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Meta Analysis of Scenario Results

The aim of the EU project STEPs (Scenarios for the Transport System and Energy Supply and their Potential Effects) was to develop, compare and assess possible scenarios for the transport system and energy supply of the future taking into account the autonomy and security of energy supply, effects on the environment, the economy and technological development and the impacts of measures to internalise external costs and the interactions between transport and spatial development (Fiorello et al., 2006).

In the project six existing integrated models of spatial development in Europe and in five urban regions, Edinburgh, Dortmund, Helsinki, Brussels and South Tyrol in Italy, were applied (more information about the models is available in STEPs, 2005) :

- The ASTRA model describes the linkages between the transport system, the economy and the environment at the European level. Economic activity affects transport demand through the amount of goods produced and higher mobility due to increased employment. The effect on the environment depends on the amount of traffic and the technology of the vehicle fleet.
- SASI is a model of socio-economic development of 1,330 regions in Europe, subject to exogenous assumptions about the economic and demographic development of the European Union as a whole, transport infrastructure investments (in particular of the trans-European transport networks) and other transport policies.
- The Brussels IRIS model is to define a global development strategy through the analysis of the relation between land use, transport, socio-economic data and environment topics. It is a classical four-step transport model predicting peak-hour number of trips generated and attracted by each zone, modal split and traffic assignment.
- The Dortmund model predicts the impacts of policies from the fields of economic development, housing, public facilities, land use and transport in terms of intraregional location decisions of firms, residential developers and households, the resulting migration and travel patterns, construction activity and land use development and environmental quality.

- The Edinburgh MARS (Metropolitan Activity Relocation Simulator) model is a strategic land use and transport interaction model. Accessibility indicators computed from the transport model affect workplace and residential location, and the output of the land use model is used to determine origins and destinations in the transport model.
- The Helsinki model is a land-use transport model using the MEPLAN software. The local economy is represented by an input-output matrix where the interacting factors include economic sectors, population groups and floorspace. Changes of location are introduced by variations of transport costs or new transport infrastructure or services.
- The South Tyrol model is also built on MEPLAN and is therefore similar to the Helsinki model. The same input-output approach is used to simulate the interactions between the economy, population and floorspace in terms of production/consumption relationships including feedback from the transport system to land use and vice versa.

The modelling part of STEPs was a unique collaborative modelling exercise. The co-ordinated application of several complex socio-economic models to a common task presents a unique opportunity to *cross-validate* the models, i.e. to check their validity by comparing their results. There is significant agreement between the models with respect to major trends and policy options and the general conclusions to be drawn from them. However, there are also differences in detail between the models, which are of interest for the validity of the models and the transferability of their results. In this Technical Note the results of the six models applied in STEPs are compared with a *meta analysis* of the results, i.e. an analysis in which the scenario results are objects of a cross-cutting statistical analysis.

Scenarios

The energy scenarios examined in STEPs were designed following common criteria that led to a commonly agreed set of assumptions regarding energy supply, market response and policy options in the field of vehicle technology and transport demand management. All modelling teams in the project adopted these common assumptions in the specification of their scenarios comparable (more information on the scenario results of the individual models is available in STEPs, 2006). So ideally the results of the model simulations of the scenarios should be directly.

However, in practice a direct comparison of the results produced by the different models proved to be difficult. Three aspects of the modelling exercise seem to be of critical importance for the comparability of the model results: scenario specification, model mechanism and model output indicators.

Scenario Specification

Although all models in principle conformed to the common scenario definitions agreed upon, there remained significant differences between the scenario definitions of the six models for the eight 'obligatory' scenarios:

- Four models (ASTRA, Brussels, Helsinki, South Tyrol) adopted POLES-ASTRA forecasts of fuel price, fuel taxes, fuel consumption, car ownership, car fleet composition and emission factors by country. Because POLES models market response based on the different fuel demand of each scenario, this resulted in different fuel prices (after taxes) for each scenario in each country.
- Two models (SASI and Dortmund) assumed average fuel price increases at the pump of 1% p.a. for all A scenarios and 4% p.a. for all B scenarios. To represent changes to the fuel tax

policies they used the average travel/transport cost increases of 0.5% and 3.0% p.a., respectively, recommended in STEPs Deliverable D3.

- The Edinburgh model applied the growth rates of 1% and 4% p.a. to fuel resource costs and assumed fuel tax increases of 0.7% p.a. for petrol and 1.5% p.a. for diesel for the business-as-usual and technology scenarios A0/A1 and B0/B1 and 4.7% p.a. for both petrol and diesel for the demand regulation scenarios A2 and B2.
- More important is the fact that the equilibration mechanisms in the POLES model behind the POLES-ASTRA results lead to much smaller increases in fuel prices than the unmodified growth rates of 1% p.a. for the A scenarios and 4% p.a. for the B scenarios. Together with the response of POLES with respect to fuel efficiency they result in much lower car travel cost increases than if the fuel efficiency gains specified in D 3 are applied.

There are numerous other differences in the interpretation of the scenario specifications between the models (see Spiekermann & Wegener, 2006), which may be of minor importance compared to the fundamental differences in fuel prices discussed above but contribute to the difficulty of comparing the model results.

Model Mechanisms

Because the models applied in the STEPs project were not developed specifically for STEPs but built on existing model applications for regions for which they were already calibrated with existing data, there were significant differences between the models:

- The six models work at different scales.
- The modelled study areas/regions have different characteristics.
- The time horizons of the simulations were different.
- The models cover different subsystems and have different theoretical underpinnings.

These differences were unavoidable in this project. However, they made comparing the model results difficult. A reduction in total greenhouse gas emissions, for instance, has a different meaning in a growing city as Helsinki than in a declining city as Dortmund. Other differences are related to internal model mechanisms. For instance, the way travel time and travel costs are treated in the models has far-reaching consequences for the predicted behavioural response to certain policies.

Model Output Indicators

A final important aspect of comparability between model results are the model output indicators – not only the selection of output indicators but also the form in which they are presented. The comparability of output indicators is the more important as the model results are to be evaluated in a common multicriteria analysis.

Ideally, all relevant indicators should be produced by all models and should be formulated in a way independent from the size and socio-economic characteristics of the different study areas (e.g. demographic or economic growth or decline) and the length of the study period (e.g. forecasting horizon 2020 or 2030).

In STEPs all efforts were made to fulfil the above requirements. A *reference scenario* was defined (Scenario A-1), which served as benchmark against which all policy scenarios are compared. A reference scenario is a powerful mechanism to make model results as robust as possible against data errors, model errors, regional characteristics and different forecasting periods: as all these are the same in the reference scenario and each policy scenario, it can be expected (hoped) that the differences between the reference and scenario a policy scenario reflect only the impact of the policy.

Meta Analysis Method

A meta analysis is a form of scientific inquiry in which not empirical phenomena but the results of scientific research are the objects of investigation. Meta analysis is a way of cross validation of models to enhance the reliability and credibility of model forecasts by systematically comparing the results of different models based on similar assumptions.

Because of the substantial time and effort needed to set up an integrated land-use transport model for a particular region, there have been only few projects in which more than one of such models were applied so that rigorous cross validation of models could be performed. Exceptions are the International Study Group on Land Use Transport Interaction ISGLUTI (Webster et al., 1988; Wegener et al., 1991) and the EU project PROPOLIS – Planning and Research of Policies for Land Use and Transport for Increasing Urban Sustainability (Lautso et al., 2004).

In an ideal cross validation meta analysis the models to be compared work with rigorously identical assumptions. However, where, as in STEPs, rigorously comparable scenario specifications were not possible, it is still possible to conduct a cross-validation meta analysis by comparing *not scenarios with identical names* but *scenarios with similar specifications* irrespective of their name.

The meta analysis results proceeds by linking model output and model input by univariate or multivariate statistical estimation techniques. In this way it is attempted to identify and isolate the specific contribution of relevant trends or policy packages to changes in the output variables observed in the model results, just like in empirical research it is attempted to explain observed changes of phenomena by statistically linking them to potential causal factors. In both cases it is concluded that, if the statistical properties of the link (e.g. expected sign or confidence level) appear sound, the statistical link can be interpreted as a causal one, i.e. the output indicators can be interpreted as *impacts* and the input variables as *causes*.

To achieve this, a meta analysis experiment was conducted, in which the scenarios modelled by the six models were taken as observations. Preliminary results of a meta analysis were already presented in STEPs Deliverable D 5 (Section 2.5). After these preliminary tests the modelling teams were asked to provide for each of the modelled scenarios two sets of rigorously standardised input and output indicators:

- *Input indicators, or possible causes*. One group of indicators are model *input variables* set exogenously by the model user, such as assumptions about exogenous global developments, such as fuel price changes or technological progress, or explicit policy measures, such as fuel taxes, road pricing, speed limits or land use controls. In the statistical analysis these variables are independent or explanatory variables.
- *Output indicators, or possible impacts*. The other group of indicators are model *output indicators* of scientific and policy interest for which one would like to know which policies and other assumptions caused their changes in the models. For this, the causal chain is followed backwards until it is possible to identify the input variables (policies or assumptions) that caused those changes. This is done by statistical estimation methods, such as univariate or multivariate regression, with the output indicators as dependent variables.

