	0,2%
Households in the city centre	#	28812	36485	-0,7%	-1,4%	-0,6%
Employees in urbanised zones	#	698209	904015	0,6%	0,5%	0,7%
Employees in core metropolitan area	#	392807	499005	0,9%	0,8%	1,2%
Employees in the city centre	#	109706	127650	2,3%	2,1%	2,5%
Accessibilities						
Average home-work travel distance	kilometres	16,2	15,0	0,5%	0,9%	-0,3%
Accessibility to city centre	minutes/trip	29,3	29,8	-2,1%	-2,3%	-2,6%
Accessibility to services	minutes/trip	27,7	28,2	0,0%	0,1%	-0,1%
Productivity gain from land use	%	0,0	0,0	0,3	0,4	0,7
	HMA	diff. in % units				

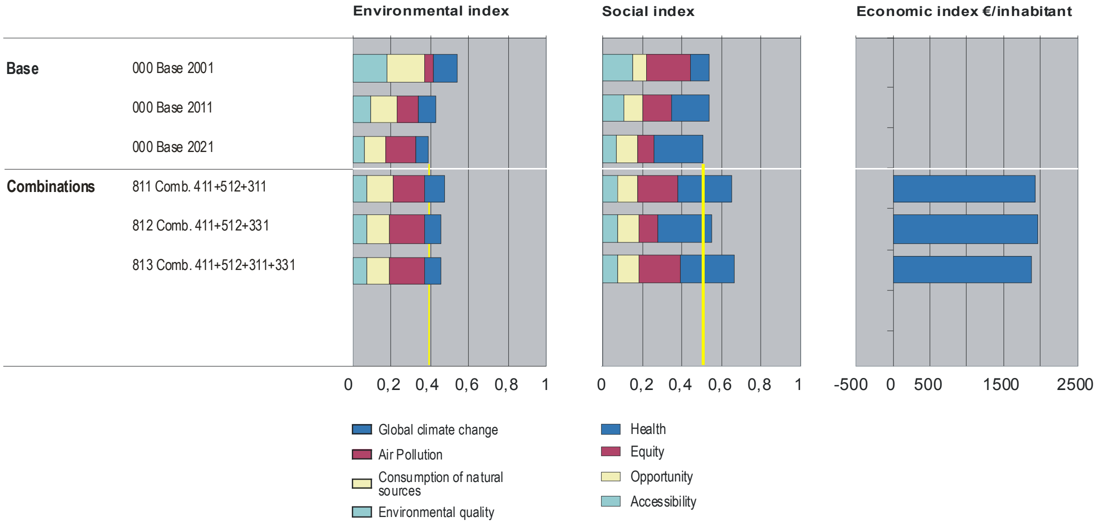


Figure 5.21: Urban sustainability indicators in Combinations policies

The combinations work efficiently against urban sprawl, car kilometres and emissions are radically reduced and also accessibilities are mainly improved. Thus the most effective way to tackle sprawl is to create policy packages that combine the best qualities of individual policy measures and even out some inevitable side-effects or problems of the used main measures. What is still particularly difficult to control are both the household and employment sprawl at the same time.

The sustainability evaluation shows that the policies are able to simultaneously improve all the dimensions of sustainability compared with the base scenario alternative. In some cases they also maintain or improve the current level of sustainability.

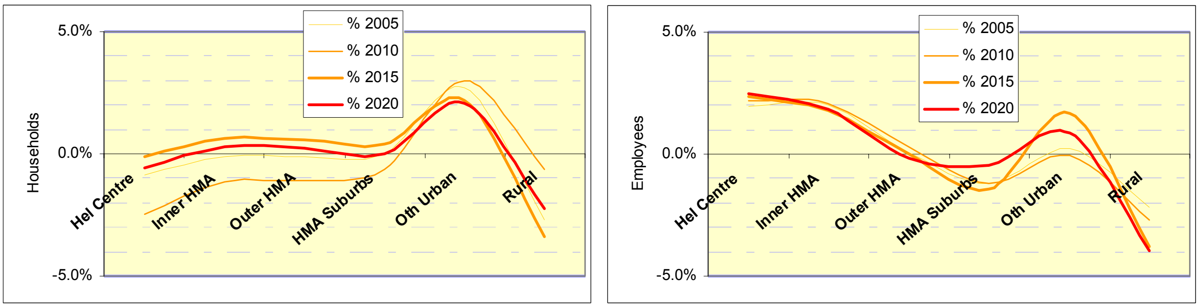


Figure 5.22: Combination policy 813 H (411 - vehicle operating costs +50%, 512 - public transport fares –20% , 311 – land use development fee and 331 – land use pricing) impacts on sprawl

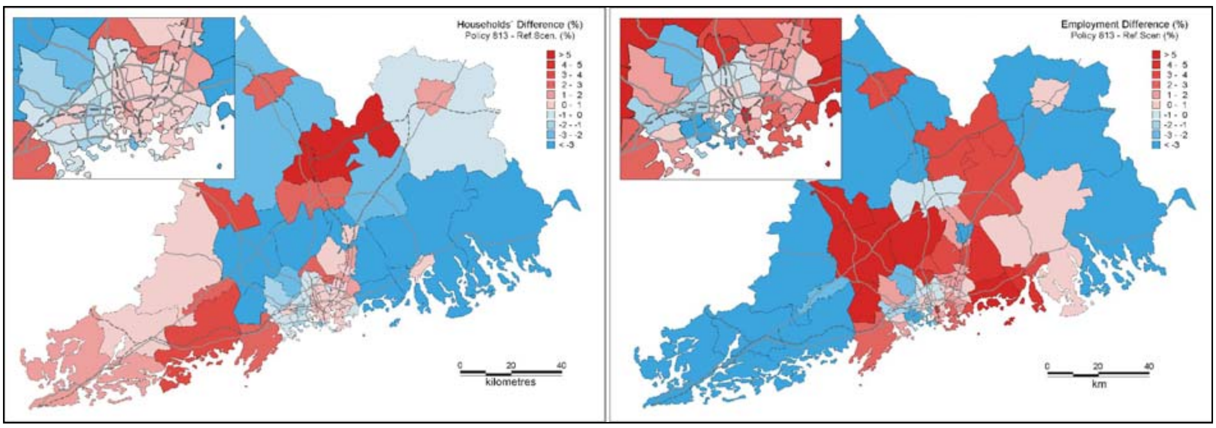


Figure 5.23: Combination policy 813 H (411 - vehicle operating costs +50%, 512 - public transport fares –20% , 311 – land use development fee and 331 – land use pricing)

5.7. General remarks about sprawl in Helsinki

As a general rule, the relation between the accessibility and sprawl is the following (according to the Helsinki modelling case study experience):

- Firms (employment) try to utilise the agglomeration benefits of the centre by locating as close to it as possible. Therefore the crowding out -effect of land use increases the value of land, which forces the households to live outside the centre by commuting in. Transport accessibility (and mobility due incomes) largely determines how far this is possible.
- Firms need to remain accessible to the employees (households) living outside. If the accessibility reduces, they need to move towards the supply of labour. Sprawl happens. If accessibility increases, employment sprawl decreases.
- The inverse is true for households. When the (especially the radial) accessibility increases the households utilise the better access by moving further out and sprawl increases. If accessibility reduces, sprawl reduces, as people need to move closer to their jobs.

This pattern is repeated in most of the policy tests with the case study model. As the analysis above shows, there are various effective policies to counteract sprawl, especially when they are combined as policy packages. Nevertheless, if Figure 5.5.4 above is compared with Figure 5.6.17, one can see that still the sprawl could not be reversed by this combined policy. Therefore it can be assumed that much policy work is required to overcome the future development of sprawl (as estimated here).

What developments or phenomena are we actually trying to reverse in the base forecast? Special base scenario analysis was also conducted with the Helsinki model to see how certain characteristics (transport prices, land use regulation and the overall congestion due growth) in the base forecast is a reason to the sprawl.

Figure 5.24 shows the effect of not increasing the transport prices in the base forecast as described above. Therefore without the expected increases in the price and taxation of both petrol and transit fares, the problem of sprawl would be even worse. Congestion affects sprawl in two ways: it reduces the accessibility over the congested areas and therefore shortens the distances but also encourages the travellers to move away from the congested part of the network. As Figure 5.25 shows the first effect seem to apply stronger to employment and the latter to households. A particular problem in the Helsinki Metropolitan Area is the (seemingly) little available land for new development near the city centre. Figure 5.26 shows the effect of relaxing the current land use regulatory constraints in the base forecast.

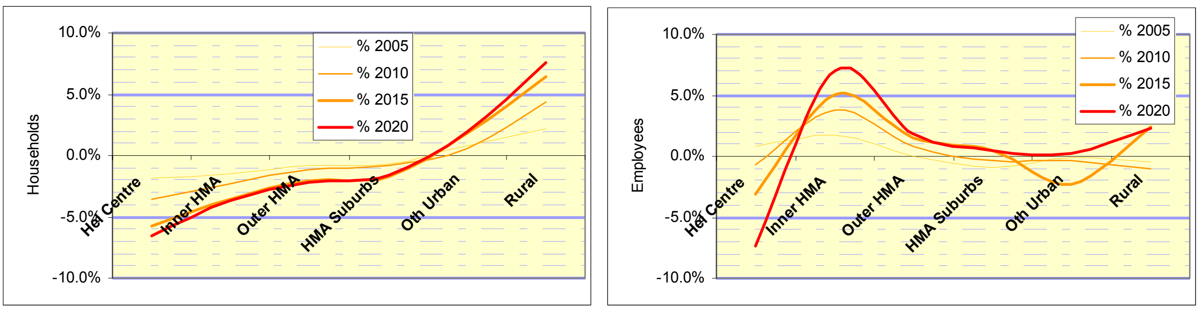


Figure 5.24: The effect of keeping the real prices of transport (petrol and fares) at the current level

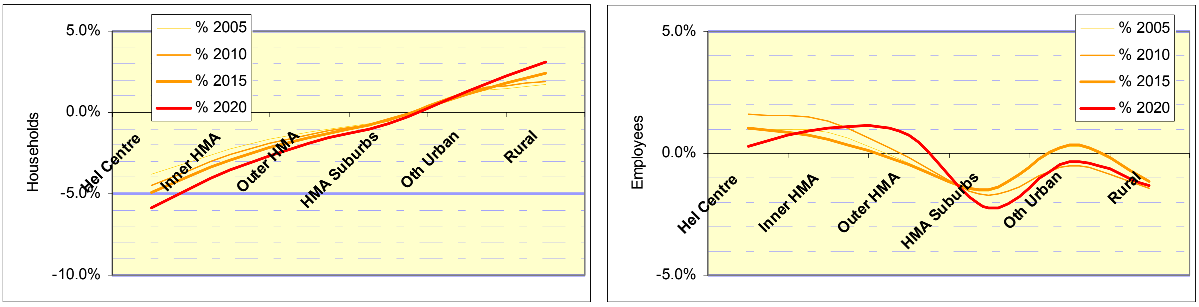


Figure 5.25: The effect of "removing" the congestion

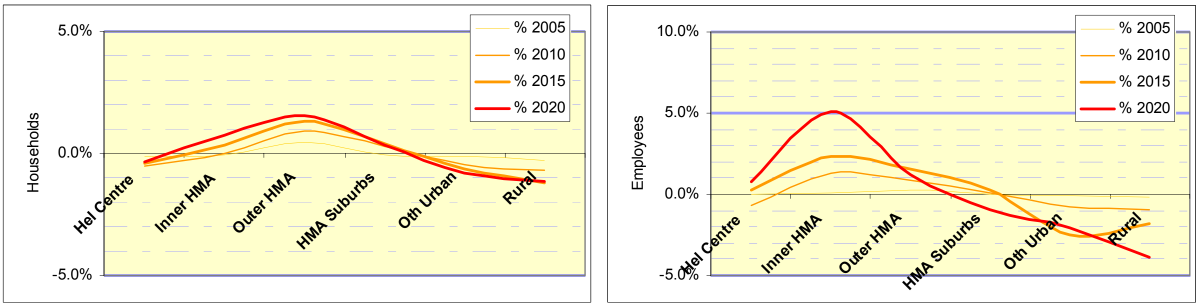


Figure 5.26: The effect of releasing the current land use regulation

Again compared with Figure 5.4 the assumptions of the policy trends in the base forecast do not explain the level of sprawl occurring in it. Figure 5.27 shows the outcome of remaining expected socio-economic trends - population and welfare growth - on the observed and estimated sprawl in the Helsinki region. It seems to indicate that sprawl is a natural outcome of population and economic growth.

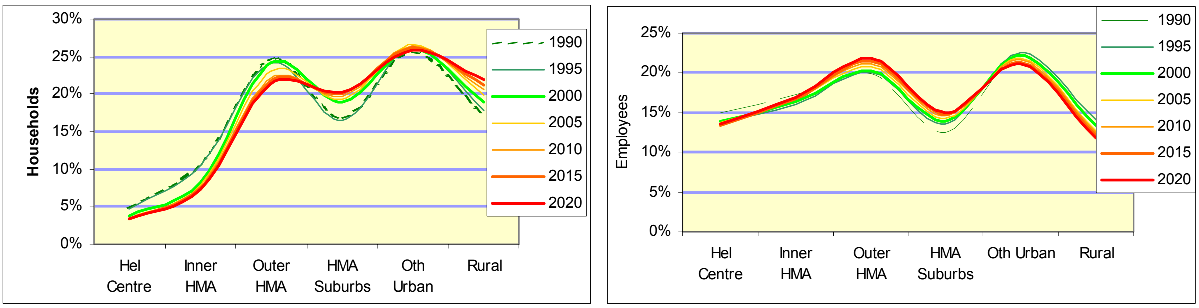


Figure 5.27: The effect of population growth and mobility increase (increase in income) on sprawl

The above analysis makes the fighting against sprawl rather onerous task in the Helsinki region:

- The overall mega-trend of population/economic growth that result in higher mobility would require strong counteractive measures decreasing accessibility (time, cost and comfort of travel) in a right way.
- Current trends and plans most probably lead to more sprawl;
- Investments (popular measures) reducing especially radial congestion increase population sprawl;

- General price increases of petrol and fares and especially more effective pricing measures that would alleviate sprawl while saving travel times are very unpopular measures;
- Regulation is difficult too and may lead to unexpected side-effects.

5.8. Summary of results at city-level

The sustainability evaluation showed that most of the tested policies reducing sprawl also improved the three dimensions of sustainability. This means that reduced sprawl also adds to sustainability. However, the PT improvements may add to city sprawl but still add to urban sustainability.

Congestion proved a significant constraint on sprawl as the lack of accessibility makes it difficult to live far away from the central areas where the jobs usually reside. Therefore the investment policies that tackle congestion especially enhancing the access from the peripheral locations may in many cases increase kilometres travelled and emissions and have city sprawl effects. However, this depends on the exact circumstances and from the sustainability point of view their effect proved small in this analysis.

The theoretical study concerning alternative locations of a “new town” in the Helsinki Metropolitan region showed that the differences between the alternatives were small even if the relocation effects were significant. The most central location had some advantages but also added to city sprawl due to very good traffic connections.

The land use policies had some positive effects on the city sprawl variables but from the sustainability point of view the differences compared with the base scenario were small. Land use pricing was particularly effective. The sprawl patterns indicated that various regulatory actions (both land-use and transport) like could also be efficient constraints on sprawl due to their pure nature of directly affecting the development of the region.

The most effective policies to tackle urban sprawl were the car pricing policies. They also clearly added to urban sustainability. Out of the pricing policies the cordon peak pricing alternative was the most effective one but had at he same time some negative land use impacts. Reducing PT fares also worked well from the sustainability point of view but had, as a negative side effect, the consequence of adding to sprawl. When combining the car pricing and the PT fare reduction policies this side effect could be mitigated.

Overall the best policies were the combinations of car pricing, PT fare reduction and land use policies. They had positive impacts on most of the city sprawl variables and improved simultaneously all dimensions of sustainability. They were economically very efficient, could socially improve the current situation and environmentally improve the situation of the reference scenario. The results included:

- 14-18% car-km reduction
- 11-12% reduction in CO_2 emissions
- 12-14% accident reduction
- 1900€/inhabitant economic benefits (net present value)
- less exposure to noise and pollutants
- improved accessibilities
- less sprawl.

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6. THE STUTTGART CASE CITY

6.1. Description of the Stuttgart case city

The Stuttgart Region and the case city of Stuttgart is situated in the south-west of Germany and covers five state districts (Kreise) called Boeblingen, Esslingen, Goeppingen, Ludwigsburg and Rems-Murr, and the City of Stuttgart with a total of 179 (Gemeinden) communities (Figure 6.1 and Figure 6.2). The overall population of the Stuttgart Region is about 2.6 million inhabitants. Together with its state capital, the City of Stuttgart, it represents the economic and cultural centre of the state of Baden-Wuerttemberg. With an area of 3,700 km^2 this region is one of the most densely populated regions of Germany.

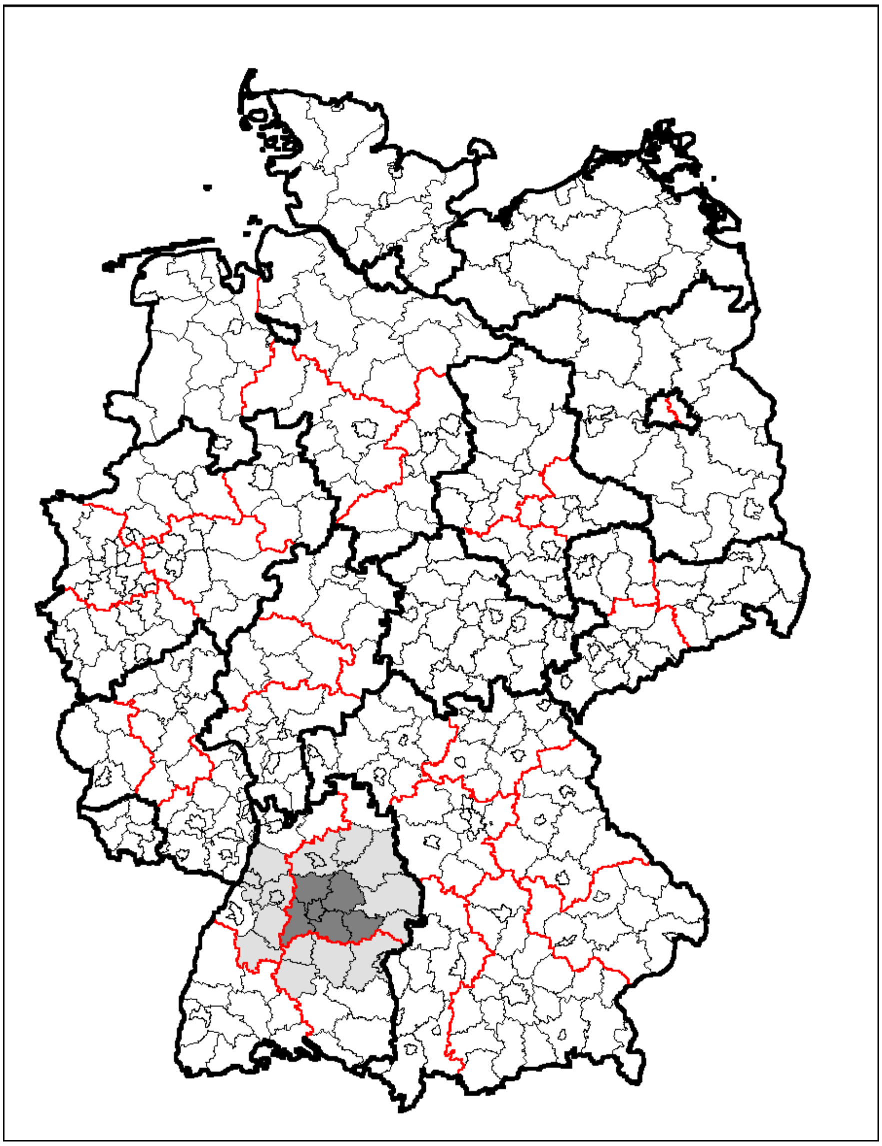

Figure 6.1 The location of the Stuttgart Region and the Case City of Stuttgart within Germany

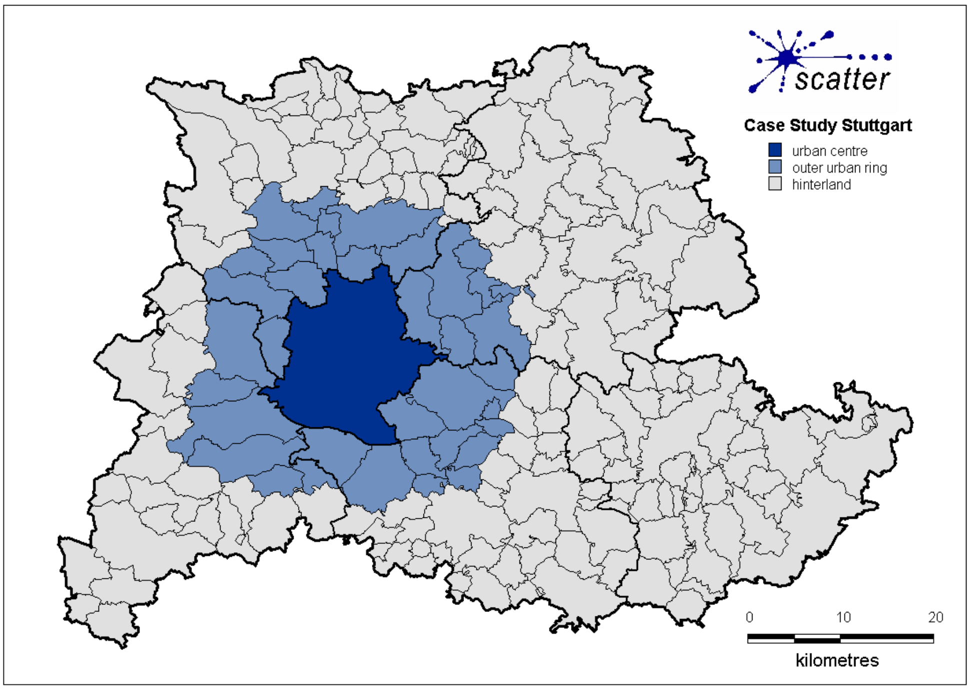

Figure 6. 2 Urban definition of case study Stuttgart

The urban development is almost uniformly spread over the whole area. This is reflected in the location of many medium size and big municipalities (sub-centres) organised almost uniformly around the City of Stuttgart (see Figure 6.3).

Figure 6.3 Map of the Stuttgart Region (120 km x 80 km)

There are about 589,000 inhabitants concentrated in the City of Stuttgart. This corresponds to 22% of the total population of the Stuttgart Region. Taking into account the adjacent communities (Sindelfingen, Boeblingen, Esslingen, Leonberg, Leinfelden-Echterdingen, Ludwigsburg, Schorndorf) within a small circle (15 Km) around the centre of the City of Stuttgart about 38% of the total population can be found. Both the City of Stuttgart and its neighbouring communities are densely populated.

6.2. The Stuttgart land use/transport model: the STASA modelling framework

The commuter flows are modelled via the master equation framework. In order to analyse both inter- and intra-regional flows the STASA-transport/land-use model (Weidlich/Haag 1988; BMBVW 1999; Weidlich/Haag 2000; Haag 2001, Binder, Haag, Rabino 2003) had to be modified. In the following, a rather short description of the general modelling framework is presented. Especially the differences with other “integrated approaches” should become obvious.

Investments into the transport sector and communication networks improve the accessibility and attractiveness of suburban areas. This may lead to a redistribution of migration flows and traffic flows and is discussed as one possible reason for urban sprawl. The quantitative treatment of those nested processes of the different subsystems (transport-, population-, communication-subsystem) and its interactions require an integrated modelling.

On the one hand the dynamics on the macrolevel - i.e. the development of the traffic subsystem and of the urban/regional subsystem - is determined by the behaviour of the individuals on the micro-level. On the other hand “attractivity” differences between the spatial units (traffic cells), which depend on the macro-variables, influence the decisions of the individuals as well. Apart from rational motives of the actors several elements of uncertainty, e.g. irrational behaviour as a result of insufficient information, have to be taken into account. Hence, the description of decision processes is based on a stochastical and dynamical decision model within the master equation approach.

The traffic subsystem as well as the urban/regional subsystem form a complex intertwined system. Its dynamics take place on different time scales but are modelled making use of the same principles:

a) The daily flows of traffic in the region of Stuttgart are the result of very quick decision processes of the actors to realize a trip between two traffic cells (origin - destination) with a special purpose. Decision processes for a certain destination, the moment of the setting out, the mode of transportation, the choice of the route etc. take place on a very short time scale.
b) The development of the urban/regional subsystem (e.g. spatial population distribution) is a process on a long-term time scale. The population distribution changes because of migration acts of individuals. The equations of motion which describe the migratory behaviour contain transition rates, i.e. migration flows between the cells. These flows depend on accessibility measures (coupling to the transport subsystem) and “attractivity” differences as a result of different regional advantages.

The total number of in- and out-commuters of communities has increased steadily in Germany for the last twenty years. In particular, this trend appears for far distance commuting but nevertheless the willingness to commute diminishes sharply at a time distances larger than approximately 45 minutes (Johansson et al 2001). Commuting offers the possibility to choose a new home by retaining the workplace and vice versa. This is often combined with the acquisition of real estate or the improvement of working conditions by retention of the place of work without simultaneously losing the advantages of an existing residence (Steierwald/Kühne 1993).

The organisation of the traffic network is of crucial importance for commuting, and thus for urban sprawl, because the decision to commute depends among others on accessibility measures. Commuter flows represent an essential part of traffic flows in the rush hours. Considering this, it is obvious that changes in the socio-economic environment and investments in the traffic infrastructure has an impact on the number of commuter and distance of commuter flows, with feedback effects to the housing market.

The imbalance between labour demand and labour supply on the level of communities is partially compensated by the commuter dynamics. The development of regional employment, the regional gross wage payment and parts of the community revenues are strongly dependent on the spatial distribution of commuter flows (Binder/Haag/Koller 2001).

Changes in the location of population and workplaces can be classified as a slow adjustment process. This means that commuting patterns should be expected to adjust itself to new conditions on a much faster time scale than household location pattern. Moreover econometric studies indicate that the location of firms adjusts faster than the location of households, and that workplaces tend to follow households (Mills/Carlino 1989, Holmberg et. al.2001, Oppenheim 1995, Schnabel/Lohse 1997, Johansson 2001).

The "empirical data base" consits of traffic flows (all modes) between the traffic cells, as well as population numbers and migration flows on a yearly base between all cells, and data on the traffic network.

These data base is used to estimate the system parameters of the transport and urban/regional subsystems, e.g. "transport attractivities" and "distance" (or resistance) parameters for the transport subsystem and "regional attractivities" for the urban/regional subsystem. In a further step these "attractivities" have been connected with appropriate macro-variables (key-variables) making use of a multiple regression.

The calibrated integrated model was applied to the region of Stuttgart (Haag/Binder 2001).

6.3. The design of the Stuttgart land use/transport model

The population distribution is denoted by $\vec{n} = \{n_1, ..., n_i, ..., n_L\}$, where n_i is the number of individuals (households, persons) living in community *i*. n_i will be modified by the decisions of the people to commute between community *i* and any one of the other communities. Therefore, the population distribution $\vec{n}$ is connected via commuter related activities or migration events with individual decision processes.

Let $P(\vec{n}, t)$ be the configuration probability to find a certain population distribution $\vec{n}$ at time *t*, taking into account the complicated interactions of those agents. Of course this probability $P(\vec{n}, t)$ must satisfy the normalisation condition

$$\sum_{\vec{n}} P(\vec{n}, t) = 1 \tag{1}$$

where the sum extends over all possible population configurations $\vec{n}$.

The temporal evolution of the probability distribution $P(\vec{n}, t)$ can be described by the master equation (Weidlich/Haag 1983; Haag 1989)

$$\frac{d}{dt} P(\vec{n}, t) = \sum_{\vec{k}} F_t(\vec{n}, \vec{n} + \vec{k}) P(\vec{n} + \vec{k}, t) - \sum_{\vec{k}} F_t(\vec{n} + \vec{k}, \vec{n}) P(\vec{n}, t) \tag{2}$$

where the sum on the right hand side extends over all $\vec{k}$ with non vanishing configurational transition rates $F_t(\vec{n} + \vec{k}, \vec{n})$ and $F_t(\vec{n}, \vec{n} + \vec{k})$. Hereby the transition rate $F_t(\vec{n} + \vec{k}, \vec{n})$ (transition probability per unit of time) specifies the transition from any population distribution $\vec{n}$ to a neighbouring distribution $\vec{n} + \vec{k}$.

The master equation (2) has a very direct and intuitively appealing interpretation. The change in time of the configuration probability $\frac{dP(\vec{n},t)}{dt}$ is due to two effects of opposite direction: first to the probability flux from all neighbouring configurations $\vec{n}+\vec{k}$ into the considered configuration $\vec{n}$ namely $\sum_{\vec{k}} F_t(\vec{n},\vec{n}+\vec{k})\,P(\vec{n}+\vec{k},t)$ and second to the probability flux out of the configuration $\vec{n}$ into all neighbouring configurations $\vec{n}+\vec{k}$, namely $\sum_{\vec{k}} F_t(\vec{n}+\vec{k},\vec{n})\,P(\vec{n},t)$. Consequently, the master equation represents a balance equation for probability fluxes. The transition rates in the master equation are directly associated with the evolution of the conditional probability.

The transition rate $F_t(\vec{n}+\vec{k},\vec{n})$ from the population distribution $\vec{n}$ to the neighbouring distribution $\vec{n}+\vec{k}$ is the sum of all the contributions $F_{ij}^{\alpha}(\vec{n}+\vec{k},\vec{n})$:

$$F_t(\vec{n}+\vec{k},\vec{n}) = \sum_{\alpha=1}^{A}\sum_{i,j=1}^{L} F_{ij}^{\alpha}(\vec{n}+\vec{k},\vec{n}) \qquad (3)$$

where $F_{ij}^{\alpha}(\vec{n}+\vec{k},\vec{n})$ indicates the number of commuter trips[1] (transitions) between the communities $i \to j$ for a member of subpopulation α. The explicit dependence of the individual terms on $\vec{n}$ indicate that all contributions related to a change of the population distribution $\vec{n} \to \vec{n}+\vec{k}$ have been summed up. In this way a summation of all such terms yields the total transition rate.

In the next step the transition rates have to be specified for the decision process to commute (Fischer et. al. 1988, Weidlich/Haag 1988). If $n_i(t)$ persons are at time *t* in community *i*, the “probability to commute” to another community will be proportional $n_i(t)$. In this way the number of trips between *i* and *j* is given by

$$F_{ij}^{\alpha}(\vec{n}+\vec{k},\vec{n}) = n_i(t)\cdot p_{ij}^{\alpha}(\vec{x};t)\,, \qquad (4)$$

where $p_{ij}^{\alpha}(\vec{n},\vec{x})$ is the individual transition rate from *i* to *j* for a member of the subpopulation α, $\vec{k} = \{0,...,\ 1_j,...,\ 0,...,\ (-1)_i,...,\ 0,...\}$ and $F_{ij}^{\alpha}(\vec{n}+\vec{k},\vec{n}) = 0$ for all other $\vec{k}$. Of course, this transition rate depends among others on the explicit spatial distribution of the population $\vec{n}$ and specific characteristics $\vec{x}$ of the communities, e.g. labour demand, labour supply, housing market, accessibility measures, specific location factors, services available for companies and households as well as leisure facilities (Domencich/McFadden 1975, Pumain/Saint-Julien 1989).

It has been tested, that mainly three sets of indicators are of importance for the transition rate to commute $p_{ij}^{\alpha}(\vec{x};t)$:

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[1] If panel data are available on the commuter-decision behaviour of the different agents of the system (micro-level), the configurational transition rates can directly be calculated via $F_{ij}(\vec{n}+\vec{k},\vec{n}) = \sum_{l\in\Gamma_i} p_{ij}^{(l)}(\vec{n},\vec{\kappa}_l)$, where one has to sum up over all individual trips of all commuter from community *i* to community *j*. This procedure is however very extensive, because of the required immense data base (Courgeau 1985).

- attractiveness indicators $u_i^\alpha(\vec{x};t)$ of the particular community *i* for the subpopulation α, which depend across-the-board on the distribution of labour demand and supply of the communes. It is commonly known that individuals (commuters) compare the attractiveness of the communities with respect to certain characteristics such as working and housing conditions. The probability not to work at the place of home *i* instead to work in community *j* (place of work) increases with increasing differences $(u_j^\alpha(\vec{x};t) - u_i^\alpha(\vec{x};t)) > 0$ of attractiveness (Fechner 1877; Weber 1909; Fazio/Zanna 1981). Without any loss of generality the attractiveness can be scaled

  $$\sum_{i=1}^{L} u_i(\vec{x};t) = 0 \cdot$$

- resistance function $g_{ij}^\alpha(t_{ij}, v_i^\alpha; t)$, representing the spatial interrelation (accessibility) of communities, depending on travel time t_{ij}, as well as regional shadow-costs $v_i^\alpha(\vec{x};t)$. The resistance function is modelled via

$$g^\alpha(t_{ij}, v_i^\alpha; t) = \exp\left(\frac{-\beta^\alpha(t)\ t_{ij}}{1+\gamma^\alpha(t)\ t_{ij}} - v_i^\alpha(\vec{x};t) \right) \tag{5}$$

  with deterrence parameters $\beta^\alpha, \gamma^\alpha$ and shadow-costs $v_i^\alpha(\vec{x};t)$. The shadow-costs $v_i^\alpha(\vec{x};t)$ take into account the heterogeneity of the communities. Shadow costs act as barriers and reduce the attractiveness of a region for commuters. By definition, the shadow-costs have to fulfil the constraint

$$\sum_{i=1}^{L} v_i(\vec{x};t) = 0 \,. \tag{6}$$

- a time-dependent scaling parameter $\varepsilon^\alpha(t)$ which correlates with the global mobility to commute.

This leads to the following commuter trip model (trip distribution):

$$\begin{aligned} F_{ij}^\alpha(\vec{n},\vec{x};t) &= n_i(t) p_{ij}^\alpha(\vec{x},t) \\ &= n_i(t) \cdot \varepsilon^\alpha(t) \cdot g_{ij}^\alpha(t_{ij}, v_i^\alpha; t) \cdot \exp(u_j^\alpha(\vec{x};t) - u_i^\alpha(\vec{x};t)) \end{aligned} \tag{7}$$

where $F_{ij}^\alpha(\vec{n},\vec{x};t)$ indicates the number of commuter trips (transitions) between the communities $i \to j$ for a member of subpopulation α.

The probability distribution $P(\vec{n},t)$ contains a huge amount of information compared with the empirical information (data base). Therefore, a less comprehensive description in terms of mean values is adequate. The mean population number in community *i* at time *t* defined as

$$\bar{n}_i(t) = \sum_{\vec{n}} n_i\ P(\vec{n},t) \,. \tag{8}$$

It is possible to derive equations of motion for the mean values directly from the master equation. For this purpose the master equation is multiplied by $\vec{n}$ from the left and summed up via all states $\vec{n}$. However, the resulting equations are not yet self-contained, since the determination of the right hand side (rhs) requires the knowledge of the probability distribution $P(\vec{n},t)$. However, if one assumes that the probability distribution is a well behaved, sharply peaked uni-modal distribution quasi-closed approximate mean value equations can be derived:

$$\begin{aligned}\frac{d\overline{n}_i(t)}{dt} &= \sum_{\alpha=1}^{A}\sum_{j=1}^{L} F_{ji}^{\alpha}(\vec{n},\vec{x};t) - \sum_{\alpha=1}^{A}\sum_{j=1}^{L} F_{ij}^{\alpha}(\vec{n},\vec{x};t) \\ &= \sum_{\alpha=1}^{A}\sum_{j=1}^{L} \overline{n}_j(t)\, p_{ji}^{\alpha}(\vec{n},\vec{x};t) - \sum_{\alpha=1}^{A}\sum_{j=1}^{L} \overline{n}_i(t)\, p_{ij}^{\alpha}(\vec{n},\vec{x};t) \\ &= E_i^W(t) - E_i^H(t) = NC_i\,(t)\end{aligned} \tag{9}$$

Therefore the master equation provides the link between decisions to commute on the micro-level and the commuter flows on the macro-level. The dynamics of the mean population number $\overline{n}_i(t)$ of community *i* can be calculated on the basis of the commuter flows $F_{ij}^{\alpha}(\vec{n},\vec{x};t)$ and $F_{ji}^{\alpha}(\vec{n},\vec{x};t)$ between the different communities *i* and *j*. The first sum on the rhs of (13) equals the employees at the place of home $E_i^H(t)$, the second sum equals the employees at the place of work $E_i^W(t)$. Therefore the dynamics of the population redistribution on the macro-level depends on the development of the net commuters $NC_i\,(t)$.

Long-term effects, e.g. structural development effects have to be considered as well. It is reasonable to assume that the attractiveness $u_i^{\alpha}(\vec{x},t)$ and shadow-costs $v_i^{\alpha}(\vec{x};t)$ of a community depend on a set of socio-economic variables $\vec{x}$ (among other things also on the population distribution $n_i(t)$). Therefore, the impact of commuting on the population redistribution is of importance (Figure 6.4). Depending on the initial conditions, such as the distribution of population at a given time and the further system parameters, the non-linear dynamics lead to self-organised commuter flow pattern (Nijkamp/Reggiani 1992; Goodwin 1994).

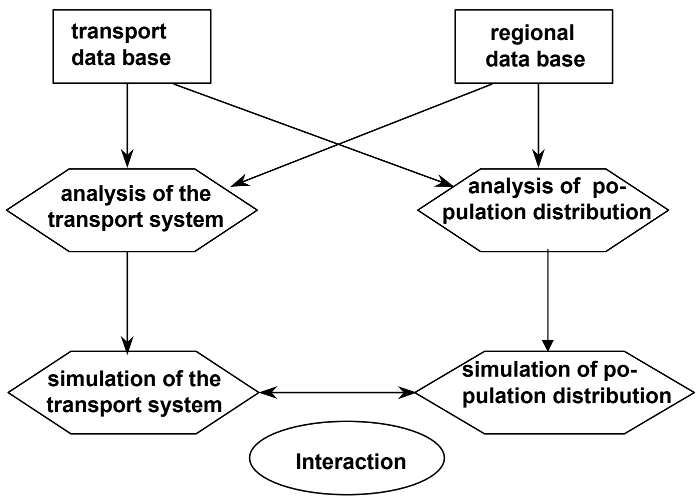

Figure 6.4 Principle structure of the nested transport and urban model

6.4. Calibration of the Stuttgart model

The system parameters (11), such as mobility $\varepsilon^{\alpha}(t)$, attractiveness $u_i^{\alpha}(\vec{x},t)$, shadow-costs $v_i^{\alpha}(\vec{x};t)$ and the resistance function parameters $\beta^{\alpha}(t)$ and $\gamma^{\alpha}(t)$ can directly be linked to the empirical (statistical registered) commuter flow matrices $F_{ij}^{\alpha\ emp}(t)$ (index *emp*), and the population numbers $n_i^{emp}(t)$, respectively. The minimisation of the functional (entropy-estimation)[2] (Wilson 1970, 1981)

$$\begin{aligned} G(u_i, v_i, \varepsilon, \beta^{\alpha}, \gamma^{\alpha}; t) &= MIN\left(\sum_{\alpha=1}^{A} \sum_{i,j=1}^{L} F_{ij}^{\alpha\ emp}(t) \cdot \ln\left(\frac{F_{ij}^{\alpha\ emp}(t)}{F_{ij}^{\alpha}(t)} \right) \right) \\ &\approx MIN\left(\sum_{\alpha=1}^{A} \sum_{i,j=1}^{L} \left(\frac{F_{ij}^{\alpha\ emp}(t) - F_{ij}^{\alpha}(t)}{F_{ij}^{\alpha}(t)} \right)^2 \right) \end{aligned} \tag{10}$$

with the constraint

$$\sum_{\alpha=1}^{A} \sum_{i,j=1}^{L} F_{ij}^{\alpha\ emp}(t) = \sum_{\alpha=1}^{A} \sum_{i,j=1}^{L} F_{ij}^{\alpha}(t) \tag{11}$$

enables one to calculate an optimal set of system parameters ($u_i^{\alpha}(\vec{x},t)$, $v_i^{\alpha}(\vec{x};t)$, $\varepsilon^{\alpha}(t)$, $\beta^{\alpha}(t)$, $\gamma^{\alpha}(t)$).

In a second step, the estimated attractiveness and shadow-costs are linked to particular location factors (key-factors) $x_i^n, n = 1,\ldots$ gained from two different fields: from a class of the so-called synergy variables, describing general group effects (positive and negative network externalities), and from a sequence of potential explanatory indicators, e.g. number of available jobs, the number of vacant dwellings, regional income per capita, shop distribution and other local infrastructure depending factors. The set of explanatory variables and its corresponding elasticity's are determined via a multiple regression analysis:

$$u_i^{\alpha}(\vec{n},\vec{x}) = \sum_n a_n^{\alpha} x_i^n \qquad\qquad v_i^{\alpha}(\vec{n},\vec{x}) = \sum_n b_n^{\alpha} x_i^n \tag{12}$$

The elasticity's a_n^{α}, b_n^{α} assigned to the socio-economic variables x_i^n are dimensionless numbers and indicate the influence of the independent variables on the dependent variable. The selection of relevant indicators is performed using appropriate statistical characteristics (T-values, other significance tests).