Table 1 contains the input and output indicators collected for the meta analysis from the ASTRA, Brussels, Dortmund, Edinburgh, Helsinki and South Tyrol models.

Table 1. Input and output indicators for the meta analysis

			Indicator	**Unit**
Input	1	gdpc	GDP per capita	€
	2	fcpl	Fuel cost for car users including taxes	€ per l
	3	twrk	Telework (share of non-telework jobs)	%
	4	luc	Land use control (1=none, 2=weak, 3=strong)	dummy
	5	devl	Developed land per capita	sqm
	6	apts	Average public transport speed	km/h
	7	acs	Average car speed	km/h
	8	cptt	Cost of a public transport trip	€
	9	afcc	Average car fuel consumption	l/100 km
	10	palt	Share of alternative vehicles	%
	11	cc	Cost of car ownership per car per month	€
	12	ctc	Car travel cost	€/km
	13	ctcp	Car travel cost including road pricing	€/km
Output	14	tdpc	Total distance travelled per capita per day	km
	15	cdpc	Car distance per capita per day	km
	16	adt	Average distance per trip	km
	17	adct	Average distance per car trip	km
	18	swct	Share of walking and cycling trips	%
	19	sptt	Share of public transport trips	%
	20	sct	Share of car trips	%
	21	fcpc	Car fuel consumption per capita per day (l)	l
	22	co2	CO_2 emissions by transport per capita per day (kg)	kg
	23	nox	NO_x emissions by transport per capita per day (g)	g
	24	pm	PM emissions by transport per capita per day (mg)	mg
	25	cown	Car ownership per 1,000 population	#
	26	tdpm	Traffic deaths per million population per year	#
	27	acc	Accessibility	index

Tables A 1 to A7 in the Annex contain the values of the 27 indicators of the six models used in the meta analysis. Of the 56 scenarios modelled by the six models, 54 were selected for the meta analysis. Scenarios C2 and C3 of Dortmund were excluded as they are too extreme to be compared with the other scenarios. The 27 indicators of the 54 scenarios were subsequently transformed into index form, i.e. expressed as percent of the corresponding values in the Reference Scenario A-1 in the target year of the model 2020 or 2030, respectively.

In the following sections, the results of the meta analysis are presented, first the results of univariate regressions and then the results of multivariate regressions.

Univariate Regressions

Univariate regressions explore the *correlation* between *two* scenario attributes based on a *hypothesis* about a cause-effect relationship between them. If the coefficient of determination (r^2) is high, the agreement between the models about the cause-effect relationship is high. The effects explored can be classified as *direct* or *indirect* effects.

Direct Effects

Direct effects of energy trends or policies are *behavioural responses* to changes in transport options due to energy trends or policies, such as changes in fuel prices, fuel taxes public transport fares, road charges, parking fees, vehicle technology, fuel consumption, travel speed, traffic regulations or land use regulations. Figures 1 to 6 show examples of direct effects of travel cost increases.

One example of a behavioural response is choice of mode. Figures 1 and 2 show the shares of trips by public transport and car, respectively, predicted by the six models as a function of car travel cost including road pricing. The scatter diagrams shows the large differences in scenario definitions.

In a perfect world, all scenarios with the same name should have the same assumptions on car travel costs, i.e. lie on the same vertical line. However, the assumptions about car travel cost increases differ substantially in the scenarios: In the Brussels and South Tyrol models, for instance, car travel cost in the worst-case scenario B2 increase by 42 and 27 percent, respectively, whereas in the Dortmund model they increase by 450 percent.

However, the scatter diagrams show also that the simulation results of the six models, despite their differences in scenario specification, are more similar than they appear at first sight. If one compares not scenarios with identical *names* but scenarios with similar *assumptions* about car travel cost increases, the six models show much agreement: they all show a consistent reduction in the share of car trips in response to car travel cost increases.

Similar conclusions can be drawn from Figure 3, which shows car distance as a function of car travel cost. Here, too the same differences in scenario specification are visible, but also a similar agreement about the likely response of car drivers to rising car travel costs. The dotted regression line indicates that the price elasticities assumed by the models, if taken together, are relatively low and closer to -0.2 than the proverbial price elasticity of -0.3 usually found in transport behaviour (the red dotted line). This may reflect the fact that many people, in particular long-distance commuters, depend on the car and cannot easily switch to other modes.

Similar results are achieved if fuel price including tax is used as explanatory variable (Figure 4) or if average trip length is used as dependent variable (Figures 5 and 6).

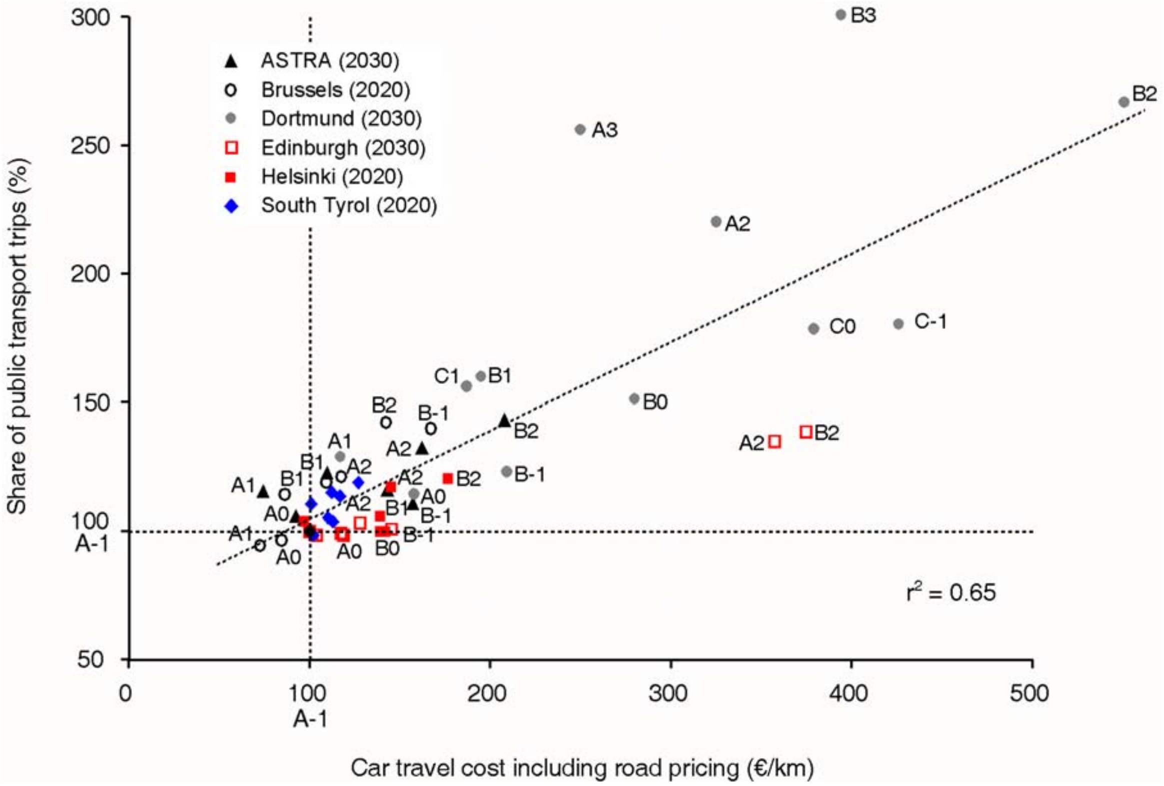


Figure 1. Share of public transport trips v. car travel cost including road pricing

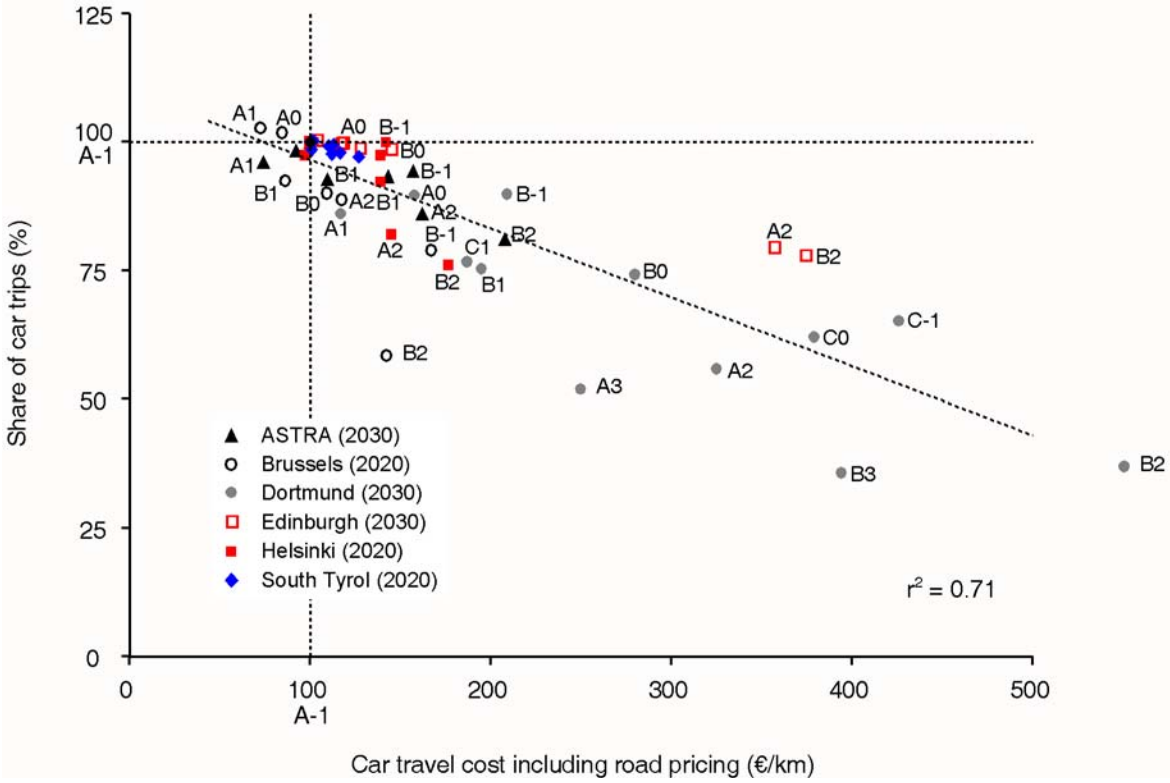


Figure 2. Share of car trips v. car travel cost including road pricing

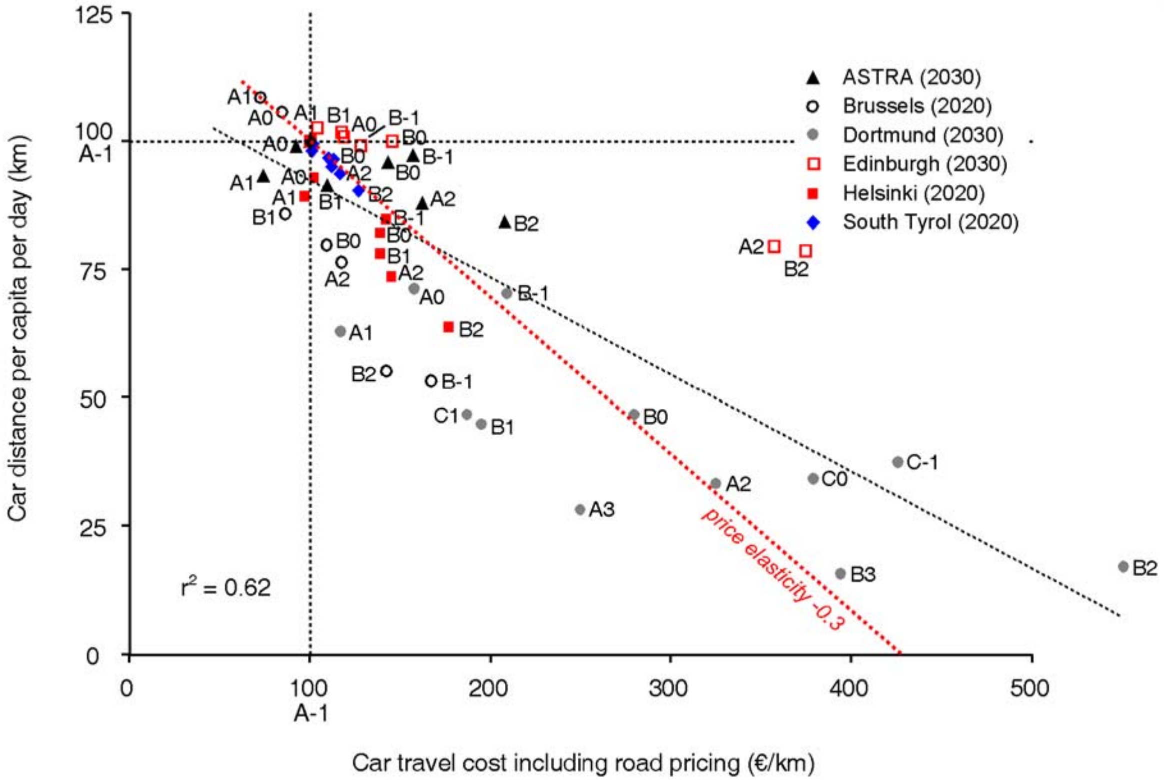


Figure 3. Car distance v. car travel cost including road pricing

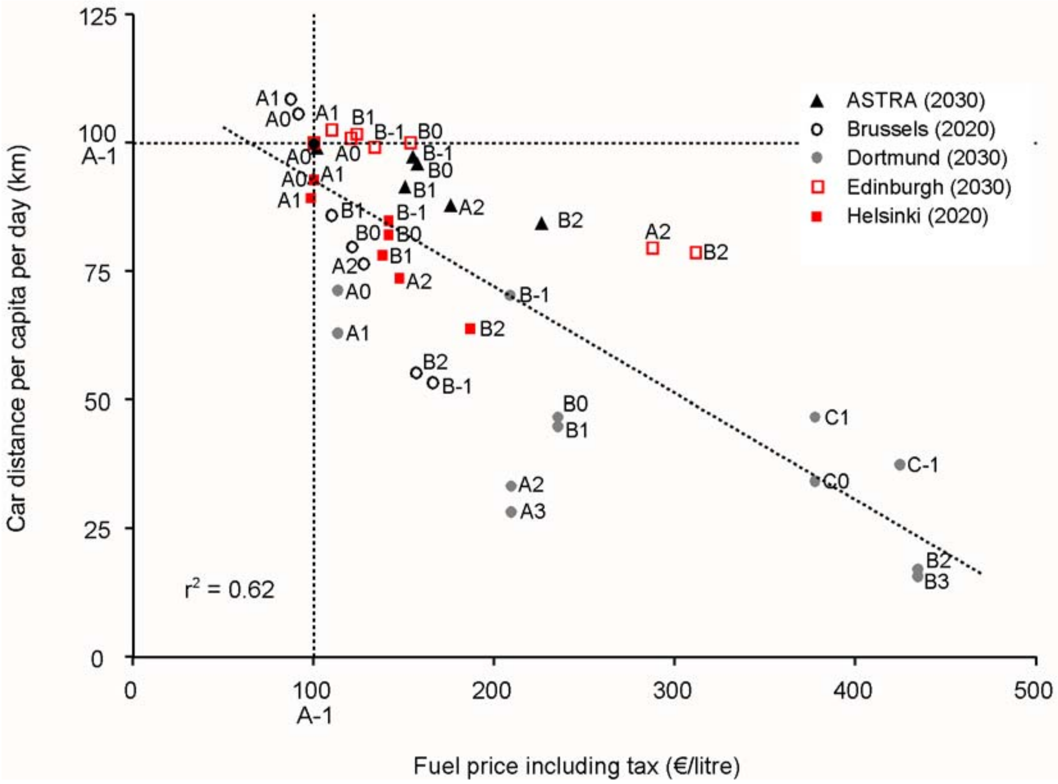


Figure 4. Car distance v. fuel price including tax

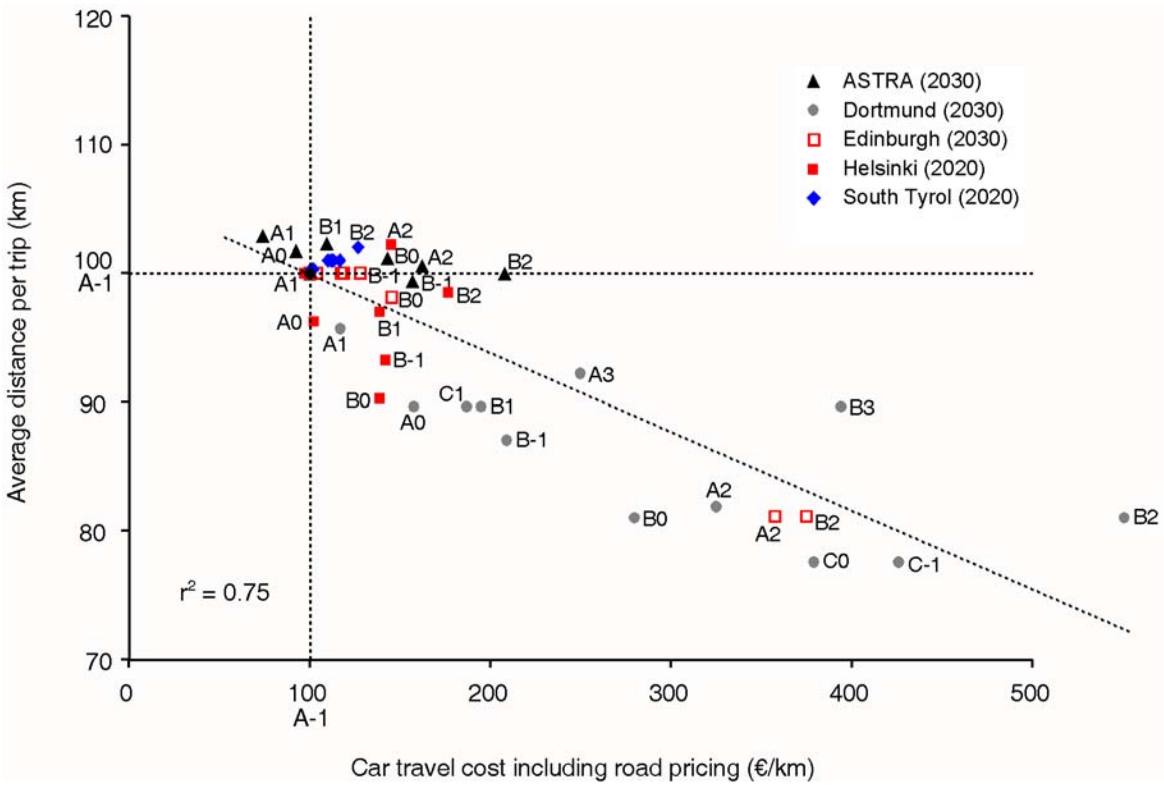


Figure 5. Average distance per trip v. car travel cost including road pricing

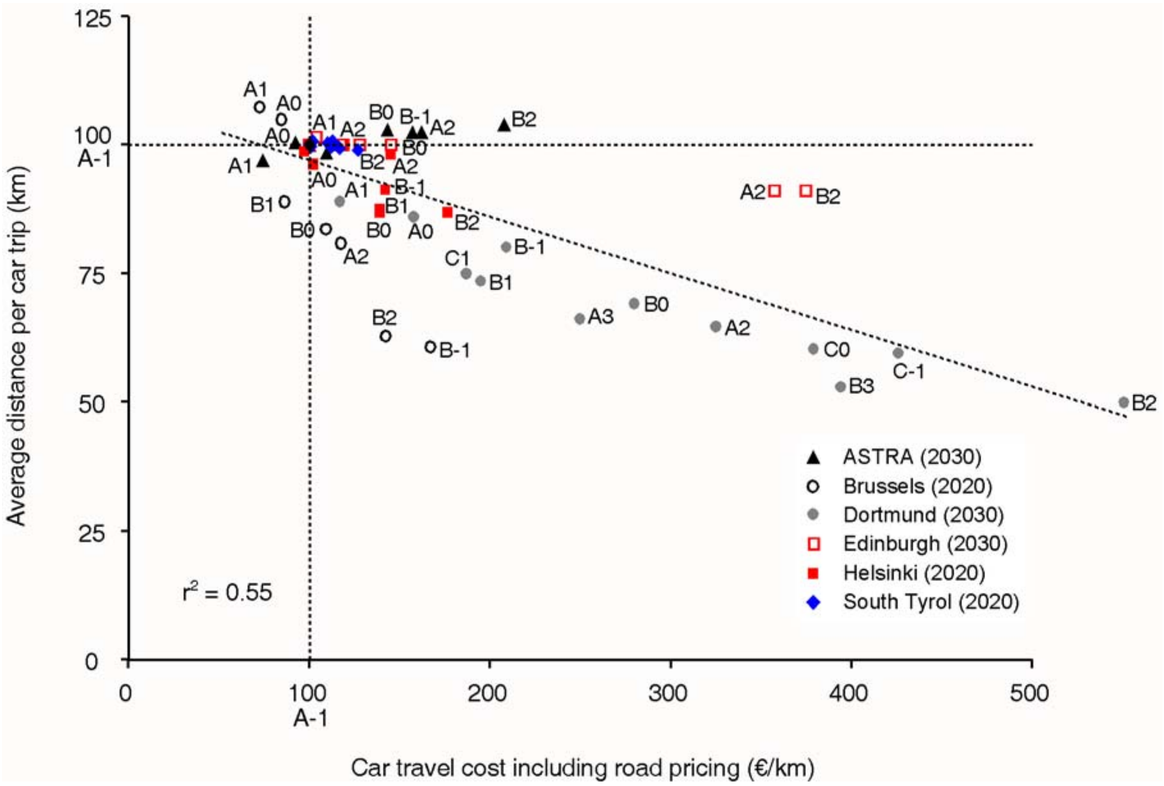


Figure 6. Average distance per car trip v. car travel cost including road pricing

Indirect Effects

Indirect effects of energy trends or policies are *changes caused by behavioural responses* to changes in transport options due to energy trends or policies, such as CO_2 emissions, NO_x emissions, PM emissions, traffic deaths, traffic injuries and accessibility. Figures 7 to 10 show examples of indirect effects.

Figures 7 to 9 show emissions of CO_2, NO_x and PM and Figure 10 traffic deaths as functions of car distance travelled. Here the agreement between the models is even better. It appears that the modellers used the same or very similar emission and accident probability functions. Figure 10 is based on the results of only three models because the other three models did not predict traffic accidents.