The results of the regression for the attractiveness (shadow costs) explains about 83% (75%) of the data variation (Haag, Binder 2001b). Because commuting describes trips from home to work and vice versa, the explaining variables are related to the following :

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[2] Using test series it was determined that the least-square-estimation represent the single flows $F_{ij}(t)$ much better then the entropy procedure estimation. On the other hand, the specific entropy-estimation takes into account that the origin and destination flows of each community are equal to the employees at the place of home (empirical origin flows) and employee at the place of work (empirical destination flows). This property of the entropy procedure can also be derived analytically by geometric programming (Kádas, Klafszky 1967).

- Labour market (distribution of work places, wages,…)
- Housing market (distribution of apartments, dwellings, houses, price of land, rent level,…)
- Accessibility (travel time, travel costs, parking possibilities,…)
- Other specific indicators (availability of different services, neighbourhood, environment, recreation possibilities,…)

6.5. Definition of the simulated scenarios

The following table details the simulated measures aiming to reduce the negative impacts of urban sprawl in the Stuttgart case city. Of course, some of those applied scenarios are currently not realizable and are more of pure scientific interest.

Table 6.1: Measures simulated in the Stuttgart case city

Policy code	Description of the policy
	Stuttgart
0	***Reference scenarios***
001, 002, 003	Different reference scenarios : • **001S** = without motorway A81, without S1 extension, without road tunnel Kappelberg • **002S** = with motorway A81, with S1 extension, without road tunnel Kappelberg • **003S** = with motorway A81, with S1 extension, with road tunnel Kappelberg The reference scenarios (001S) are used for all policy codes 111S – 114S, reference scenario (002S) is used for policy code 115S, all other policy codes refer to the reference scenario (003S). The time horizons are: horizon (001S): 1995 horizon (002S): 2015 horizon (003S): 2020
1	**Transport infrastructures / services : radial infrastructures decreasing travel times between centre and periphery**
11	**Implementation of a radial transport infrastructure linking centre and periphery : rail infrastructure, motorway, buses, HOV**
111 ***Common policy***	**111S**: Extension of the light rail (S-Bahn) S1 (parallel to the corridor of the motorway A81) without motorway (length 16 km) This is tested on the 001S reference scenario, to which also the following measures (policy codes 112S, 113S, 114S) in the Stuttgart case city are compared.
112 ***Local policy***	**112S:** Completion of the missing link of the motorway A81 in 1978 (length 23.9 km) , without S1 (light rail) parallel to the corridor of the A81
113 ***Local policy***	**113S**: Completion of the missing link of the motorway A81 in 1978 (length 23.9 km), and extension of the S1 (light rail) parallel to the corridor of the A81 in 1992 (length 16 km)
114 ***Local policy***	**114S**: Completion of the missing link of the motorway A81 in 1978 (length 23.9 km), and extension of the S1 (light rail) parallel to the corridor of the A81 in 1992 (length 16 km), with park&ride facilities (6 park&ride facilities, 7.500 new Parking spaces (about 19%))
115 ***Local policy***	**115S**: 114S and building of a new road tunnel (tunnel Kappelberg) of the Bundesstrasse B29 in east-direction (Schwäbisch Gmünd)
12	**Implementation of a transport infrastructure with radial and tangential components (the latter one thus provides improved services for trips from periphery to periphery)**
121 ***Common policy***	
2	**External factor: relocation of work places**
211 ***Local policy***	**211S**: Relocation of 10.000 workplaces from Esslingen and Stuttgart-Untertürkheim to Sindelfingen (due to a shift of a production plant of DaimlerChrysler) tested on reference 003S
3	**Land use measures having an influence on urban sprawl**
31	**Fiscal measures applied to residential developments**

Policy code	Description of the policy
	Stuttgart
311 ***Common policy***	**311S** : • annual tax (development impact fee) applied on households locating in non-urban zones (about 670€ / household / year) and redistribution of the revenue of impact fee to the urban areas, as fiscal incentive to all households located in urban zones (Stuttgart, Ludwigsburg, Sindelfingen, Böblingen, Esslingen and Göppingen) tested on reference 003S
32	**Regulatory measures applied to offices, inspired form the ABC theory**
321 ***Common policy***	**321S** : ABC-type policy applied to a part of the tertiary sector: • obligation (regulatory measure) for all jobs of the employment sector “business services”, to locate in A-type zone • an A zone is a zone of the capital of a district (NUTS3). In general those zones are also served by high quality public transport at regional scale. In these scenario, there are 7 A-zones in the Stuttgart Region tested on reference 003S
33	**Fiscal measures applied to offices, inspired form the ABC theory**
331 ***Common policy***	**331S:** ABC-type policy applied to a part of the tertiary sector: • tax on new jobs of the employment sector “business services” locating in non-A-type zone; the tax amounts to 976 €/job • an A zone is a zone of the capital of a district (NUTS3). In general those zones are also served by high quality public transport at regional scale. In these scenario, there are 7 A-zones in the Stuttgart Region tested on reference 003S
4	**Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car**
41	**Increase of car use cost**
411 ***Common policy***	**411S**: increase by 50 % of the cost per km for all drivers tested on reference 003S
412 ***Common policy***	**412S:** cordon pricing (the cordon is located just inside the city of Stuttgart and the adjacent communes Ludwigsburg, Sindelfingen, Böblingen and Esslingen); tariff: 2,1 €/day applied to all drivers tested on reference 003S
5	**Measures aiming at a modal shift towards public transport by decreasing travel costs or times by public transport, or by providing P&R facilities**
51	**Change in the fare of public transport**
512 ***Common policy***	**512S**: decrease of fare by 20%, applied to all public transport users tested on reference 003S
52	**Park&ride facilities**
521 ***Local policy***	**521S:** Park and ride facilities see scenario 114S tested on reference scenario 113S

Policy code	Description of the policy
	Stuttgart
8	**Combinations of selected measures**
811 ***Common policy***	Combination **811S** = 411 + 512 + 311 ▪ increase by 50% of the private car cost/km applied to all drivers ▪ decrease of PT fare by 20%, applied to all public transport users ▪ fiscal measure on residential developments: see scenario 311 tested on reference 003S
812 ***Common policy***	Combination **812S** = 411 + 512 + 331 ▪ increase by 50% of the private car cost/km applied to all drivers ▪ decrease of PT fare by 20% for home-work trips ▪ ABC-type policy applied to a part of the tertiary sector: see scenario 331 tested on reference 003S
813 ***Common policy***	Combination **813S** = 411 + 512 + 311 + 331: ▪ increase by 50% of the private car cost/km applied to all drivers ▪ decrease of PT fare by 20% for home-work trips ▪ fiscal measure on residential developments: see scenario 311 ▪ ABC-type policy applied to a part of the tertiary sector: see scenario 331 tested on reference 003S

6.6. Simulation results in the Stuttgart case city

6.6.1. The reference scenarios

In the following a short description of the meaning of the different reference scenarios is given.

- ***Reference scenario 001S (1995)***

The reference scenario 001S includes the demographic and socio-economic development of the Stuttgart region between 1978 and 1995.

The industrial and financial power of the Stuttgart region and the overall socioeconomic development of Baden-Württemberg focused the increase of population of the region by 0,5 % per year and of employment of about 0,5 % per year during this time period. The population of the city Stuttgart declined by about -0,1 % per year and the employment by -0,2 % per year in this period.

- ***Reference scenario 002S (horizon 2015)***

The reference scenario 002S includes the demographic and socio-economic development of the considered corridor Stuttgart – Herrenberg and the overall trends of the rest of the Stuttgart region to the horizon year 2015, as well as the following:

- The completion of the missing section between 1968 and 1978 of the motorway A81 Stuttgart – Singen – Switzerland favoured radial transport from the City of Stuttgart towards more rural areas. Between Stuttgart and the exit Herrenberg on 23,9 km there are 7 exits and 2 motorway crossings. The operation of the motorway started in 1978.
- The completion of the light rail system (S-Bahn) that runs parallel to this motorway with a length of 16 km from Boeblingen to Herrenberg. The construction phase started in 1985, the operation of the S-Bahn began in 1992 (6 stations)

In addition to the overall positive development in the Stuttgart region, the opening of the motorway A81 in 1995 accelerated the socioeconomic development in the south-western parts of the Stuttgart region considerably. There was an increase of population of the region by 0,3 % per year and of employment of about 0,2 % per year during 1995 and 2015

- ***Reference scenario 003S (horizon 2020)***

The reference scenario 003S includes the demographic and socio-economic development of the considered corridor Stuttgart – Herrenberg and the overall trends of the rest of the Stuttgart region to the horizon year 2020, as well as the following:

- completion of the motorway A81 Stuttgart – Singen – Switzerland
- extension of the S-Bahn S1
- road tunnel Kappelberg

It is assumed, in addition to the overall positive development in the Stuttgart region, an increase of population of the region by 0,3 % per year and of employment of about 0,1 % per year during 2000 and 2020.

6.6.2. The tested measures

The simulated policies and measures for the Stuttgart case city are described below.

- ***Scenario 111S – 114S:***

Implementation of radial transport infrastructure

In this scenario the interactions between the settlement development and the (modal and intermodal) transport system are investigated and evaluated (Figure 6.5). The case study covers the Stuttgart - Singen corridor, characterised by the implementation of different policies and measures such as:

- **111S**: Extension of the light rail (S-Bahn) S1 (parallel to the corridor of the motorway A81) without motorway (length 16 km)
- **112S:** Completion of the missing link of the motorway A81 in 1978 (length 23.9 km) , without S1 (light rail) parallel to the corridor of the A81
- **113S**: Completion of the missing link of the motorway A81 in 1978 (length 23.9 km), and extension of the S1 (light rail) parallel to the corridor of the A81 in 1992 (length 16 km)
- **114S**: Completion of the missing link of the motorway A81 in 1978 (length 23.9 km), and extension of the S1 (light rail) parallel to the corridor of the A81 in 1992 (length 16 km), with park&ride facilities (6 park&ride facilities, 7.500 new Parking spaces (about 19%))

Some of the results are related to the European project EUROSIL (EUROSIL 1999) and part of the SILUS[3] case study. Since the SILUS case study area is only a part of the Stuttgart region, the results had to be transformed accordingly.

[3] SILUS is an abbreviation for Strategic Links Urban Area of Stuttgart. The study was performed by SSP-consult and STASA (Steinbeis-Transfer Centre Applied System Analysis)

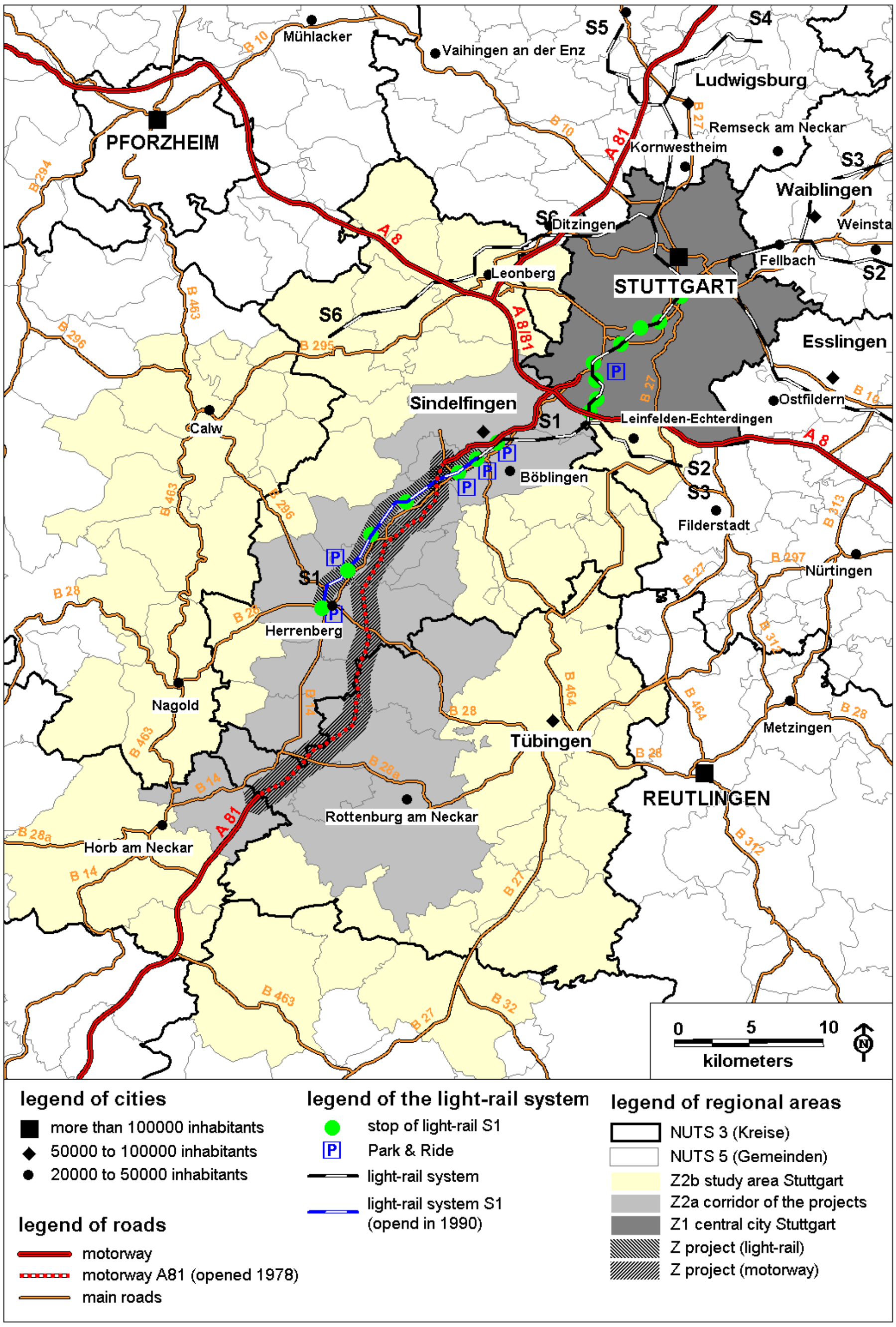


Figure 6.5 The Stuttgart – Singen corridor as part of the Stuttgart region (study area)

These elements of the Trans-European Network (TEN) represent an important link in the international traffic in the Northern-Europe-Germany-Switzerland-Italy chain. Both schemes (A81 and S1) run in parallel and concern the link of the capital to villages and new settlements far from the city centre of Stuttgart by radial elements. Due to urban and regional traffic, the transport network, especially the A81 is highly overburdened in the outskirts of Stuttgart. The consequences are overloading (congestion) leading to serious obstructions in long-distance traffic, as well as an increase of environmental pollution in the Stuttgart area.

In SCATTER the causes of the regional traffic are assumed to be related to decisions of individuals and interactions within the traffic system as well as with the settlement structure. The development of the population in the examined corridor in the nearer Stuttgart area is characterised by a strong growth in the periphery of the city. In addition, an enormous growth in industrial and business zones of cities along the A81 corridor can be observed accompanied with an increase of workplaces and a redistribution of workplaces from the city centre of Stuttgart towards the outer urban ring.

The reference scenario (001S) is the situation in 1995, when the motorway A81 and the S1 were already in use. Data exist for this case, containing traffic flows and travel time matrices of the individual as well as public transport, population numbers, numbers of employees and other characteristics (location factors) related to the traffic cells (communities). This data build the base for the analysis of the transport system and population and workplace redistribution.

- ***<u>Scenario 115S:</u>***

In this scenario (115S) the effect on urban sprawl of a new road tunnel project (tunnel Kappelberg) in combination with the shift of the B29 is investigated (Figure 6.6). The measures are:

- **115S**: Completion of the missing link of the motorway A81 in 1978 (length 23.9 km), and extension of the S1 (light rail) parallel to the corridor of the A81 in 1992 (length 16 km), with park&ride facilities (6 park&ride facilities, 7.500 new Parking spaces (about 19%)) and building of a new road tunnel (tunnel Kappelberg) of the Bundesstrasse B29 in east-direction (Schwäbisch Gmünd)

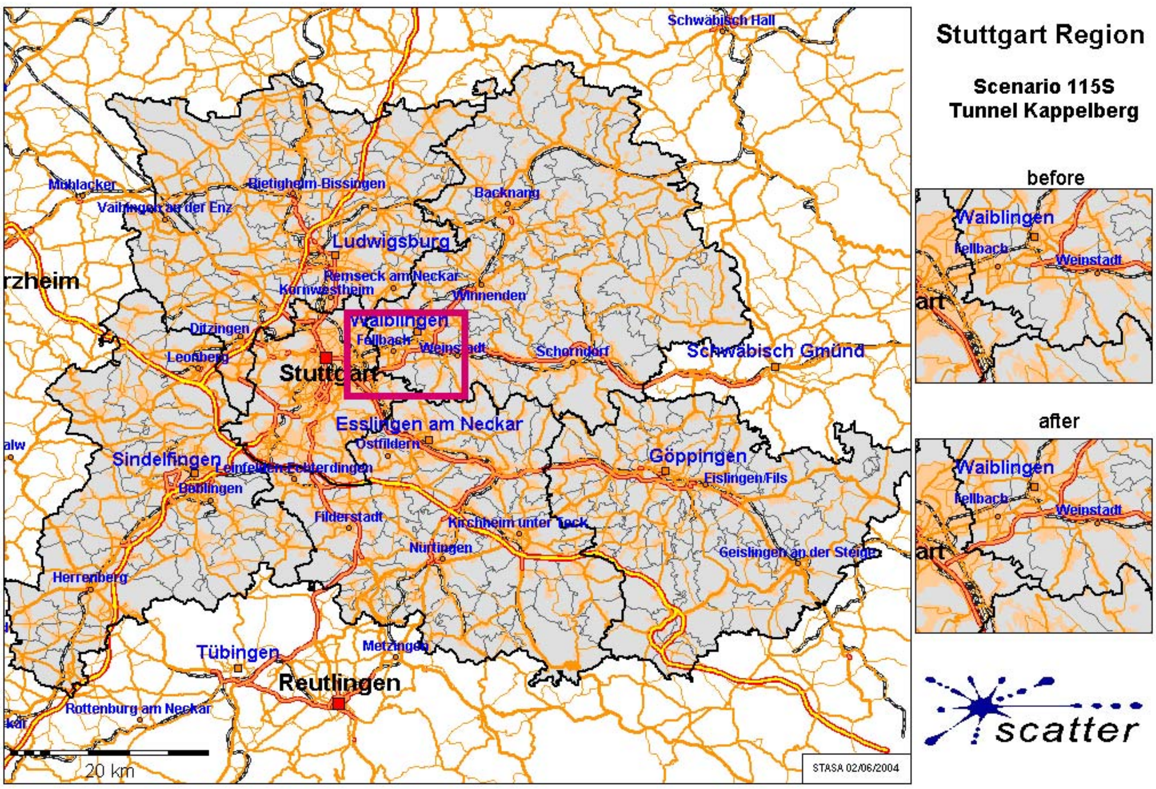


Figure 6.6 Scenario 115S: Transport investment in radial direction – road tunnel Kappelberg (corridor Stuttgart – Aalen – Nürnberg)

➢ ***Scenario 211S:***

Relocation of workplaces

In this scenario (211S) the impact of external factors such as the redistribution of workplaces from one part (east of city centre) of the Stuttgart region to the southern part, and its influence on the different socio-economic levels of the transport and settlement system is investigated (Figure 6.7):

- **211S**: Relocation of 10.000 workplaces from Esslingen (5.000 workplaces) and Stuttgart-Untertürkheim (5.000 workplaces) to Sindelfingen (10.000 workplaces), due to a shift of a production plant of DaimlerChrysler.

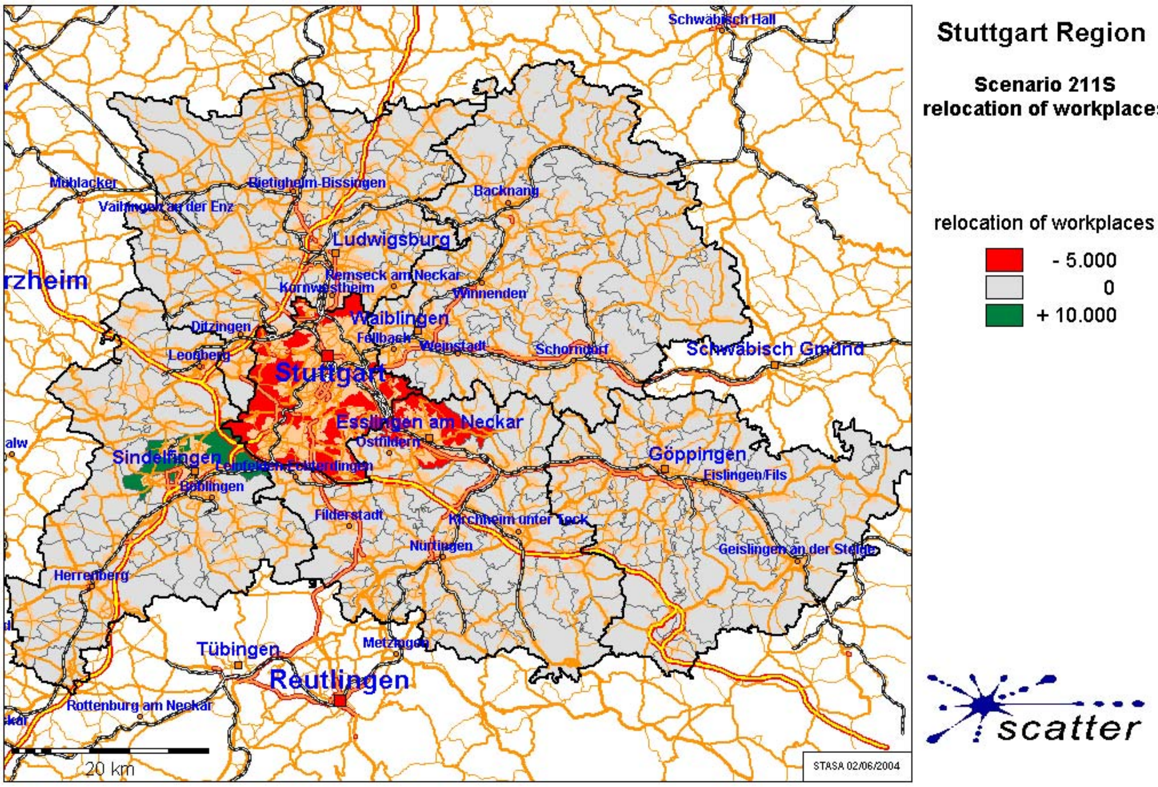


Figure 6.7 Scenario 211: Relocation of 10.000 workplaces within the area of the Stuttgart region

➢ ***Scenario 311S, 321S, 331S:***

Regulatory and fiscal measures applied to companies

In this scenarios (311S, 321S, 331S) the functioning of regulatory and fiscal measures with respect to urban sprawl is considered. Different policy strategies are discussed:

- **311S:** annual tax (development impact fee) applied on households locating in non-urban zones (about 670€ / household / year) and redistribution of the revenue of impact fee to the urban areas, as fiscal incentive to all households located in urban zones (Stuttgart, Ludwigsburg, Sindelfingen, Böblingen, Esslingen and Göppingen)

- **321S:** ABC-type policy applied to a part of the tertiary sector: ·obligation (regulatory measure) for all jobs of the employment sector “business services”, to locate in A-type zone
- **331S:** ABC-type policy applied to a part of the tertiary sector: tax on new jobs of the employment sector “business services” locating in non-A-type zone. The tax amounts to 976 €/job.

An A-type zone is a zone of the capital of a district (NUTS3). In general those zones are also served by high quality public transport at regional scale. In these scenarios, there are 7 A-type zones (Stuttgart, Ludwigsburg, Sindelfingen, Böblingen, Esslingen, Waiblingen and Göppingen) in the Stuttgart Region (Figure 6.8)

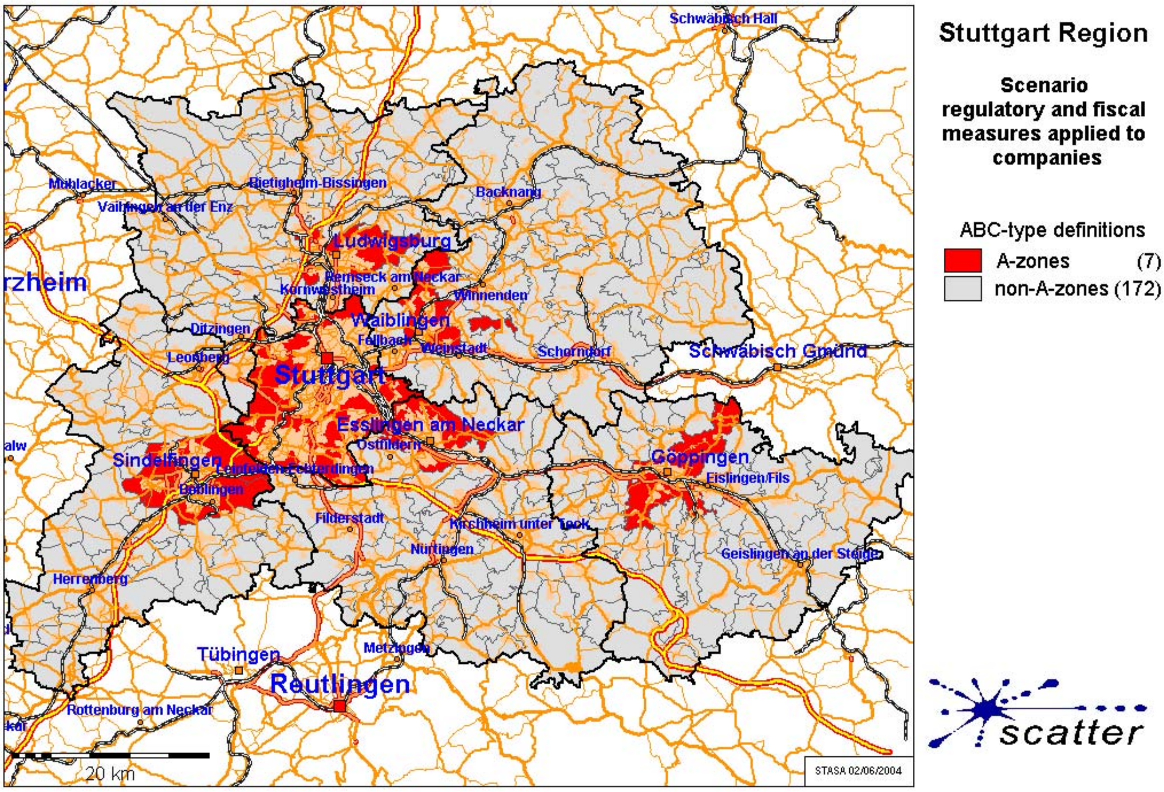


Figure 6.8 Scenario 321S, 331S: Definition of the A-type zones of the Stuttgart region

- ***Scenario 411S, 412S:***

Increase of travel costs or time by private car

In these scenarios (411S, 412S) the effects of an increase of private car travel cost on urban sprawl are simulated and tested via the reference scenario 003S. The policies are:

- **411S**: Increase by 50 % of the cost per km for all drivers
- **412S:** cordon pricing with a tariff of 2,1 €/day applied to all drivers (the cordon is located just inside the city of Stuttgart and the adjacent communes Ludwigsburg, Sindelfingen, Böblingen and Esslingen).

- ***Scenario 512S:***

Decrease of public transport travel costs

Another strategy to shape the effects of urban sprawl could be scenario (512S)

- **512S:** decrease of fare by 20%, applied to all public transport users (reference scenario 003S)
- **521S = 114S** (tested on reference scenario 113S)

- ***Scenario 811S, 812S, 813S:***

Combination of measures

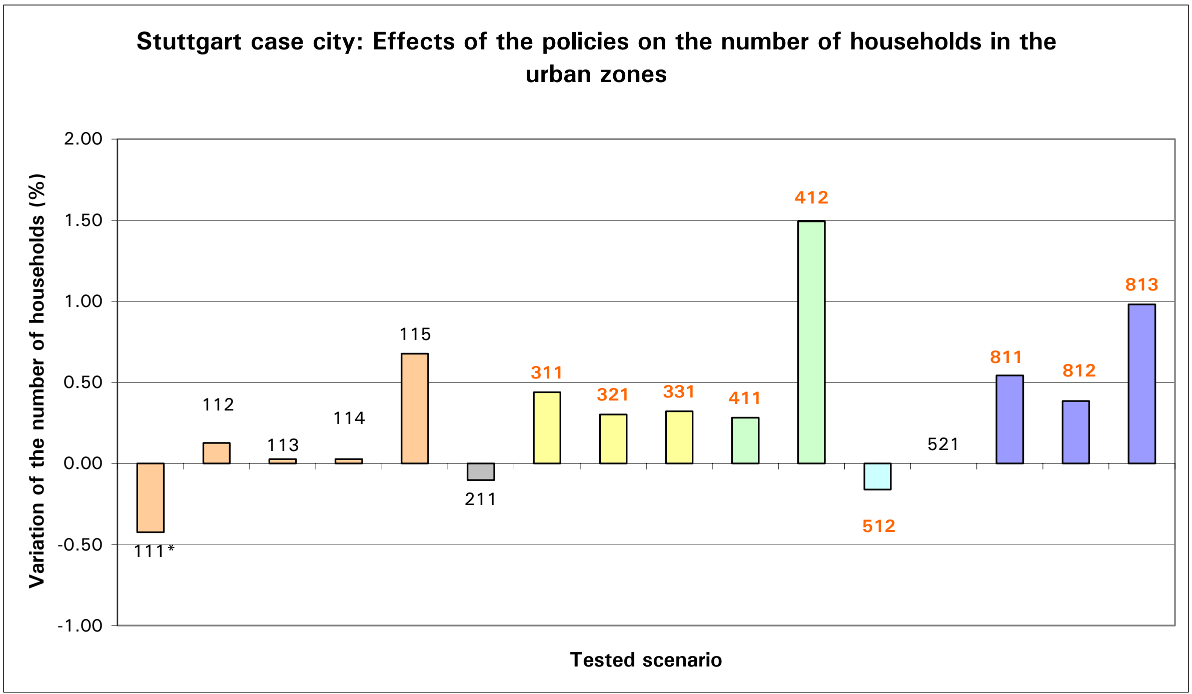
The possibility to diminish or control the negative impacts of urban sprawl are investigated via a combination of different policy measures.

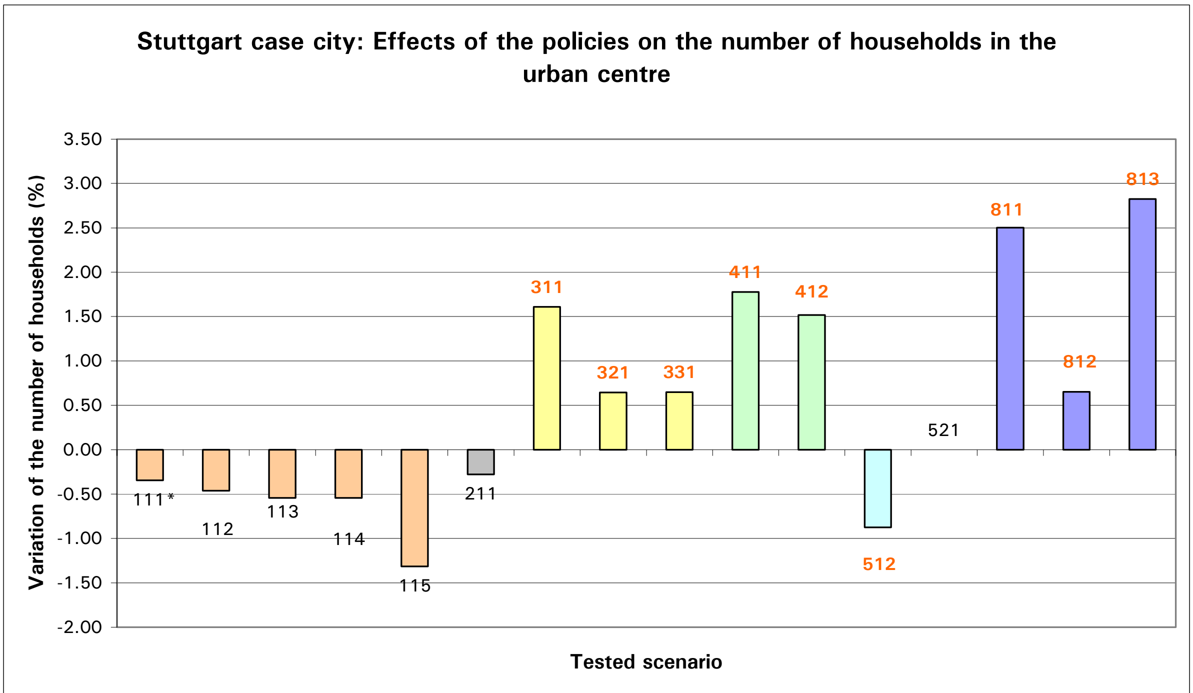
- **811S:** increase by 50% of the private car cost/km applied to all drivers,decrease of PT fare by 20% for all trips, fiscal measure on residential developments: see scenario 311
- **812S:** increase by 50% of the private car cost/km applied to all drivers, decrease of PT fare by 20% for all trips, ABC-type policy applied to a part of the tertiary sector: see scenario 331
- **813S:** increase by 50% of the private car cost/km applied to all drivers, decrease of PT fare by 20% for all trips, fiscal measure on residential developments: see scenario 311, ABC-type policy applied to a part of the tertiary sector: see scenario 331

As reference scenario 003S is used.

6.6.3. Assessment of the impacts

In the following sub-sections, the simulation results for the different tested measures for the Stuttgart region are presented. A summary of selected indicators are represented in diagrams in the Tables 6.1 – 6.13 below.



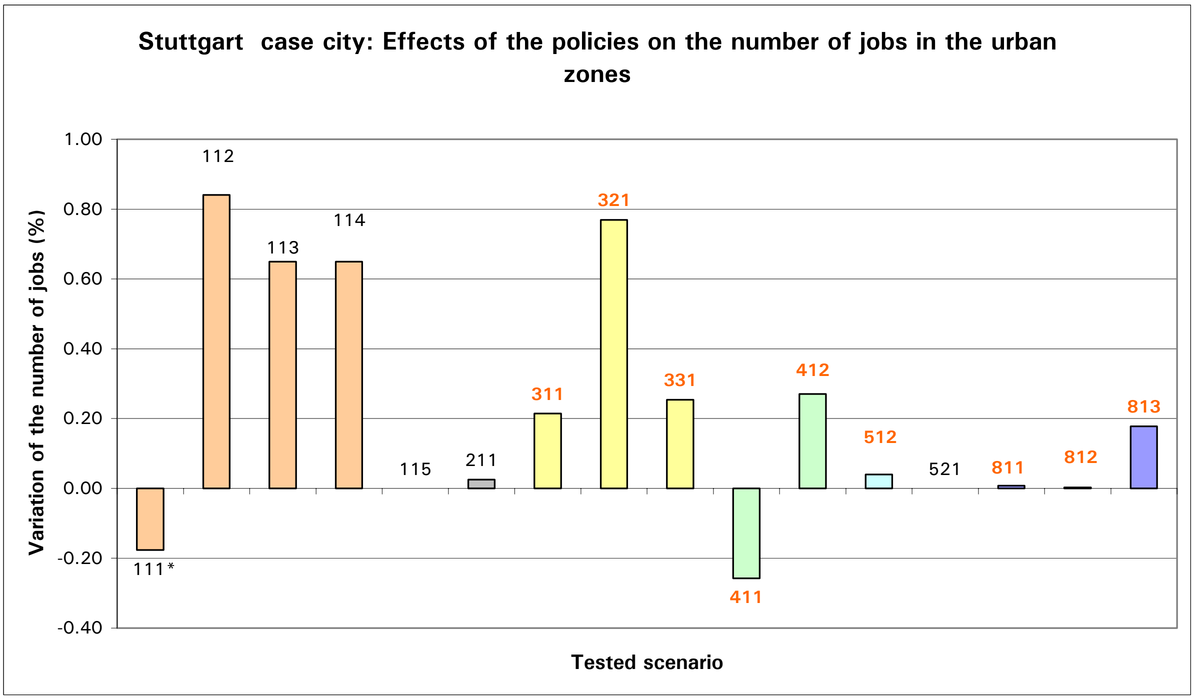


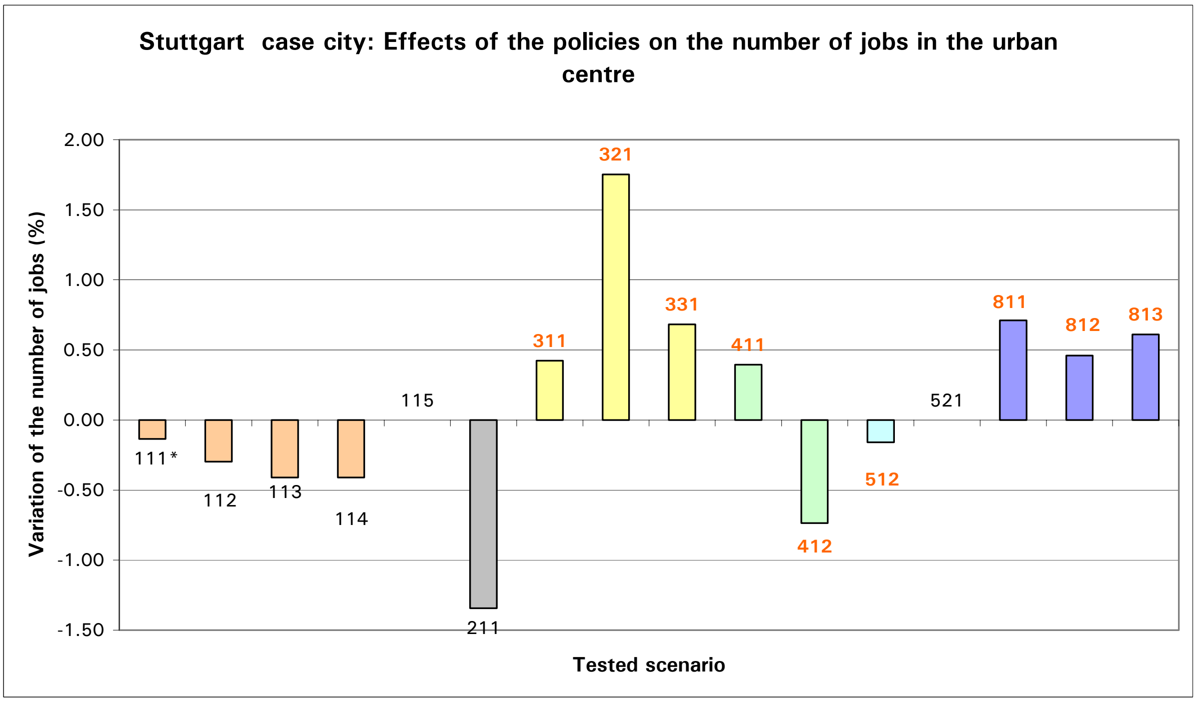
Type of scenario:

- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
- Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car
- Measures aiming at a modal shift towards public transport by decreasing travel costs or times by public transport, or by provinding P&R facilities
- Local investment plan and combinations of measures

* The effect of motorway A81 and leight rail S1 (111,112,113,114) is calculated by comparison with scenario 001 (situation without motorway and leight rail).
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)

Figure 6.9





Type of scenario:

- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
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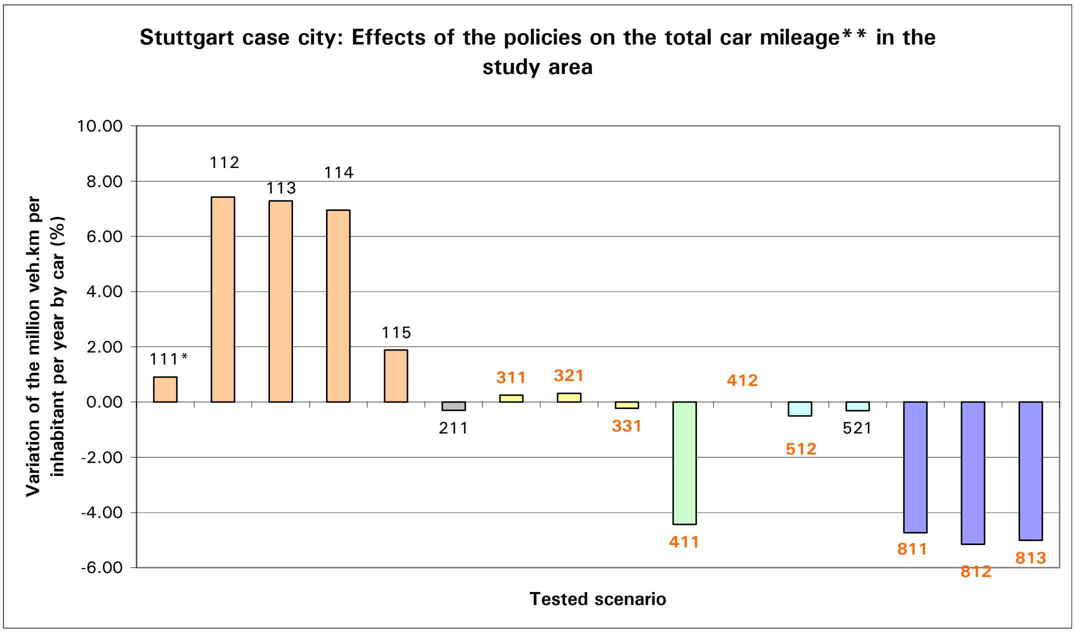
The effects of the other measures are calculated in comparison with scenario 003 (present state)

Figure 6.10



Type of scenario:
- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
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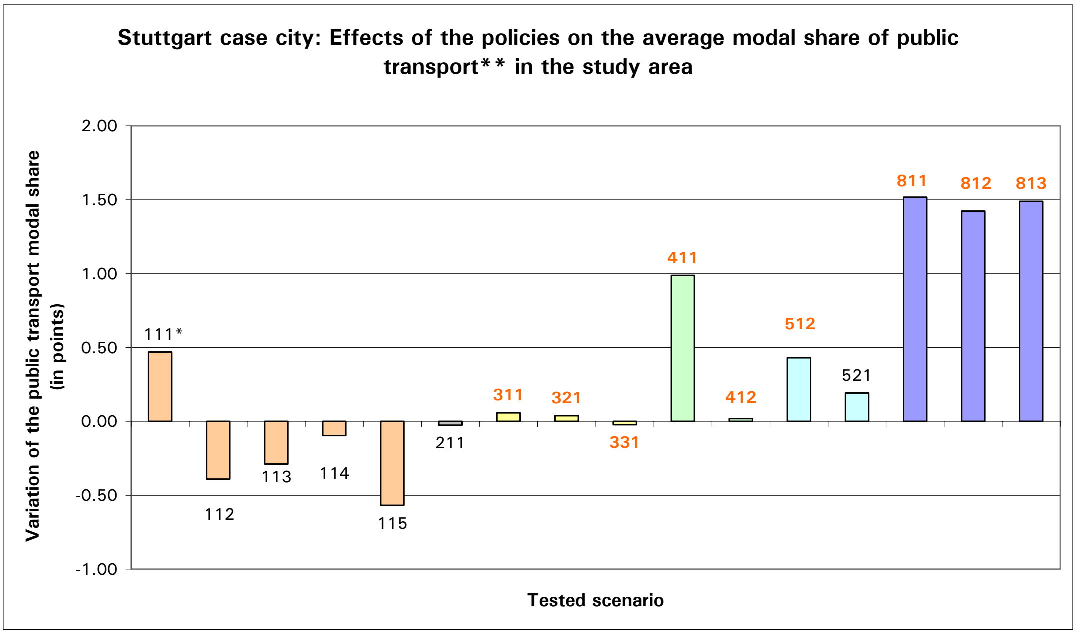
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** Total vehicle-kilometers by car per inhabitant in the study area, including the incoming and outgoing commuter trips, per year, for all purposes.