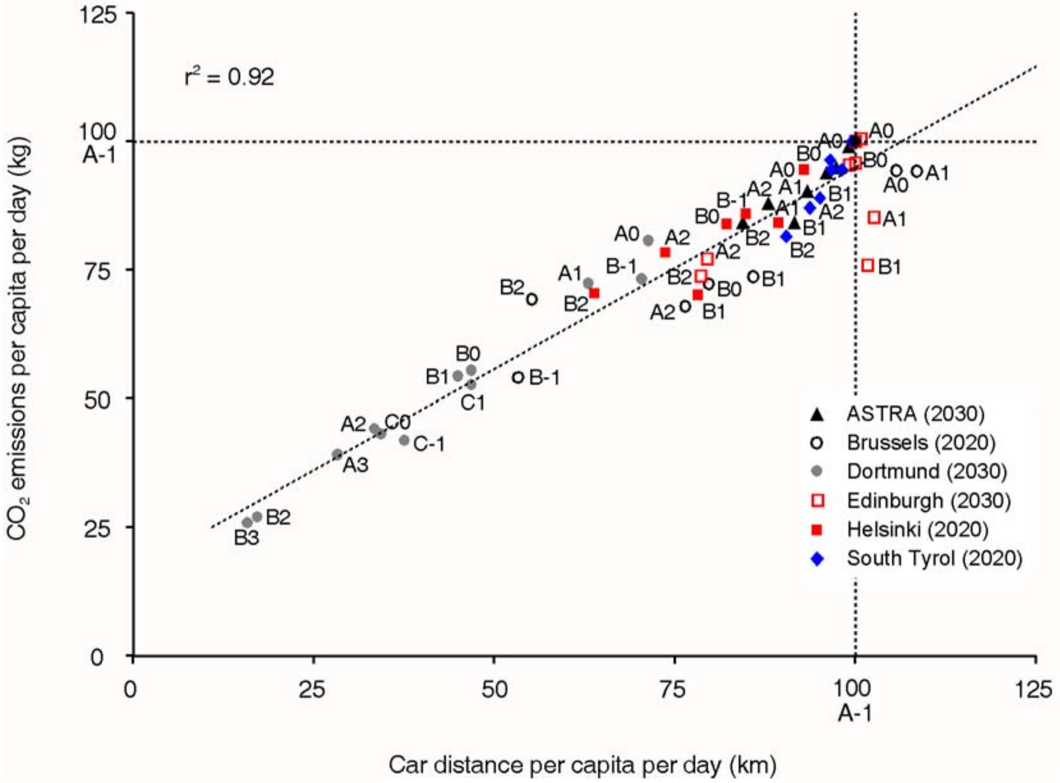


Figure 7. CO$_2$ emissions v. car distance

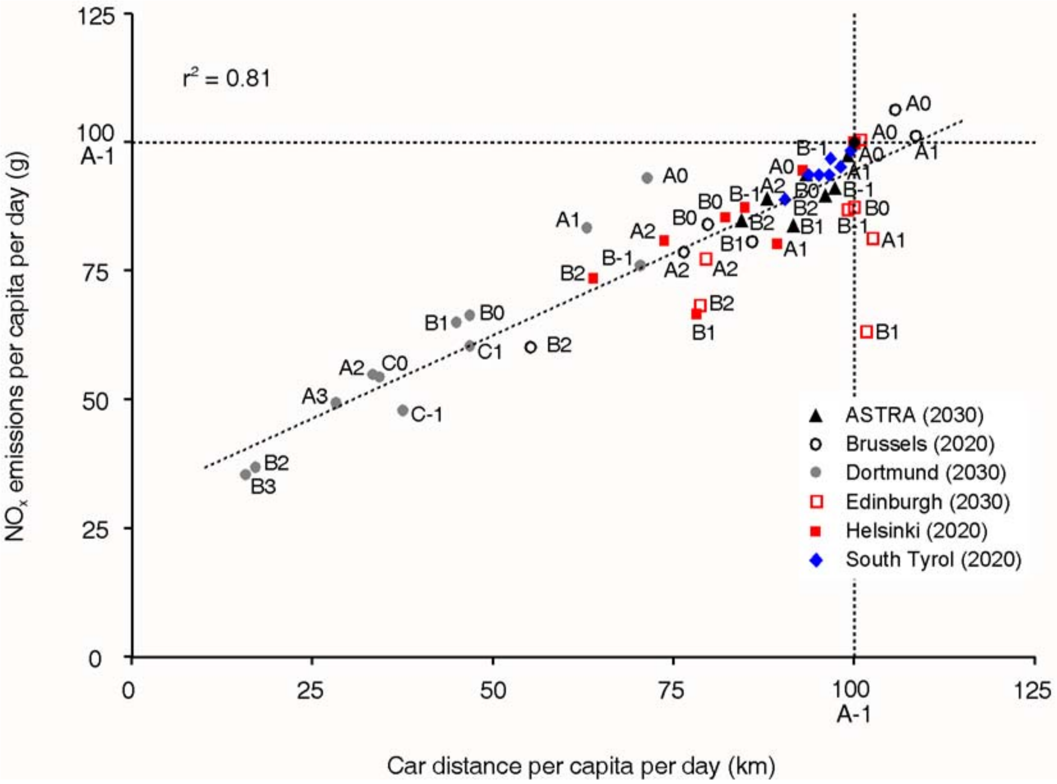


Figure 8. NO$_x$ emissions v. car distance

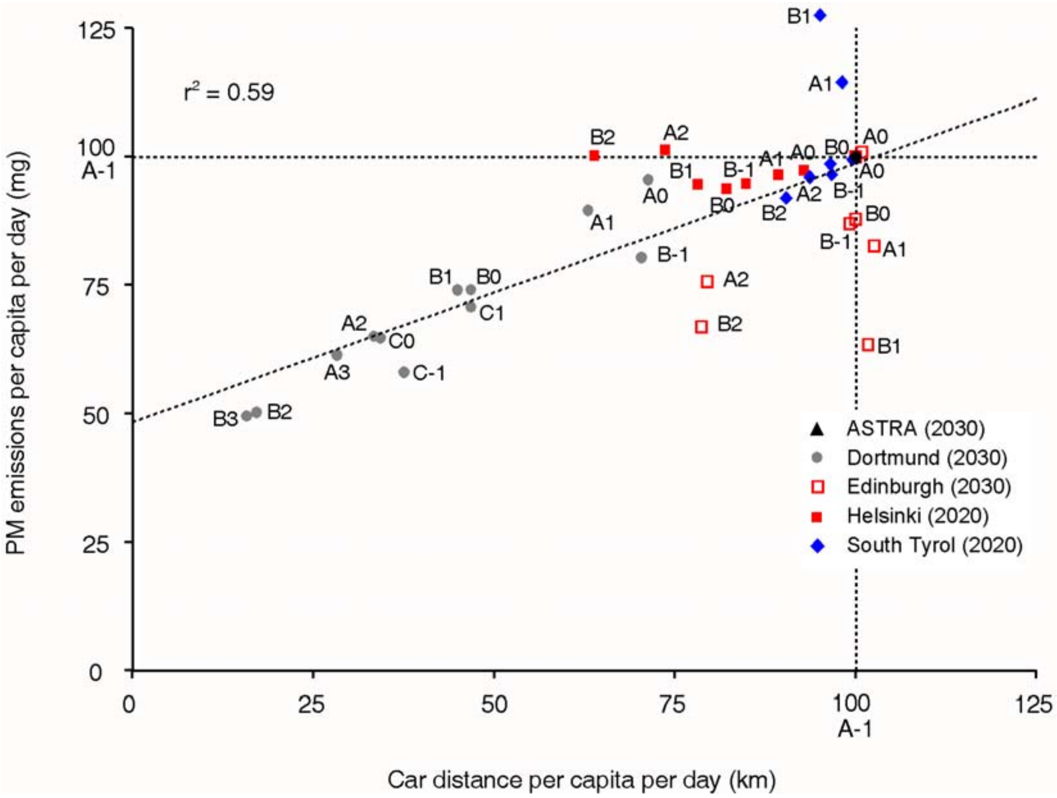


Figure 9. PM emissions v. car distance

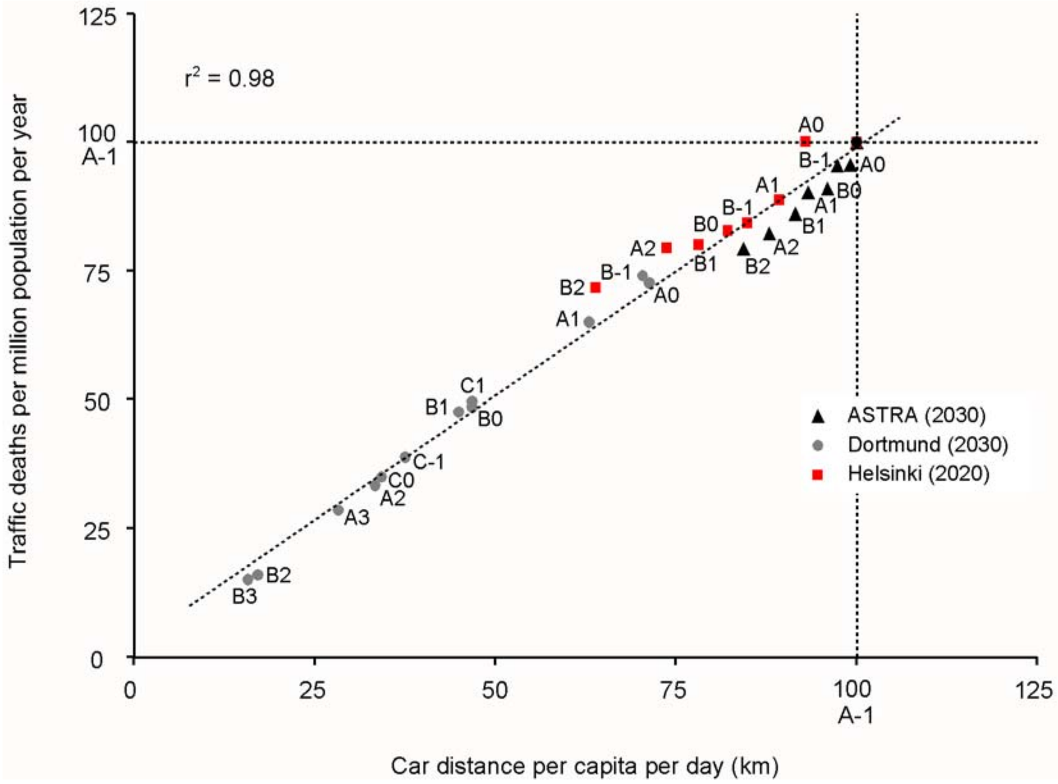


Figure 10. Traffic deaths v. car distance

Multivariate Regressions

Multivariate regressions explore the correlation between three or more scenario attributes based on *hypotheses* about cause-effect relationships between them. One of the scenario attributes is the *dependent* variable to be explained. The other attributes are the *independent* or *explanatory* variables. Multivariate regressions have the advantage over univariate regressions that they take account of interactions between explanatory variables. If the coefficient of determination (r^2) is high, the agreement between the models about the cause-effect relationships is high. A problem with multivariate regressions is that only scenarios can be included in the analysis for which all relevant dependent variables were provided. Figures 11 to 19 show examples of multivariate regressions.

Figure 11 shows the same dependent variable as Figure 2, share of car trips. The indicator values along the horizontal axis of Figure 11 correspond to those along the vertical axis of Figure 2. Only 46 of the 54 scenarios could be included in the regression because the Brussels model did not provide travel speed indicators. It is obvious that the predictive power of the statistical model improves if more than one explanatory variables are considered as indicated by the higher r^2 value.

The table under the scatter diagram shows the list of input indicators or explanatory variables that were selected by the regression procedure to predict the output indicator share of car trips. The signs of the regression coefficients of the explanatory variables indicate that the share of car trips grows if public transport becomes slower and/or more expensive and/or car travel becomes faster and/or cheaper. Interestingly, car use goes down if the share of alternative vehicles in the car fleet grows, presumably because alternative vehicles are assumed to be more expensive than conventional cars.