Type of scenario:
- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
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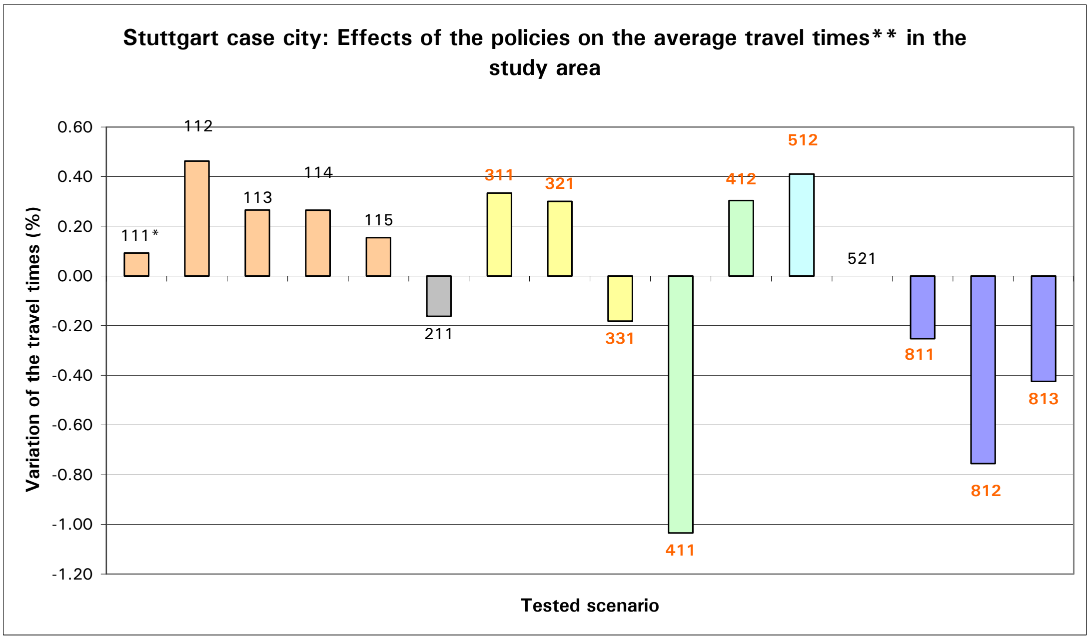
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** Average modal share of the public transport on the trips inside the study area for all purposes.

Figure 6.11



Type of scenario:

- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
- Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car
- Measures aiming at a modal shift towards public transport by decreasing travel costs or times by public transport, or by provinding P&R facilities
- Local investment plan and combinations of measures

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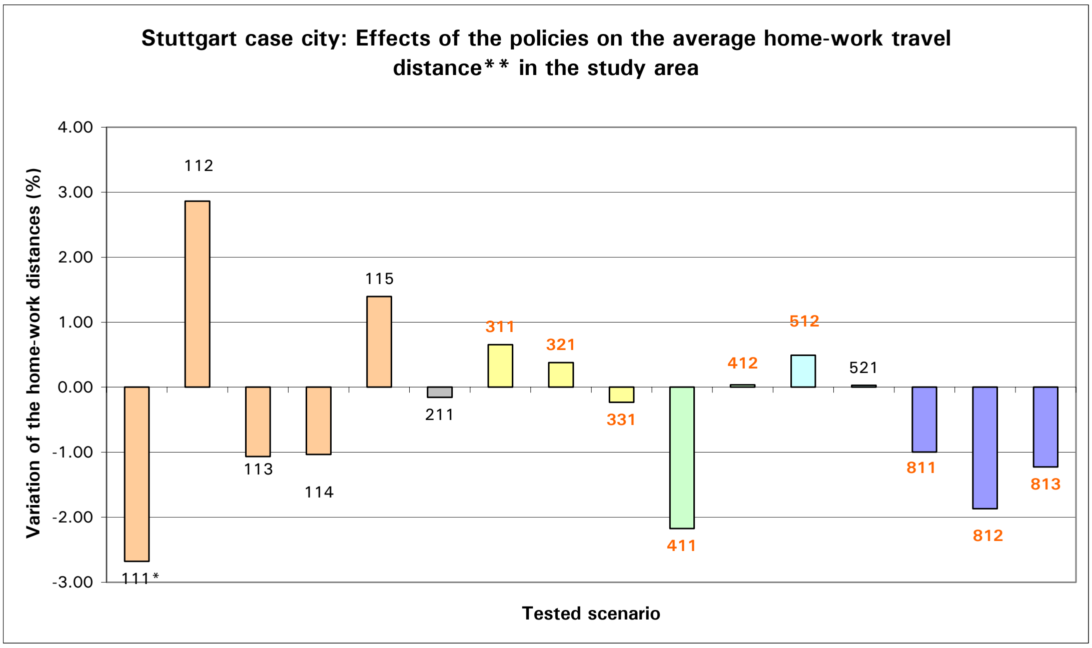
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** Average travel times for the trips inside the study area, all modes, all purposes.



Type of scenario:

- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
- Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car
- Measures aiming at a modal shift towards public transport by decreasing travel costs or times by public transport, or by provinding P&R facilities
- Local investment plan and combinations of measures

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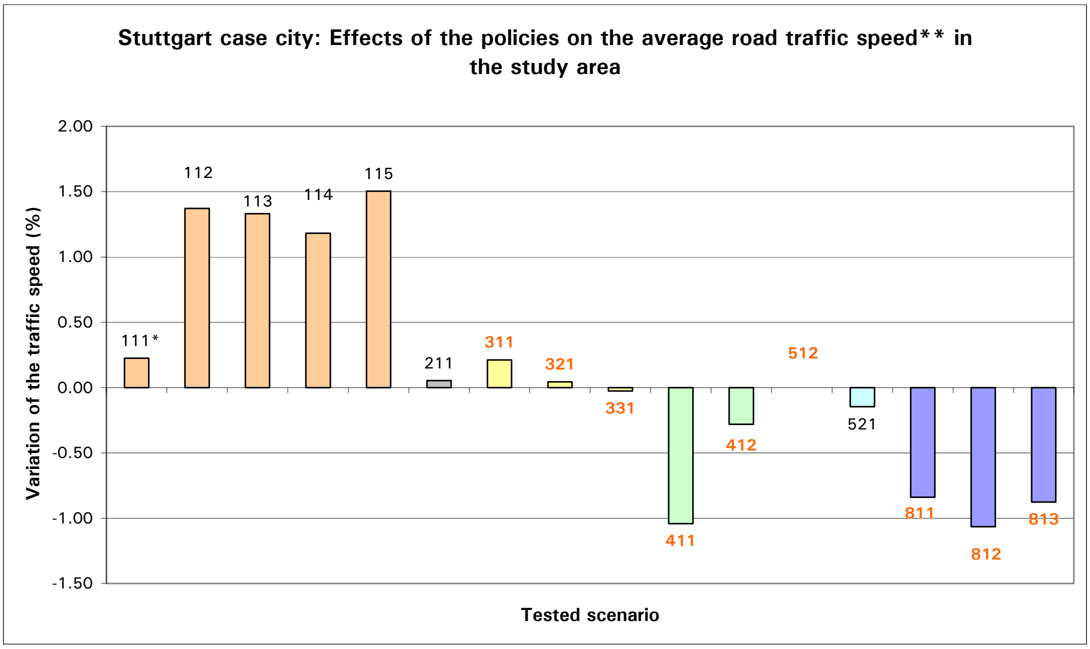
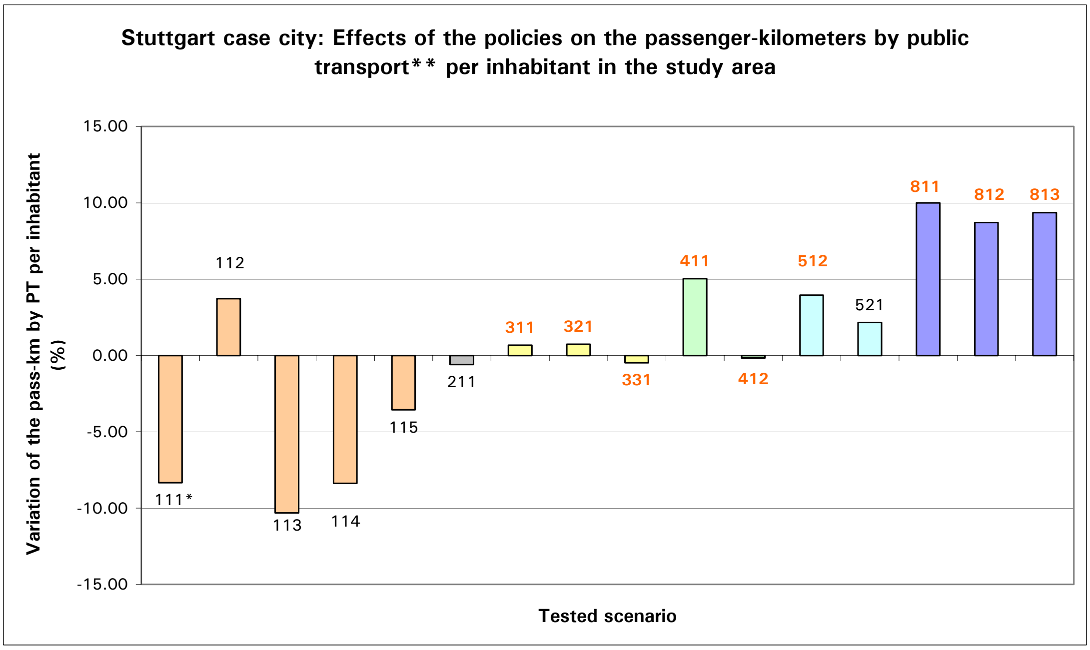
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** Average home-work travel distance for the trips inside the study area, all modes.

Figure 6.12



Type of scenario:
- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
- Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car
- Measures aiming at a modal shift towards public transport by decreasing travel costs or times by public transport, or by provinding P&R facilities
- Local investment plan and combinations of measures

* The effect of motorway A81 and leight rail S1 (111,112,113,114) is calculated by comparison with scenario 001 (situation without motorway and leight rail).
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** Average road trafic speed in km/hour for all trips (including the incoming and outgoing commuter trips), for all purposes.



Type of scenario:
- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
- Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car
- Measures aiming at a modal shift towards public transport by decreasing travel costs or times by public transport, or by provinding P&R facilities
- Local investment plan and combinations of measures

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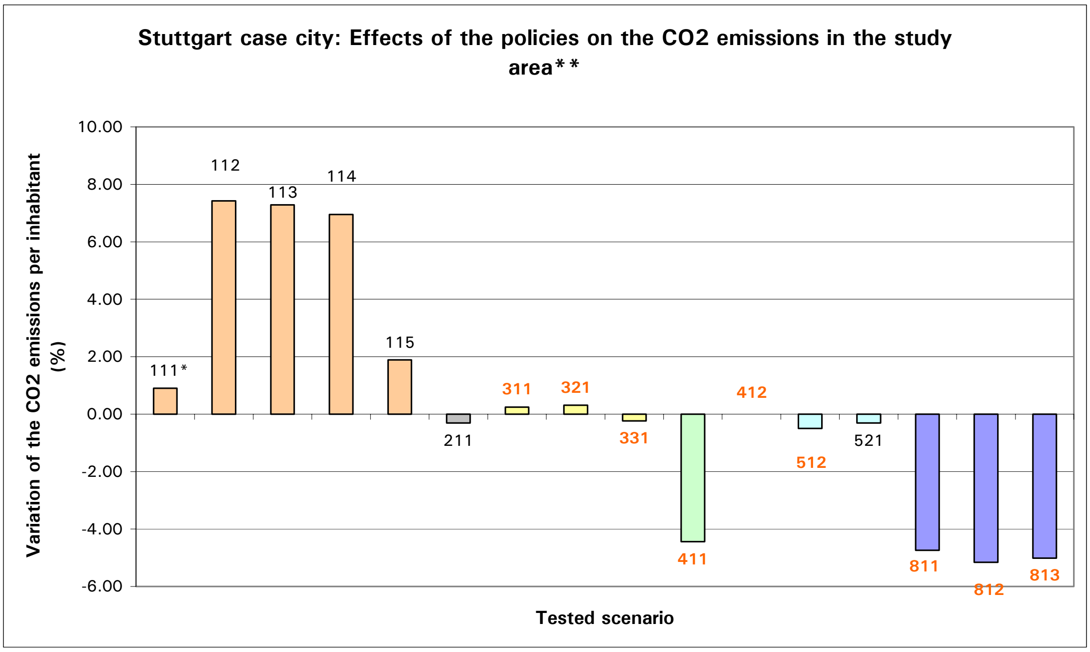
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** Total passenger-kilometers by public transport, for all trips (including the incoming and outgoing commuter trips), for all purposes.

Figure 6.13



Type of scenario:

- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
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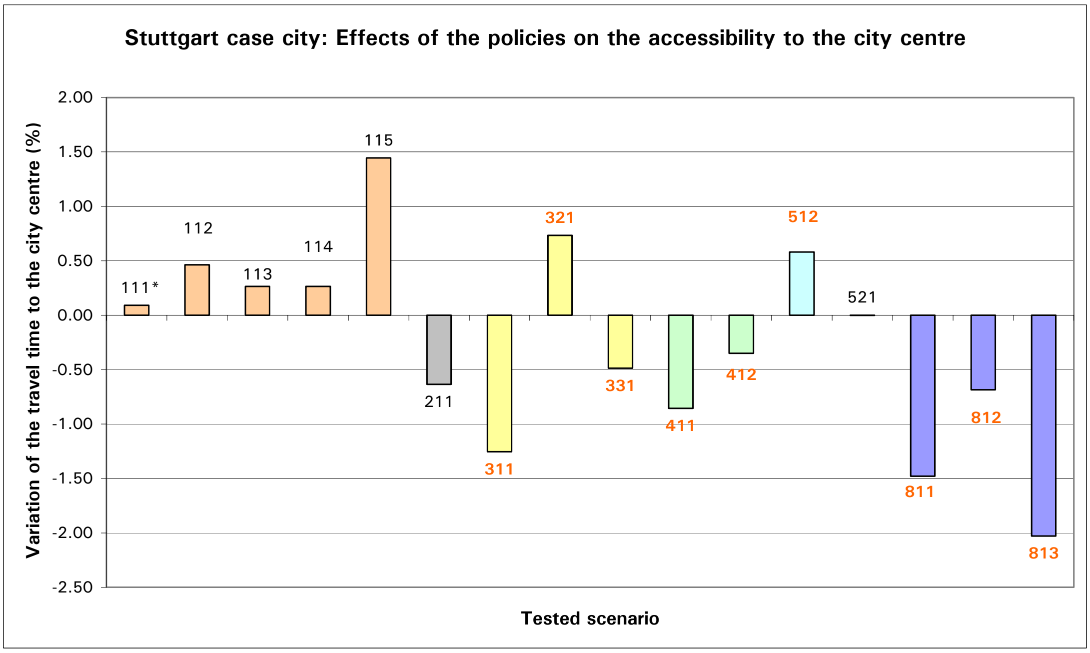
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** The CO2 emissions are calculated on the basis from the veh-km on the roads in the study are, including the incoming and outgoing commuter trips, all purposes, on one year.



Type of scenario:

- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
- Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car
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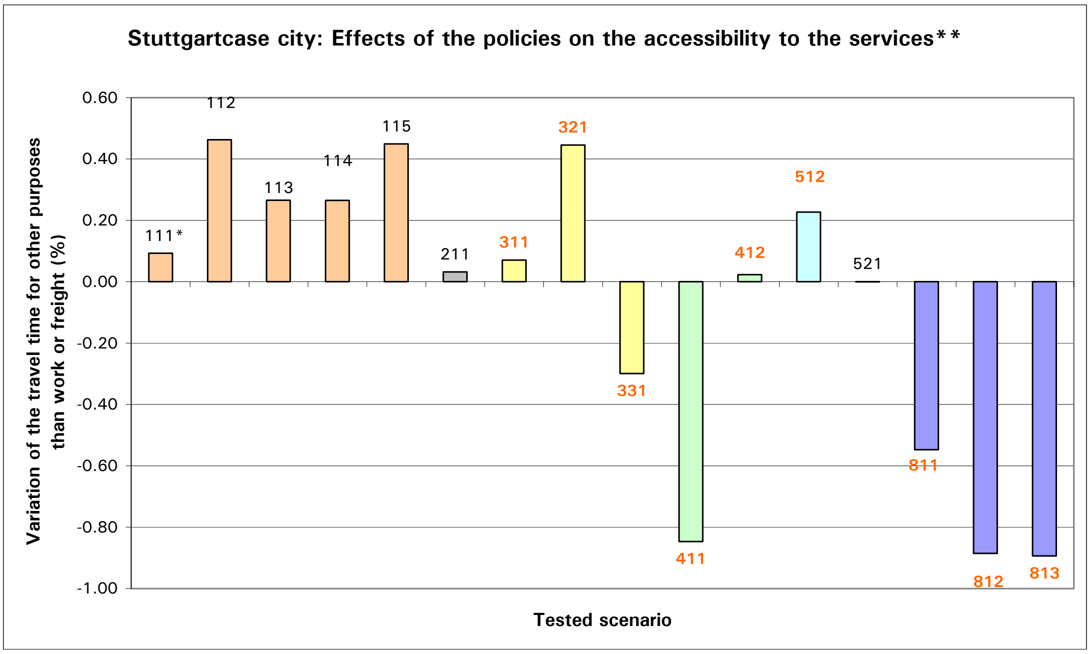
- Local investment plan and combinations of measures

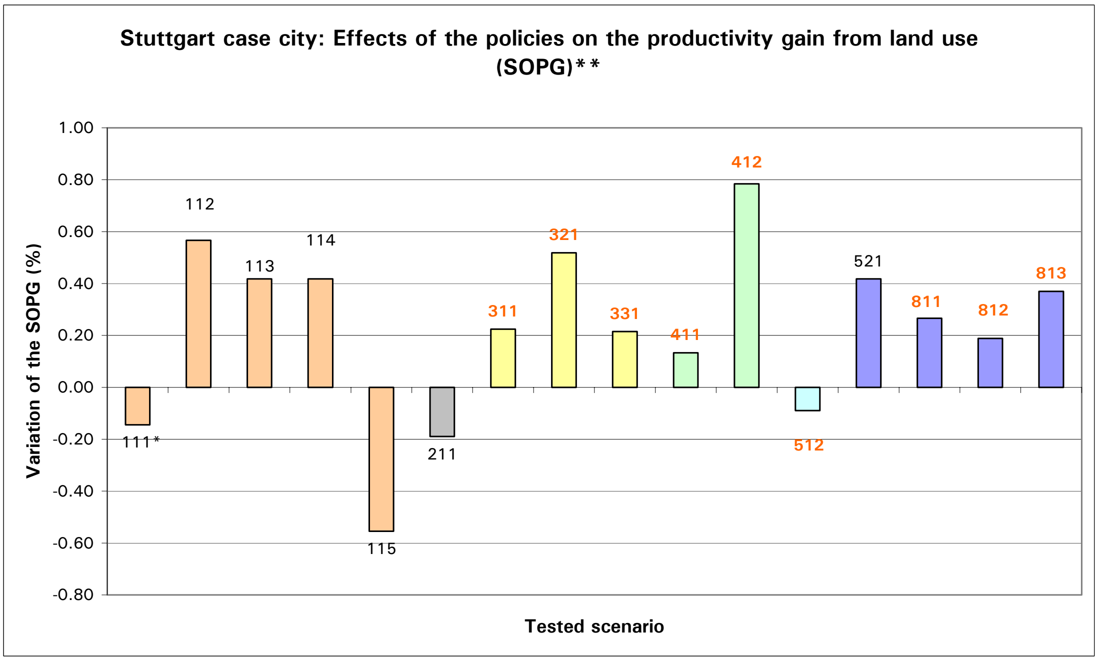
* The effect of motorway A81 and leight rail S1 (111,112,113,114) is calculated by comparison with scenario 001 (situation without motorway and leight rail).
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** The accessibility to the city centre is measured by the travel time to the city centre, from the study area, for all purposes and all modes.

Figure 6.14



Type of scenario:
- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
- Measures aiming at a modal shift towards public transport by increasing travel costs or time by private car
- Measures aiming at a modal shift towards public transport by decreasing travel costs or times by public transport, or by providing P&R facilities
- Local investment plan and combinations of measures

* The effect of motorway A81 and leight rail S1 (111,112,113,114) is calculated by comparison with scenario 001 (situation without motorway and leight rail).
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** The accessibility to the services are measured by the average travel times for all purposes except work and freight pruposes and all modes, from the study area



Type of scenario:
- Transport infrastructures / services
- External factor : relocation of work places
- Land use measures having an influence on urban sprawl
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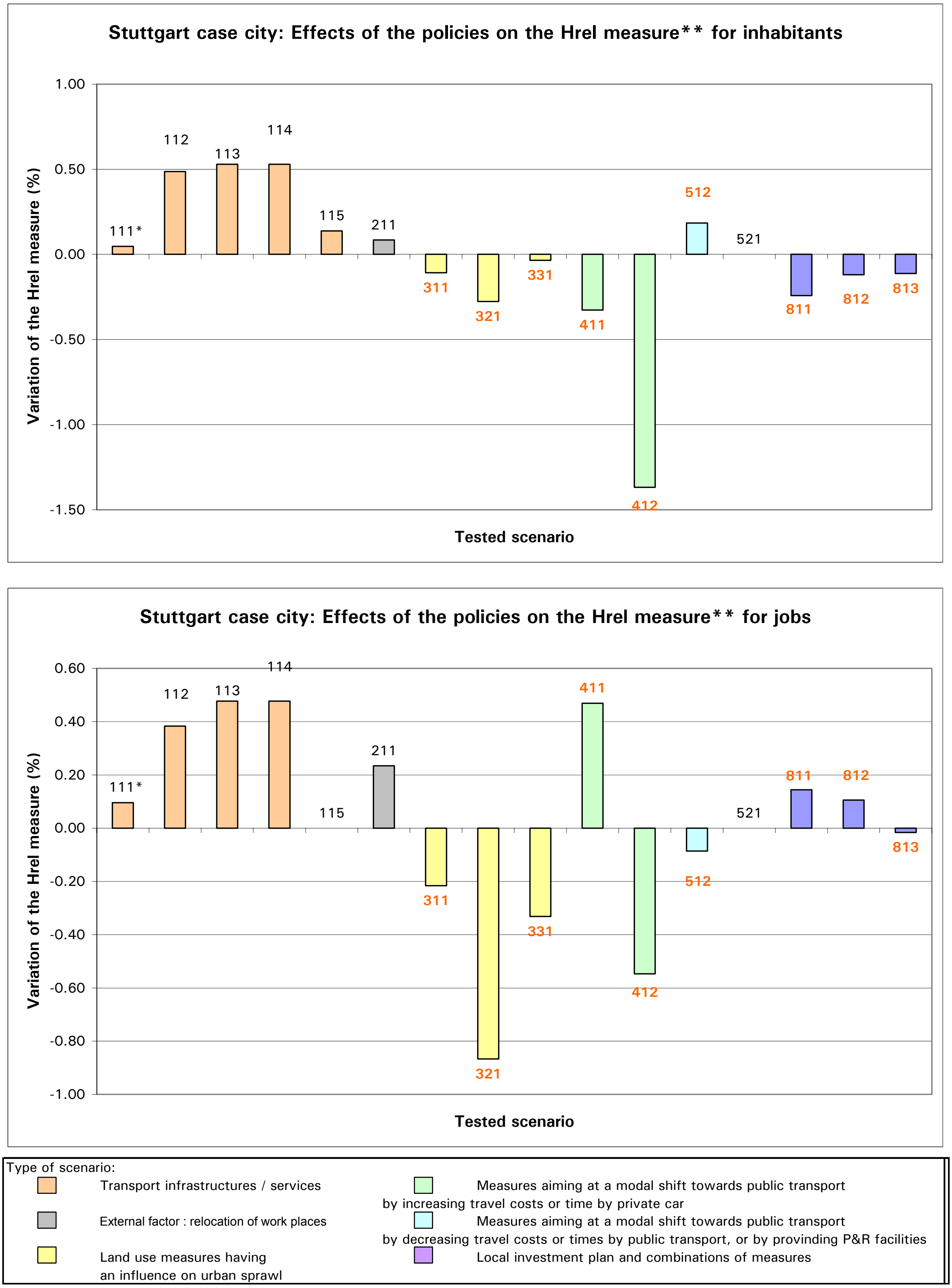
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** The SOPG indicator quantifies the social opportunities of a situation by measuring the economic efficiency of the study area. It measures the extension of the area of employment opportunitie

Figure 6.15



* The effect of motorway A81 and leight rail S1 (111,112,113,114) is calculated by comparison with scenario 001 (situation without motorway and leight rail).
The effect of tunnel Kappelberg (115) is calculated by comparison with scenario 002 (which is also 114 - situation with motorway A81 and leight rail S1).
The effects of the other measures are calculated in comparison with scenario 003 (present state)
** The H-measure is an agglomeration / urban sprawl measure for the whole investigated region

Figure 6.16

➢ ***Simulation of Scenario 111S – 114S:***

The transport system is simulated with two modes as well as the population distribution for the three planning scenarios. Thereby the interactions between both systems have to be considered.

Population distribution

For the cases without A81, the population density in the area Boeblingen / Sindelfingen, where the A81 ends before 1978, is higher than in the case with A81. For the area of Herrenberg the population density without A81 is not as high as in the case with A81. The effect of the motorway on the population distribution is therefore very strong, and a corresponding strong shift of population in the direction of the community of Herrenberg, caused by the extension of the A81 can be found. This result confirms, that the extension of radial transport lines, accompanied with a drastic reduction of travel times to the city centre, support sprawl.

For the scenario with A81 and with S1, the population density increases a little compared to the basic scenario in the area along the light rail system S1, i.e. in areas in vicinity to the train stops of the S1. The effects caused by the S1 on population distribution are not as strong as those caused by the motorway. In other words, the radial extension of the public transport system S1 has a rather moderate effect on urban sprawl, compared with the extension of the motorway A81.

According to Table 6.13 an increase of the relative *H*-measure must be stated for the policy measures S111 – S114. This indicates that the extension of the radial transport axis accompanied with an improvement of accessibility indicators in the hinterland accelerate the effect of urban sprawl in the Stuttgart region.

Transport system

If the attractiveness of a community (traffic cell) is high, the probability for a trip into this community increases. For the basic scenario the attractiveness of the communities in the areas of Stuttgart and Boeblingen / Sindelfingen is high. For the planning scenarios without A81, the attractiveness of Boeblingen / Sindelfingen increases by at least 5 to 10%, whereas the attractiveness of the area of Herrenberg decreases compared to the basic scenario. This leads to corresponding shifts in the traffic flows.

Due to the increase in the traffic volume and the overall average travel distance the travel time increase as well in the study area. Compared to public transport private vehicle traffic also increases. The modal split decreases due to the road construction measure A81.

The construction of the line S1 increases public transport use and thus shifts the modal split towards public transport. Through diverting public transport trips from previously mainly bus transport in the Herrenberg area to the rail, the extension of the S1 towards Herrenberg leads to a clear decrease in public transport mileage as well as of average travel distances in public transport. A slight decrease in the mileage of private vehicle traffic can also be registered, which is caused by the construction of the S-Bahn S1 (Table 6.3).

- ***Simulation of Scenario 115S:***

The building of a new road tunnel (tunnel Kappelberg) of the Bundesstrasse B29 in east-direction (Schwäbisch Gmünd) also can be considered as an improvement of radial transport lines between the centre (Stuttgart) and more peripheral areas of the region.

According to the Tables 6.1 – 6.13 it is obvious that this measure leads to a redistribution of households from urban centre towards urban zones between 1995 and 2015. An increase of total car mileages in the study area of about 2% and of the average home-work travel distance (about 1.4%), accompanied by a decrease of the public transport modal share (-0.6 points) is expected, since this measure favours car transport. The better link of the urban centre to the urban areas and hinterland leads also to an increase of the traffic speed and the negative effects of CO_2 emissions (+1.9%). The *H*-indicator states that an increase of sprawl must be expected, but rather moderate compared with the effect of the extension of the motorway A81.

- ***Simulation of Scenario 211S:***

In this scenario (211S) the impacts and effects of the relocation of 10.000 workplaces from Esslingen (5.000 workplaces) and Stuttgart-Untertürkheim (5.000 workplaces) to Sindelfingen (10.000 workplaces), due to a shift of a production plant of DaimlerChrysler, is simulated (Figure 6.6).

It is assumed that in the short run the housing locations of the commuters are not changed (no constraint). In the long run, however, migration of households occur. Furthermore, it is assumed that the workplace distribution is fixed (with constraint).

The relocation of work places leads to changes of attractiveness values and shadow costs in the STASA- simulation model. This results in a redistribution of the commuter flows and population (housing locations). The different constraints take into account, that all work places should be occupied and/or the housing population should be fixed.

For the region of Stuttgart a redistribution of work places is computed according to Figure 6.7. This scenario seems to be rather realistic. Of course, the effect of this direct intervention on the distribution of jobs results in a huge change of the commuter pattern and effects the travel time relationships (travel time matrix) within a large area of the conurbation. In the short time consideration, it is assumed that all persons employed maintain their work place and their place of home.

In the long run, a partial redistribution of work places and housing locations may happen, resulting in a secondary redistribution of the commuter pattern. The quite different time scales of the different relocation processes (1 year change of work place, 10 years change of housing location) lead to a temporal separation of the effects. Therefore both scenarios are of importance in the city planning process. Because Sindelfingen is in the corridor Stuttgart – Singen located, the quite good accessibilities within this corridor may encourage households to search for a location towards Herrenberg with cheaper land-prices and therefore enhance urban sprawl. However, the distribution of the commuter flows in the study area before the shift of the considered production plant occurred (reference scenario 003S - horizon 2020) shows that this measure has rather positive impacts related to the introduced indicators (Tables 6.1 – 6.13). Due to a better spatial distribution of the commuter flows and the structure of traffic network, the total car mileages and the average travel times decrease slightly. Also the average home-work travel distance is rather not changed by this measure. The effects of this policy on the relative *H*-measure for inhabitants shows a very moderate increase, the sprawl on jobs, however, is quite considerable.

- ***Simulation of Scenario 311S, 321S,331S:***

In these scenarios regulatory and fiscal measures applied to companies are simulated and evaluated with respect to urban sprawl.

- ***Simulation of Scenario 311S:***

The control mechanism of a change in the annual tax (development impact fee) applied on households locating in non-urban zones and redistribution of the revenue of impact fee to the urban areas, as fiscal incentive to all households located in urban zones, is investigated in scenario 311S. Urban zones are the cities of Stuttgart, Ludwigsburg, Sindelfingen, Böblingen, Esslingen and Göppingen.

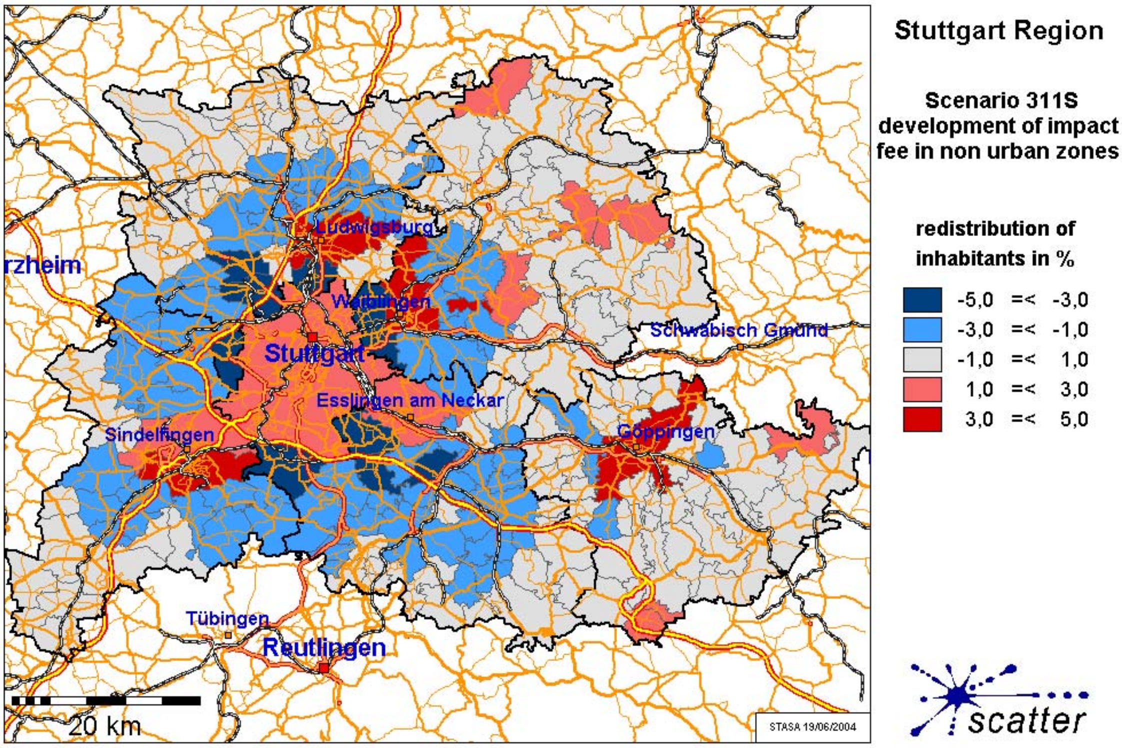


Figure 6.17 Scenario 311S: Redistribution of inhabitants in %

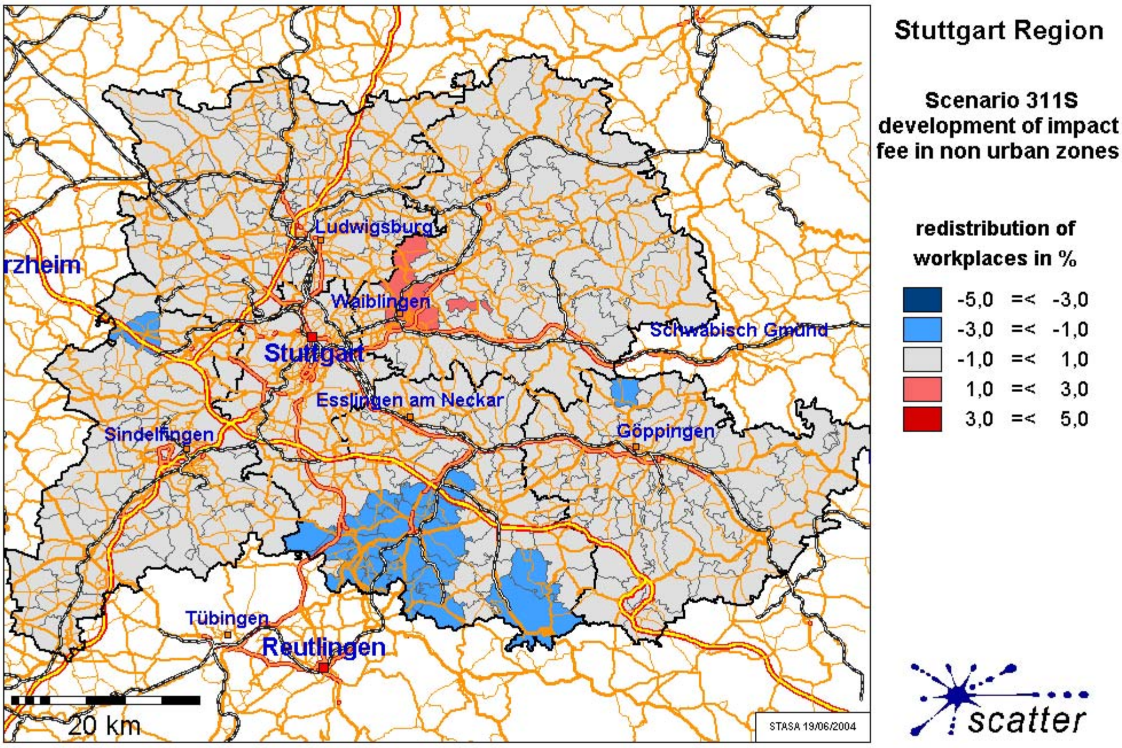


Figure 6.18 Scenario 311S: Redistribution of workplaces in %

The introduction of an impact fee in non urban zones enhances the concentration of population and workplaces in urban zones (Fig. 6.9, 6.10). The tables 6.1-6.13 show, that the concentration effect on households due to this policy measure is about a factor of 2 higher then for workplaces (jobs). Due to the topological structure of the study area, the spatial distribution of jobs and services and the transport network, model split and the average passenger-kilometres by public and car transport are not affected. However, average travel times and average home-work travel distances are slightly increased. The average travel time to the city centre is decreased due to the concentration effects. It becomes also obvious that the relative *H*-indicator is slightly diminished, indicating that this policy measure acts against sprawl.

- ***Simulation of Scenario 321S:***

In the scenarios 321S and 331S a ABC-type policy is applied. In the case of Stuttgart, an A zone is defined as a zone of the capital of a district (NUTS3) in the Stuttgart case (Figure 6.8). In general those zones are also served by high quality public transport at regional scale.

This regulatory measure is an obligation to a part of the jobs of the tertiary sector. According to fig. 6.11, 6.12 concentration effects in A-type zones of population and workplaces must be stated. Contrary to the policy 311S this measure mainly acts on the distribution of workplaces, according to the Tables 6.1 – 6.13. Accompanied with the concentration of workplaces in A-zones, and because the redistribution effect on households is rather moderate, the average home-work travel distance in the study area is slightly increased (+0.3%) as well as the average travel time and the CO2 emissions between 2000 and 2020.