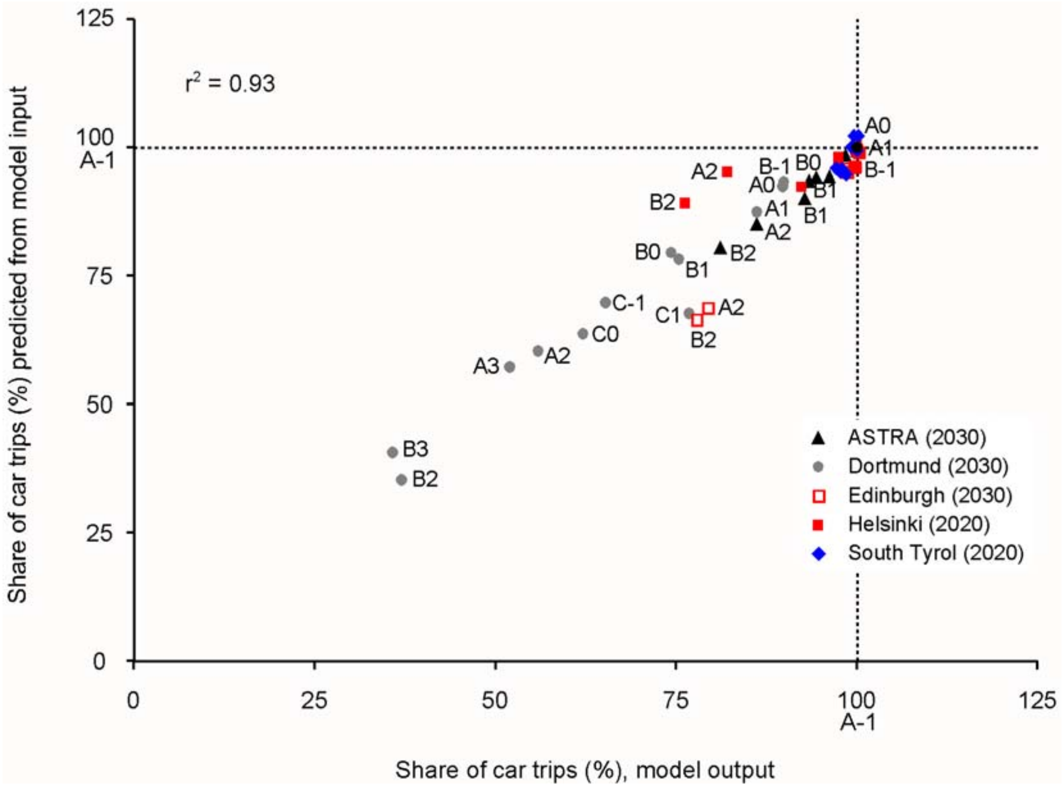
Figure 12 shows the same dependent variable as Figure 3, car distance per capita per day. Again the results of the Brussels model had to be excluded because no travel speed indicators were available for Brussels. The signs of the coefficients indicate that car distances grow if public transport becomes slower and car travel less expensive. Again car use declines if the share of alternative vehicles in the car fleet grows.

Figures 13 shows the same dependent variable as Figure 7, CO_2 emissions per capita per day. As to be expected, car distance per capita per day, is selected as main explanatory variable. Introducing also the share of public transport trips adds only little to the r^2 value.

Figure 14 shows the same dependent variable as Figure 10, traffic deaths per million population per year, again only for those models that predict traffic accidents. As this is an indirect effect, the dependent variables are output variables of the models, such as distance travelled by car or share of car trips. As to be expected, the regression procedure selects exactly those variables which were used in the model to calculate the number of traffic deaths. And as not only one explanatory variable is considered, the estimation is almost perfect, better than that of the univariate regression shown in Figure 10. The result also shows that relatively simple accident probability functions are used by the models, probability functions that do not take account of the significant achievement in traffic safety made in the last years.

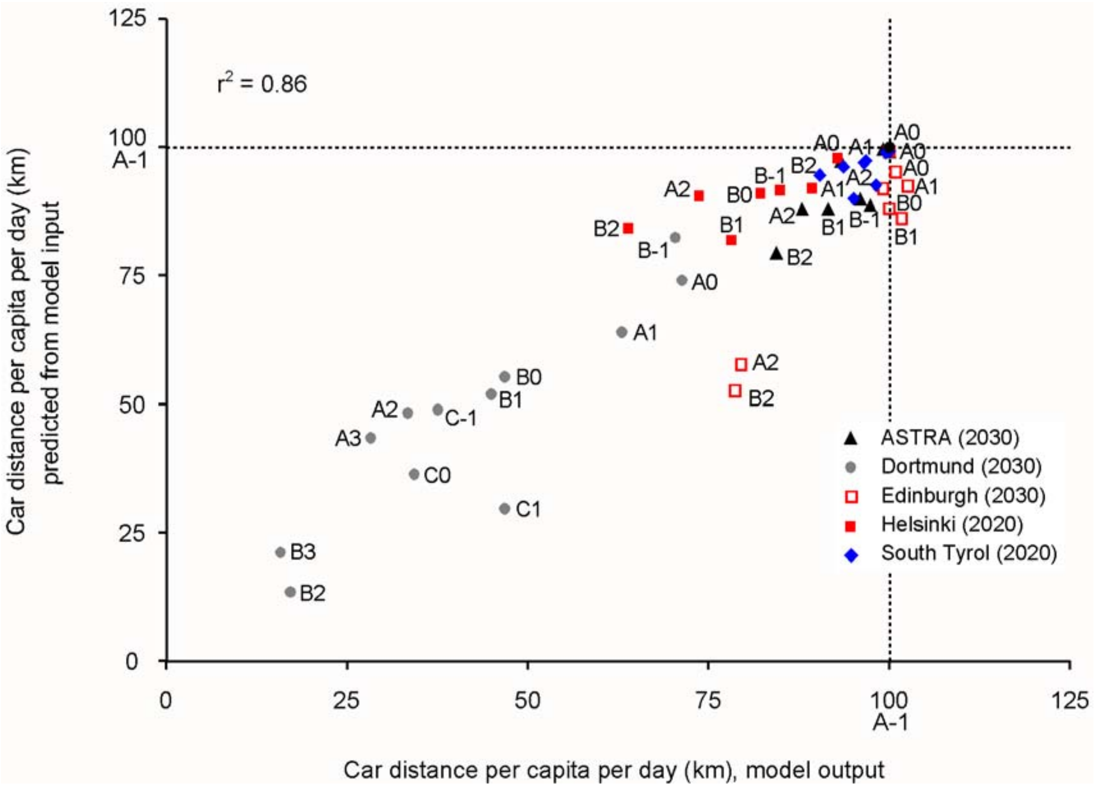
Figure 15 shows the results of the multiple regression for car ownership. According to the regression, average car fuel consumption and car travel costs are the main explanatory variables, though with different signs – this may indicate the trade-off people make between their desire to drive larger cars and their and the need to save travel costs, but may also be due to the fact that no income variable was included in the data set for the meta analysis.

Figure 16 shows the results of the multiple regression for accessibility. Main explanatory variables are average car speed and car travel cost, with the signs as expected. However, the low r^2 value indicates that the models applied very different definitions of accessibility. Therefore the same analysis was conducted for three models for Dortmund, Edinburgh and South Tyrol separately. (see Figures 17 to 19). It becomes apparent that the three models give different weights to car travel and public transport. Whereas in the Dortmund model accessibility is largely dominated by car speed and affordability, the other two models also consider public transport speed and fares.



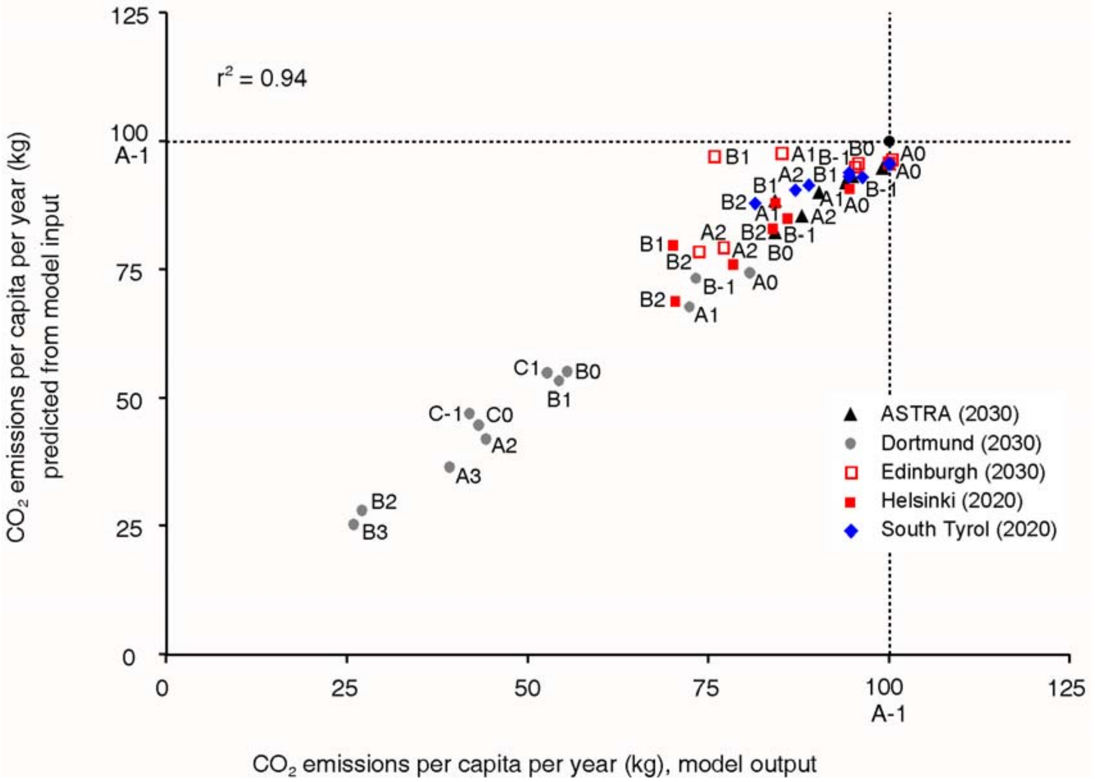
		Explanatory variables	Coefficient
6	apts	Average public transport speed (km/h)	-0.35609
7	acs	Average car speed (km/h)	1.06922
8	cptt	Cost of a public transport trip (€)	0.23018
10	palt	Share of alternative vehicles (%)	-0.00910
12	ctc	Car travel cost (€/km)	-0.10308
		Constant	16.28384
Number of scenarios			46
F level			-0.43898
Standard deviation of estimate			4.97826
Multiple correlation coefficient			0.96253
Coefficient of determination (r^2)			0.92647

Figure 11. Multiple regression of share of car trips



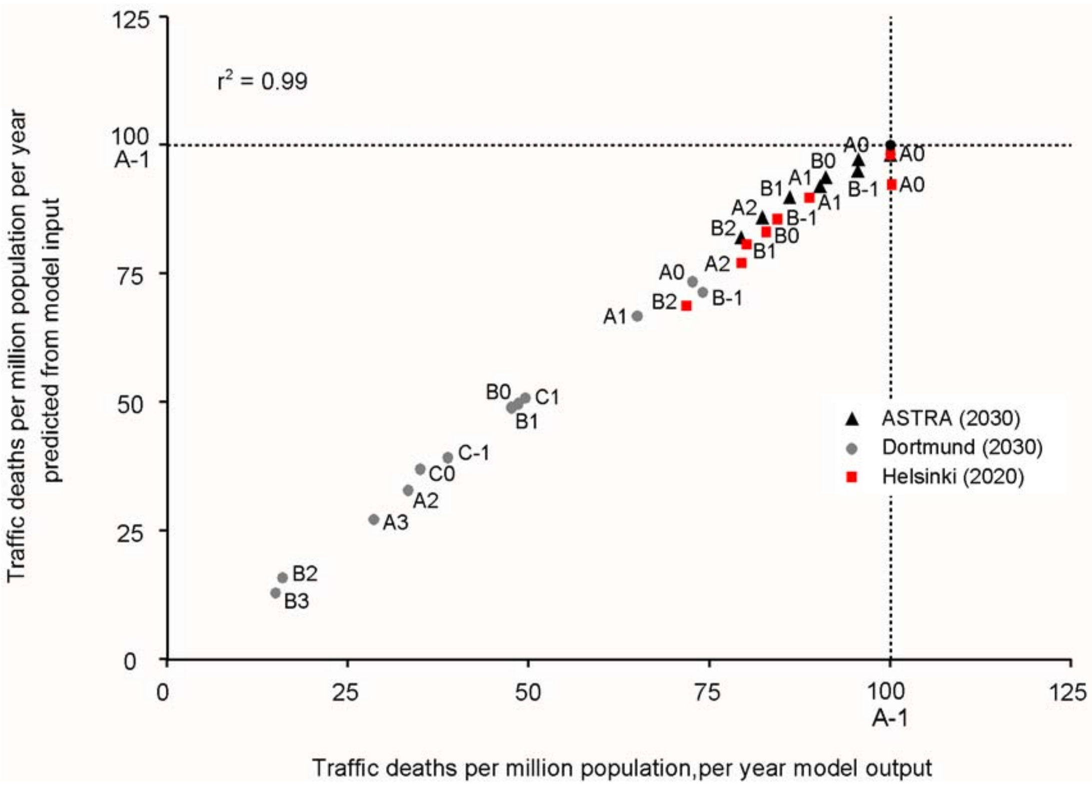
		Explanatory variables	Coefficient
6	apts	Average public transport speed (km/h)	-0.23280
10	palt	Share of alternative vehicles (%)	-0.03106
13	ctcp	Car travel cost including road pricing (€/km)	-0.15433
		Constant	141.03989
Number of scenarios			46
F level			1.19170
Standard deviation of estimate			9.83328
Multiple correlation coefficient			0.92731
Coefficient of determination (r^2)			0.85990

Figure 12. Multiple regression of car distance



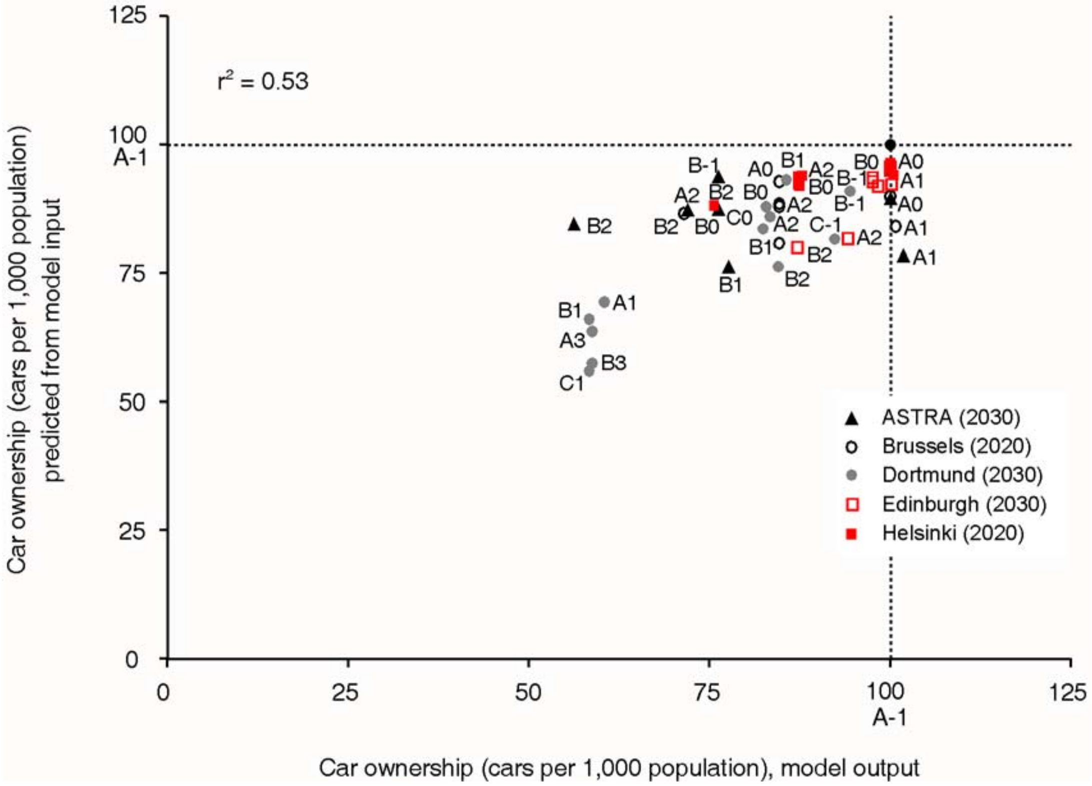
		Explanatory variables	Coefficient
15	cdpc	Car distance per capita per day (km)	0.06915
19	sptt	Share of public transport trips (%)	0.03749
		Constant	29.36626
Number of scenarios			46
F level			1.83565
Standard deviation of estimate			5.14750
Multiple correlation coefficient			0.97059
Coefficient of determination (r^2)			0.94205

Figure 13. Multiple regression of CO_2 emissions



		Explanatory variables	Coefficient
15	cdpc	Car distance per capita per day (km)	0.75100
16	adt	Average distance per trip (km)	0.17353
19	sptt	Share of public transport trips (%)	-0.10058
		Constant	15.77382
Number of scenarios			30
F level			2.32100
Standard deviation of estimate			2.53968
Multiple correlation coefficient			0.99594
Coefficient of determination (r^2)			0.99189