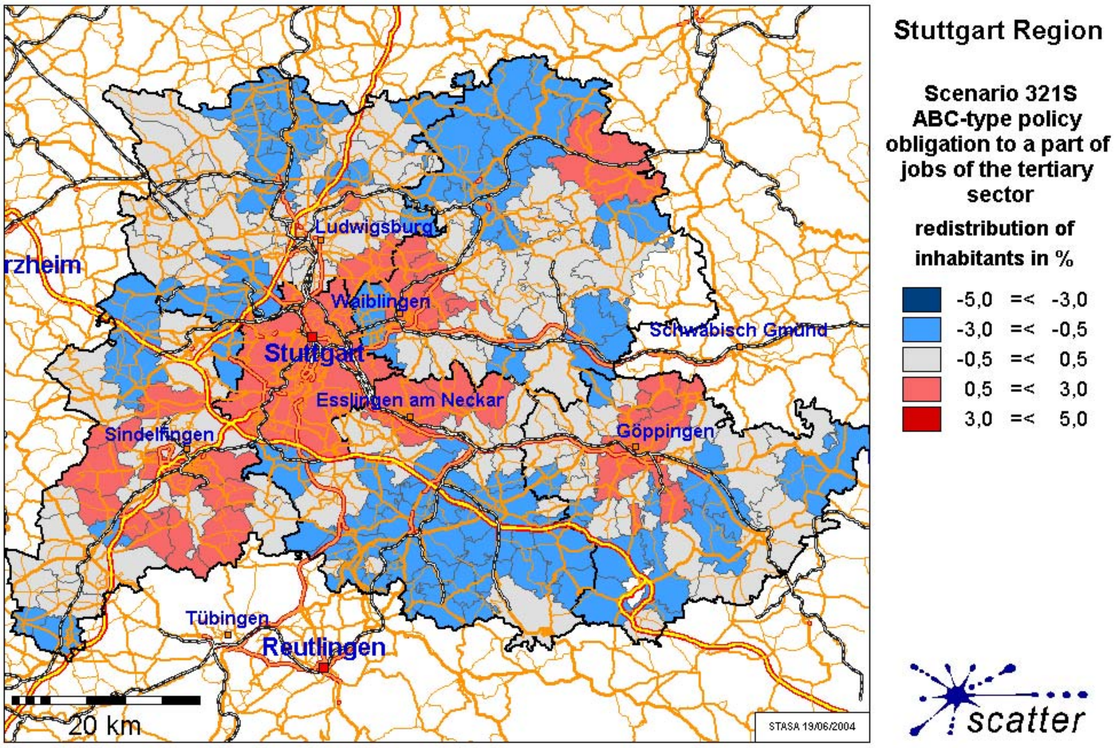


Figure 6.19 Scenario 321S: Redistribution of inhabitants in %

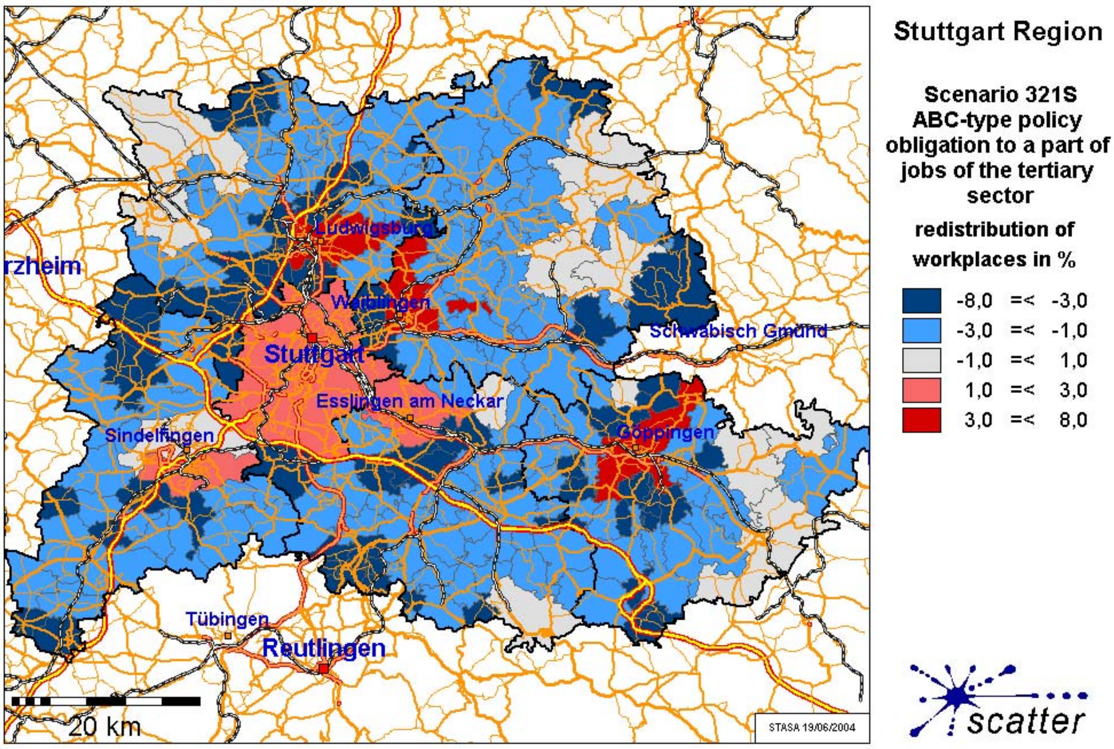


Figure 6.20 Scenario 321S: Redistribution of workplaces in %

Measure 321S leads to an increase of the accessibility to the city centre and to services (+0,5%), due to changes in the commuter flows and travel times. This policy also diminish the relative *H*-indicator of both, population and jobs. Therefore, the negative effects of urban sprawl will be reduced by this policy.

➢ ***Simulation of Scenario 331S:***

ABC-type policy applied to a part of the tertiary sector: tax on jobs of the employment sector “business services” locating in non-A-type zone. This fiscal measure works on companies. The effect of this policy on indicators of population and workplaces is quite similar to 321S. However, a moderate reduction of the total car mileage in the study area, the average travel times and the average home-work travel distance (-0,2%) is found by the simulation of this policy. Therefore, traffic performance and CO2 emissions are also reduced (tables 6.1-6.13), unlike the accessibility to the city centre and to services. With respect to urban sprawl a moderate concentration effect can be observed.

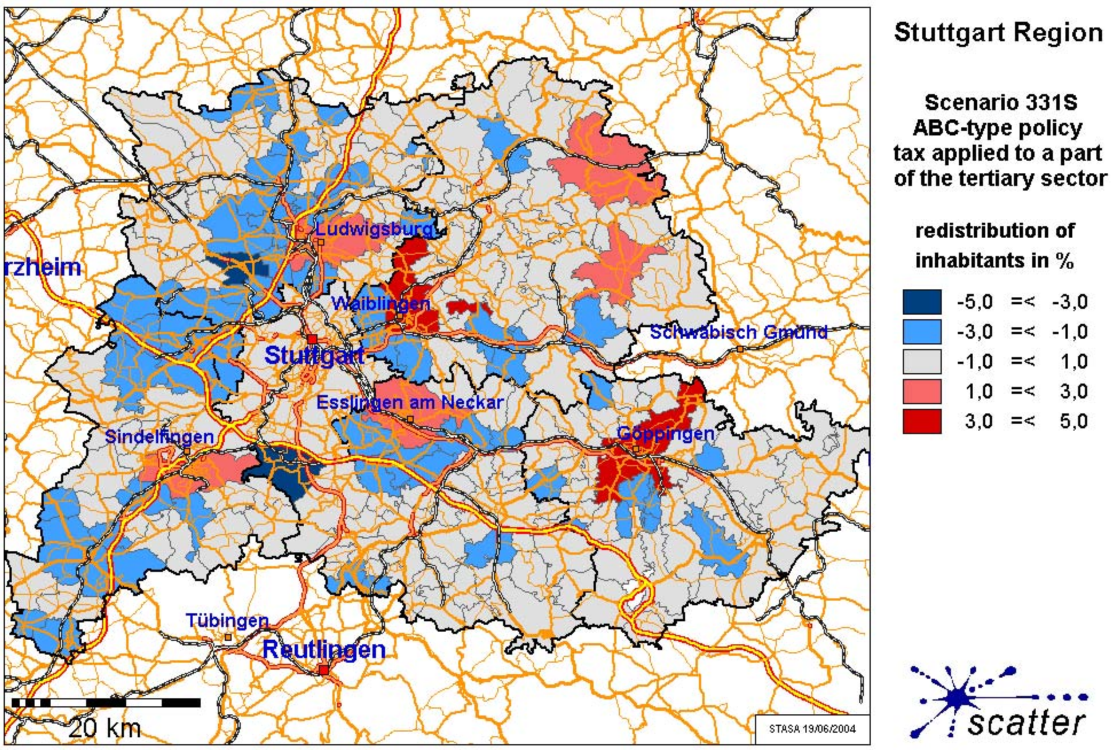


Figure 6.21 Scenario 331S: Redistribution of inhabitants in %

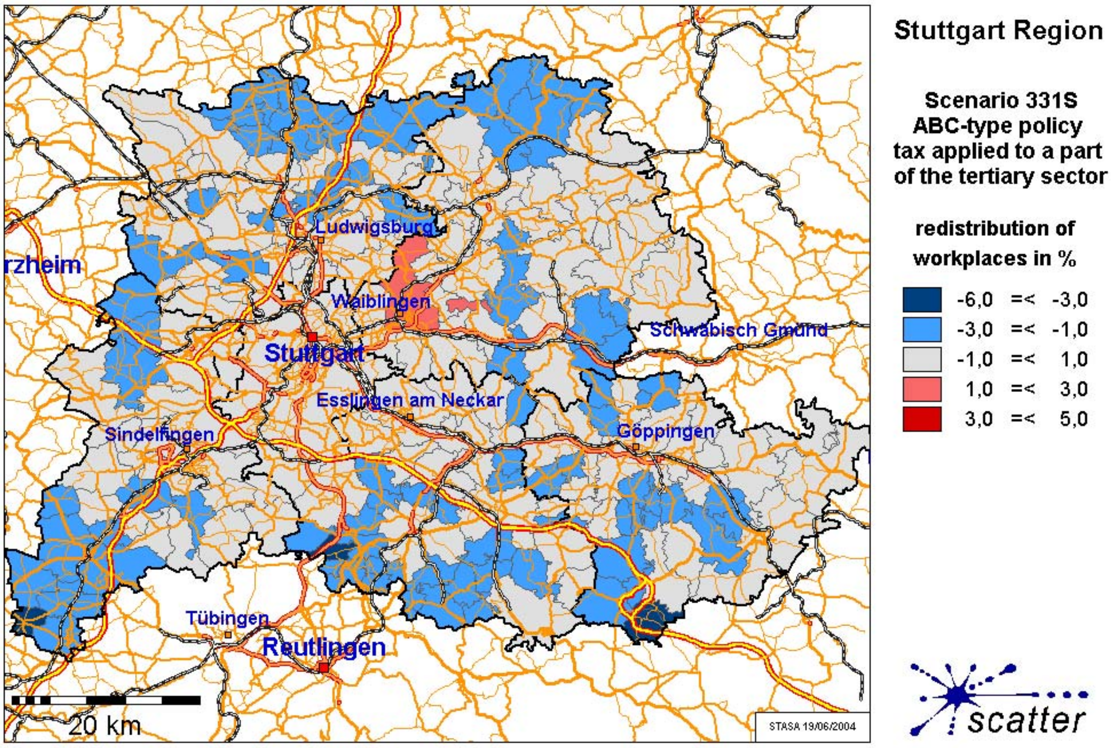


Figure 6.22   Scenario 331S: Redistribution of workplaces in %

In figure 6.13 the effect of the policy measure 331S on the spatial distribution of population is shown, and in figure 6.14 on the redistribution of workplaces.

- ***Simulation of Scenario 411S, 412S:***

In these scenarios (411S, 412S) the effects of an increase of private car travel costs on urban sprawl are simulated and tested via the reference scenario 003S (horizon 2020).

Simulation of Scenario 411S:

The policy measure 411S describes an increase by 50 % of the cost per km for all car drivers. In the long run, there is an increase in the number of households in the urban zones and in the urban centre (Stuttgart) (tables 6.1-6.13). Since car use is directly affected by this policy, the total car mileage in the study area will decrease by about 4.2% accompanied with an shift of the modal share towards public transport (1.00 points). The reduction of car use leads further to a big improvement of average travel times (-1.1%) and home-work travel time (-2.2%) and CO2 reduction (-4.5%). As a consequence public transport increases (+ 5%) and accessibility becomes worth. A positive effect on urban sprawl for households can be observed (table 6.13), but jobs are more spread over the whole region (Figure 6.15, 6.16).

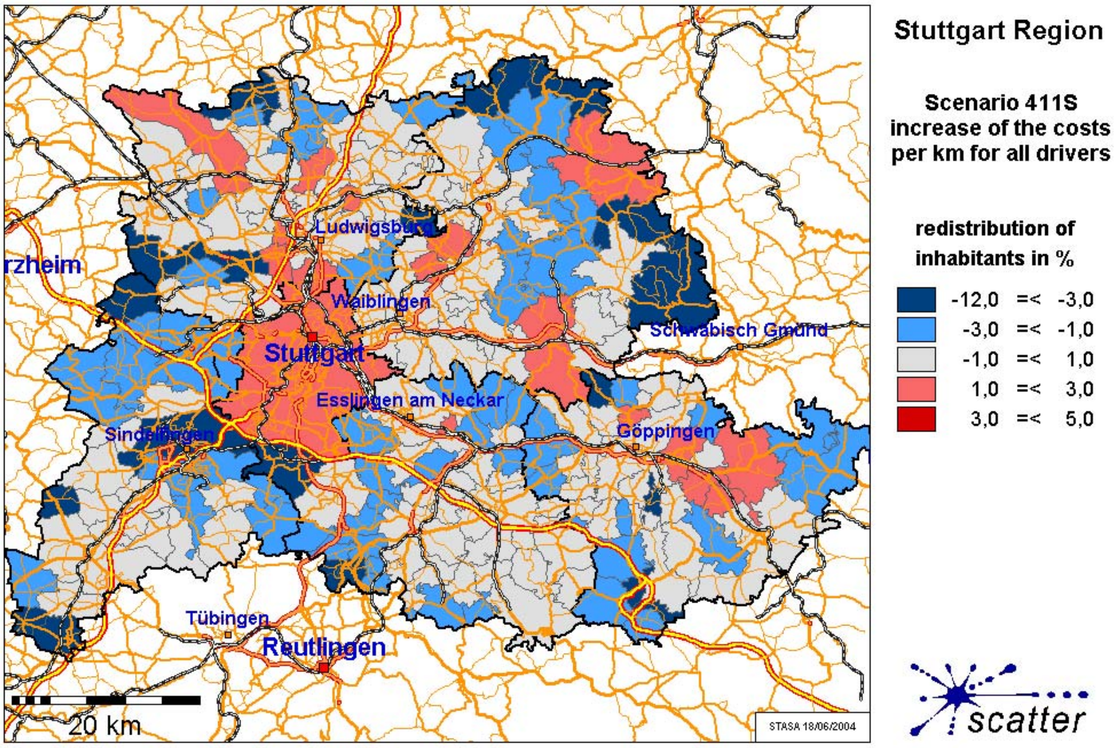


Figure 6.23 Scenario 411S: Redistribution of population in %

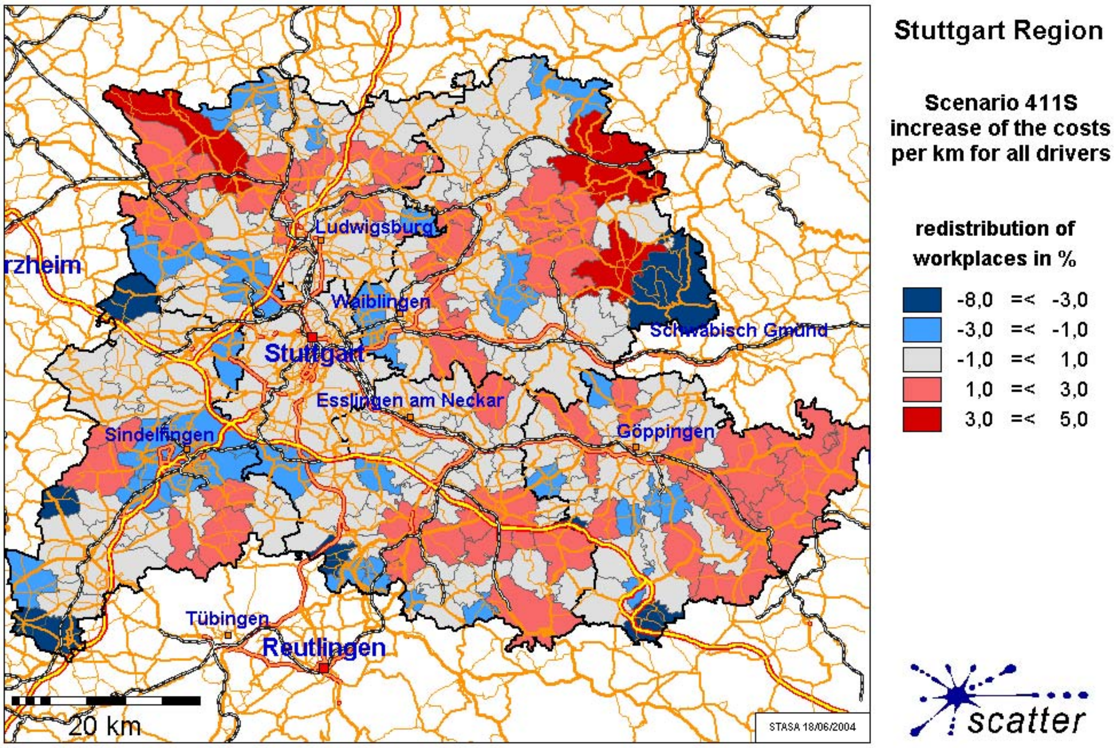


Figure 6.24 Scenario 411S: Redistribution of workplaces in %

Simulation of Scenario 412S:

The effect of a cordon pricing is simulated via this policy measure 412S. The cordon is described by the boundary of the city of Stuttgart and the adjacent communes Ludwigsburg, Sindelfingen, Böblingen and Esslingen.

The effects on the spatial population distribution and the workplace distribution are considerable (+1.5% population increase in urban zones (Tables 6.1-6.13). In the long run, the commuter flows are dramatically redistributed. The overall effect on the total car mileage and the average modal share seems to be negligible. Even the average travel time increases slightly, and the accessibility to the city centre is decreased (-0.4%). However, a positive effect on urban sprawl for households can be stated.

- ***Simulation of Scenario 512S:***

Another strategy influencing urban sprawl could be to decrease of fare by 20% for all public transport users, as described by the policy measure (512S).

According to table 6.1-6.13, a small de-concentration effect on households in urban zones can be found (see also Figure 6.17). The total car mileage in the study area decreases slightly (-0.4%). A positive effect of this policy on the average modal share of public transport in the study area can be stated (+0.4 points) and the passenger-kilometres by public transport per inhabitant increases by about 4%. Because of the increase of public transport, the public transport network and the distribution of jobs and households, an increase of the average travel times (0.4%) is expected. The effect of this policy on the *H*-measure as indicator of sprawl is diverse: The sprawl of households seems to increase slightly but the effect on the distribution of jobs is quite the opposite - slight concentration in the city centre (Figure 6.18).

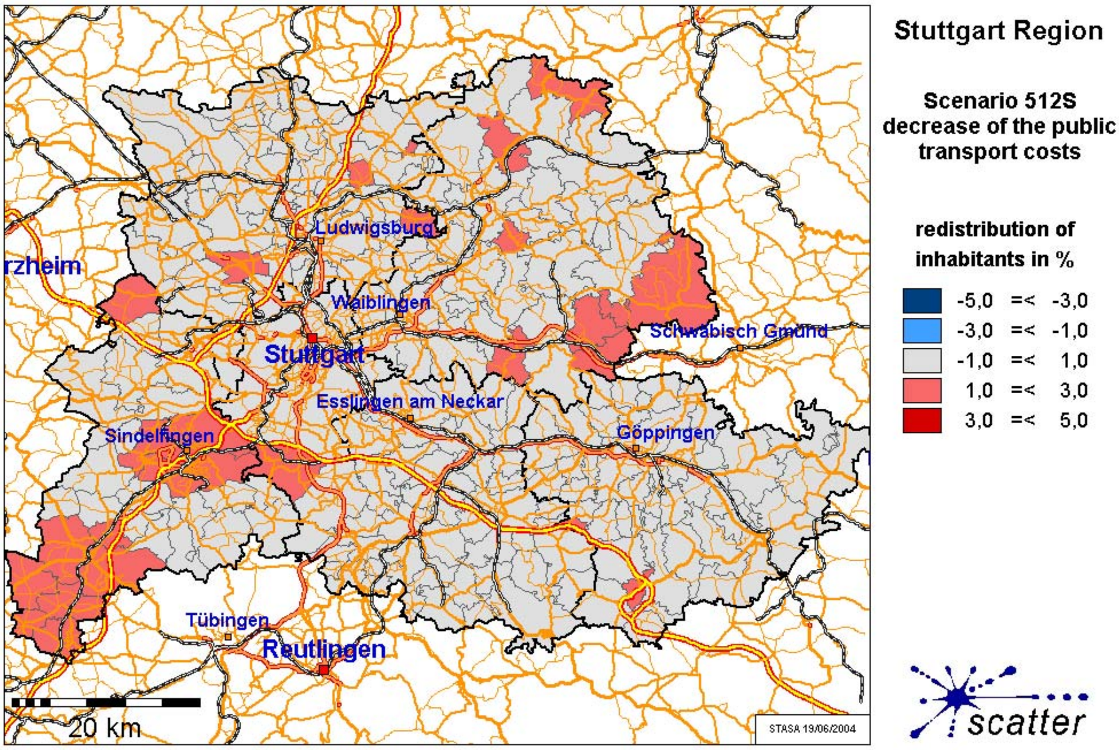


Figure 6.25 Scenario 512S: Redistribution of inhabitants in %

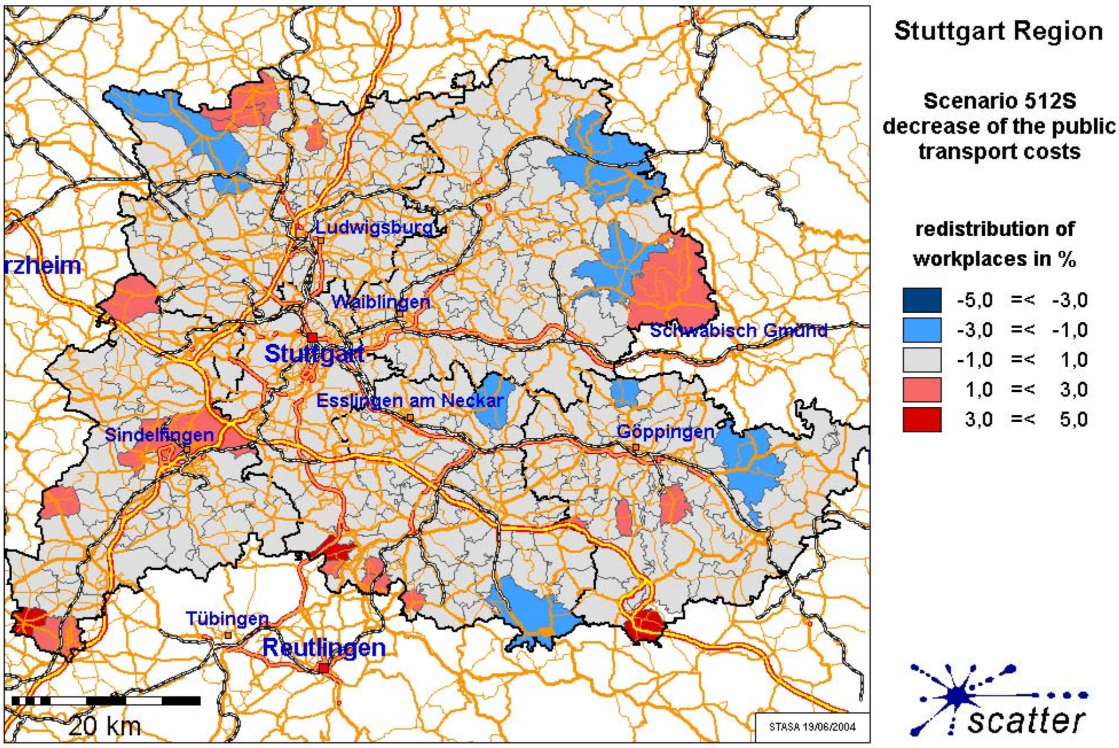


Figure 6.26 Scenario 512S: Redistribution of workplaces in %

➢ ***Simulation of Scenario 811S, 812S, 813S:***

Three combinations of different policy measures were simulated via the STASA model (scenarios 811S-813S) and the overall evaluation of the possibility to reduce sprawl through the scenario 813 is given in the next subsection. As reference scenario 003S is used with time horizon 2020.

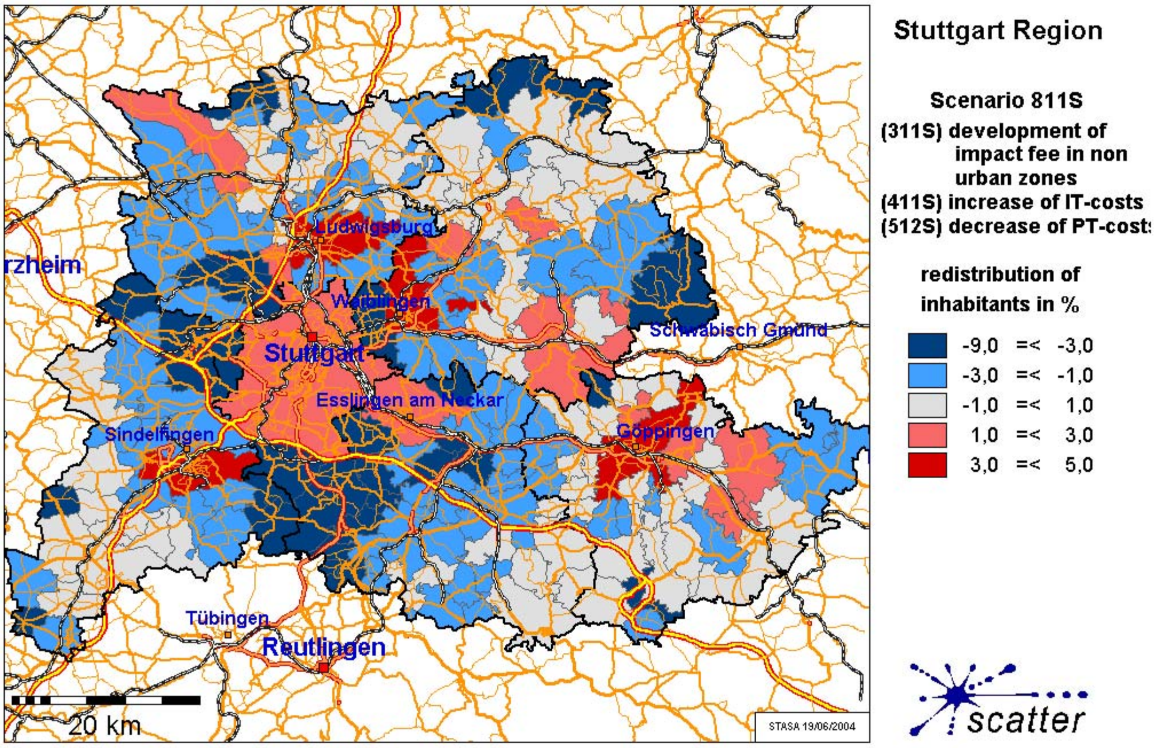


Figure 6.27 Scenario 811S: Redistribution of inhabitants in %

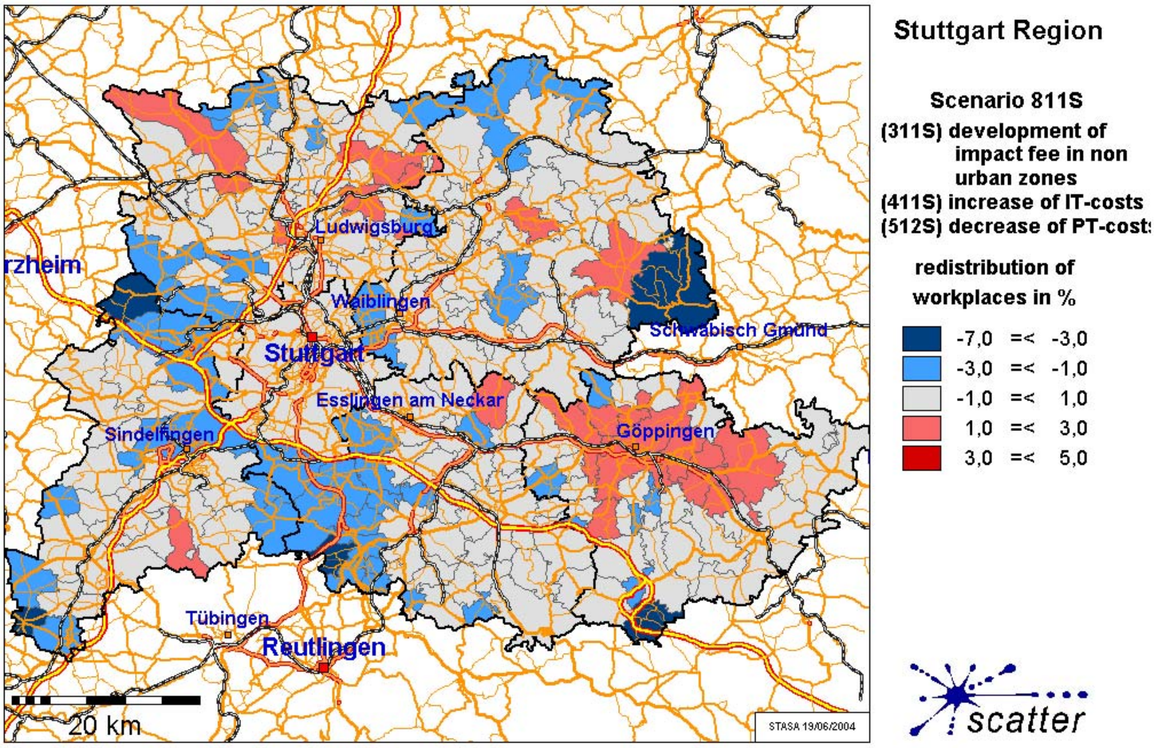


Figure 6.28 Scenario 811S: Redistribution of workplaces in %

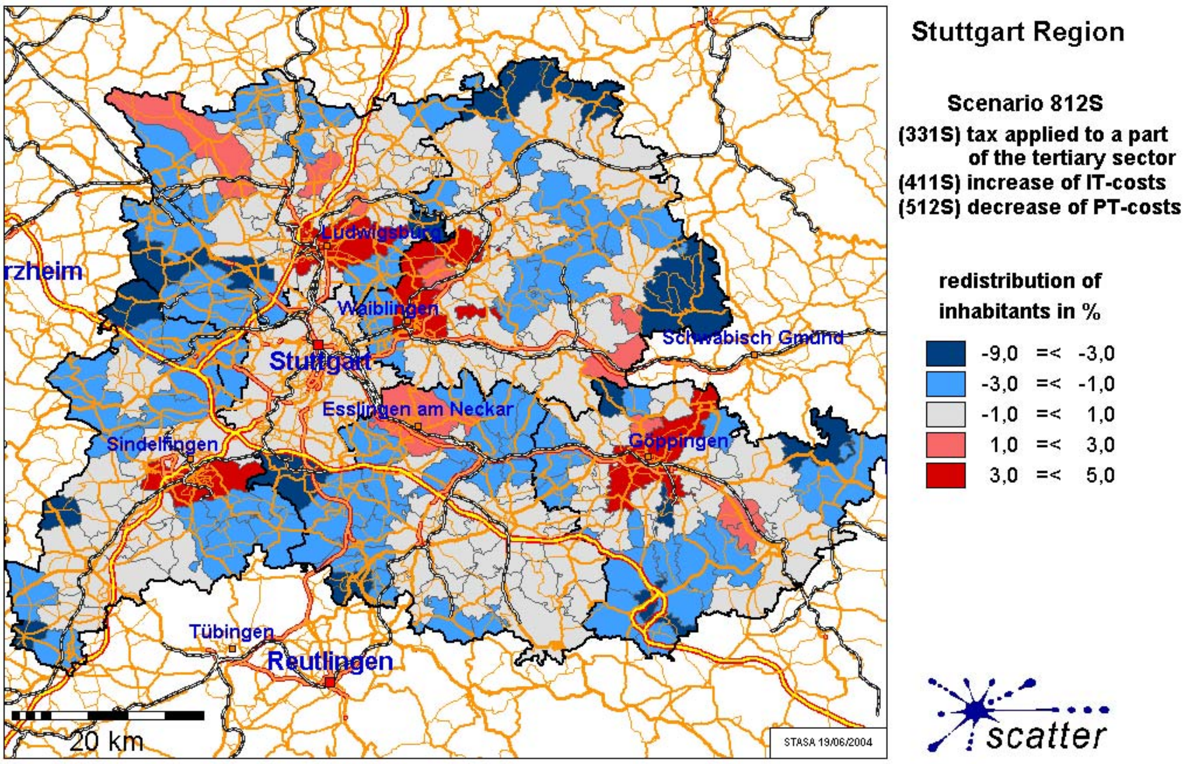


Figure 6.29 Scenario 812S: Redistribution of inhabitants in %

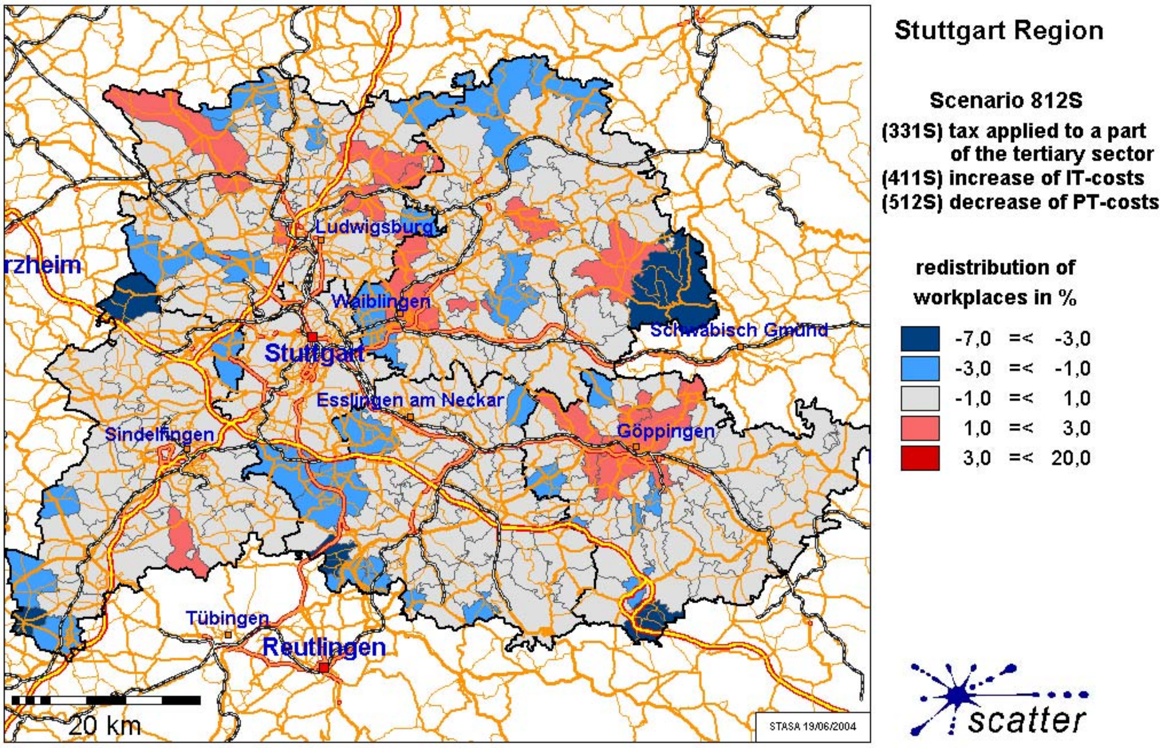


Figure 6. 30 Scenario 812S: Redistribution of workplaces in %

Simulation of Scenario 813S:

The policy 813S consists of an increase by 50% of the private car cost/km applied to all drivers, a decrease of PT fare by 20% for all trips and a fiscal measure on residential developments: see scenario 311 together with an ABC-type policy applied to a part of the tertiary sector.

A combination of the different policy measures (policy 813) has the strongest effect on the reduction of sprawl (Tables 6.1-6.13). A strong concentration of households in the urban zones (+1.0%) and urban centre (+2.8%) must be stated (Figure 6.23). The jobs follow the same pattern (Figure 6.24), namely an increase of jobs in the urban zones (+0.2%) and in the urban centre (+0.6%). This is also confirmed by the variation of the relative *H*-measures.

The total car mileage in the study area decrease by about –5.0% accompanied by a corresponding decrease of CO2 emissions. The average modal share of public transport in the study area increases by about +7.7 points. The passenger-kilometres by public transport per inhabitant increase by about 9.4%.

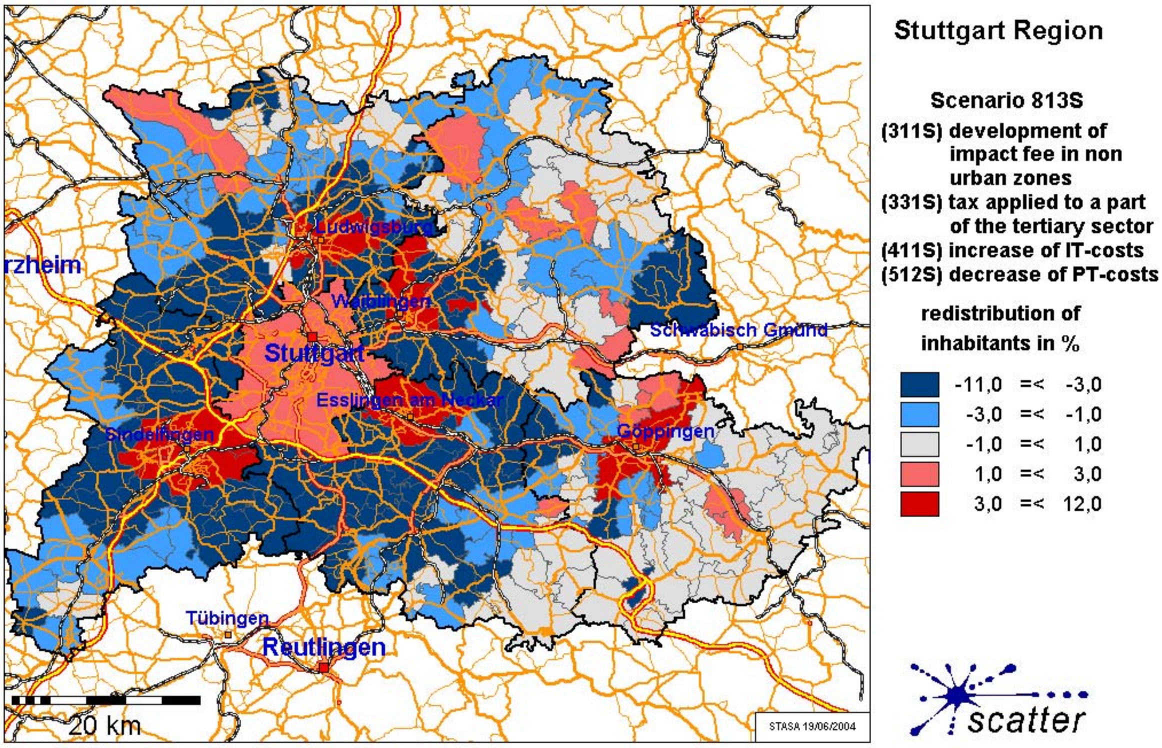


Figure 6. 31 Scenario 813S: Redistribution of inhabitants in %

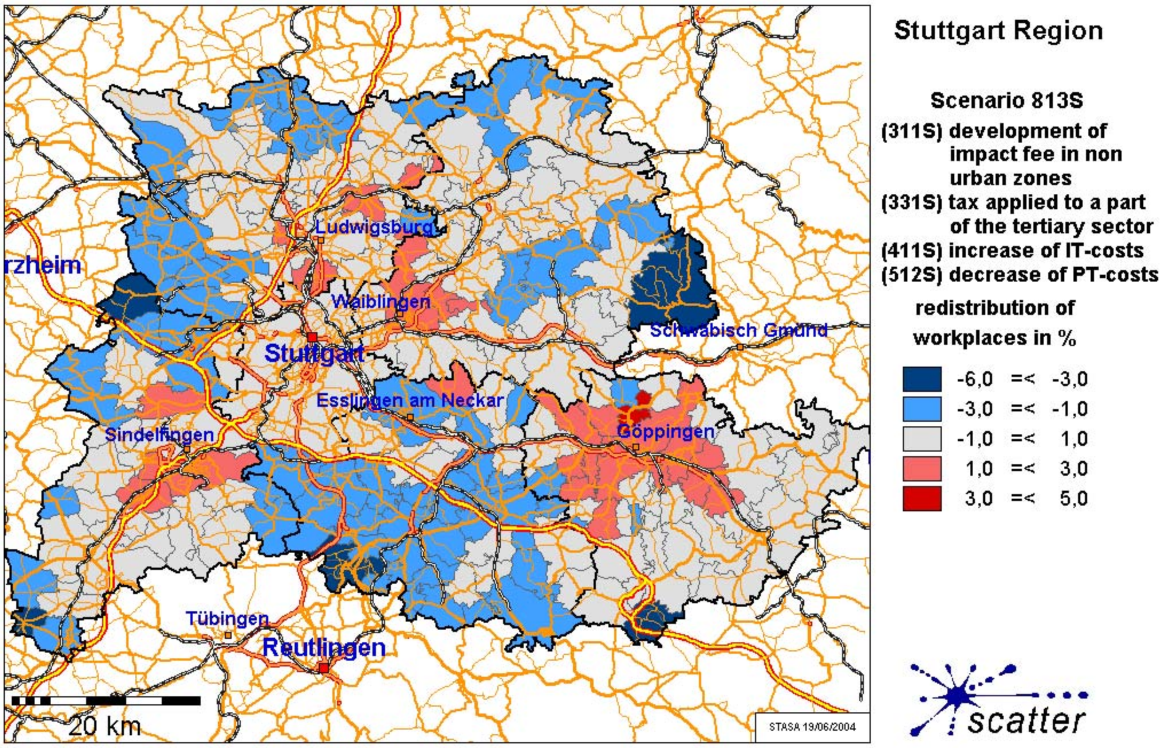


Figure 6. 32 Scenario 813S: Redistribution of workplaces in %