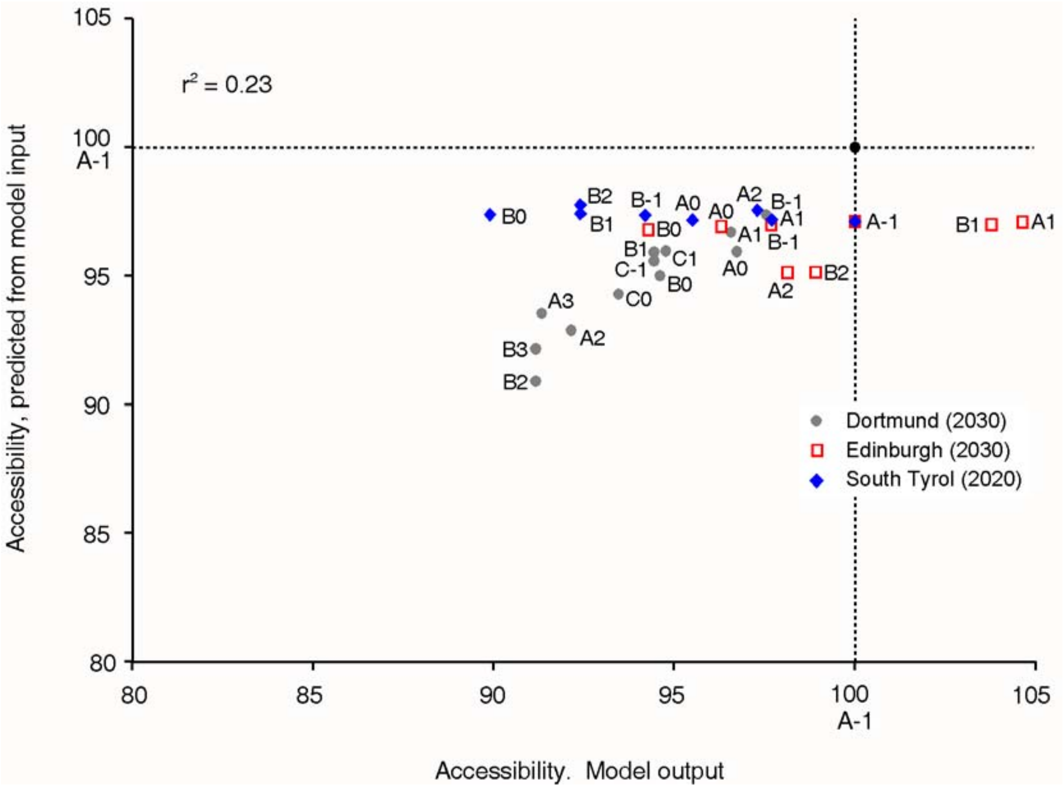
Figure 14. Multiple regression of traffic deaths



Explanatory variables			Coefficient
9	afcc	Average car fuel consumption (l per 100 km)	0.71027
13	ctcp	Car travel cost including road pricing (€/km)	-0.04298
		Constant	28.89003

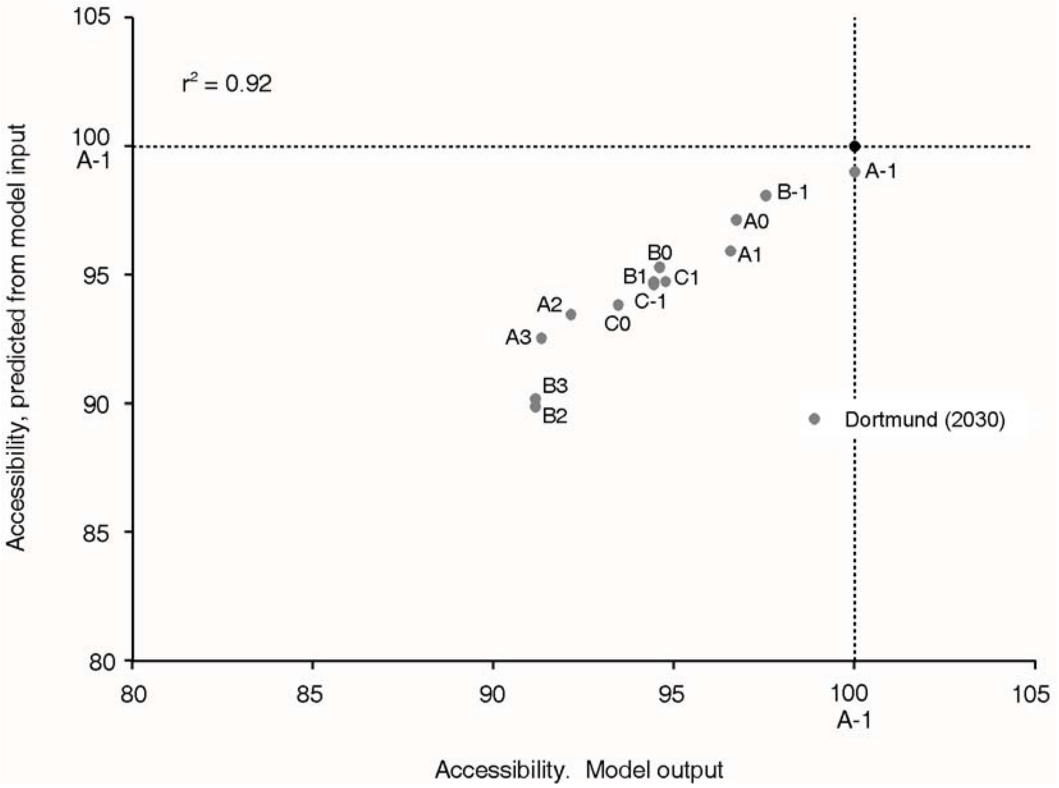
Number of scenarios	46
F level	10.25562
Standard deviation of estimate	9.80873
Multiple correlation coefficient	0.72837
Coefficient of determination (r^2)	0.53053

Figure 15. Multiple regression of car ownership



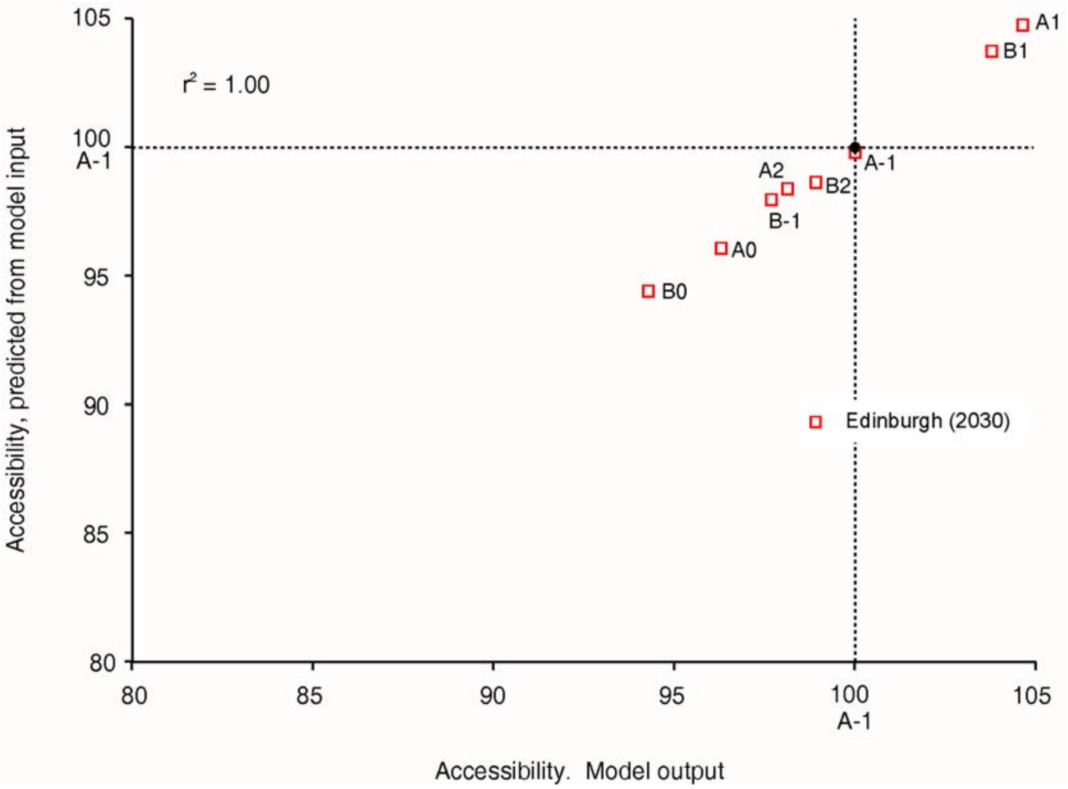
		Explanatory variables	Coefficient
7	acs	Average car speed (km/h)	0.22063
13	ctcp	Car travel cost including road pricing (€/km)	-0.00723
		Constant	75.77412
Number of scenarios			30
F level			1.41465
Standard deviation of estimate			3.34738
Multiple correlation coefficient			0.47513
Coefficient of determination (r^2)			0.22575

Figure 16. Multiple regression of accessibility



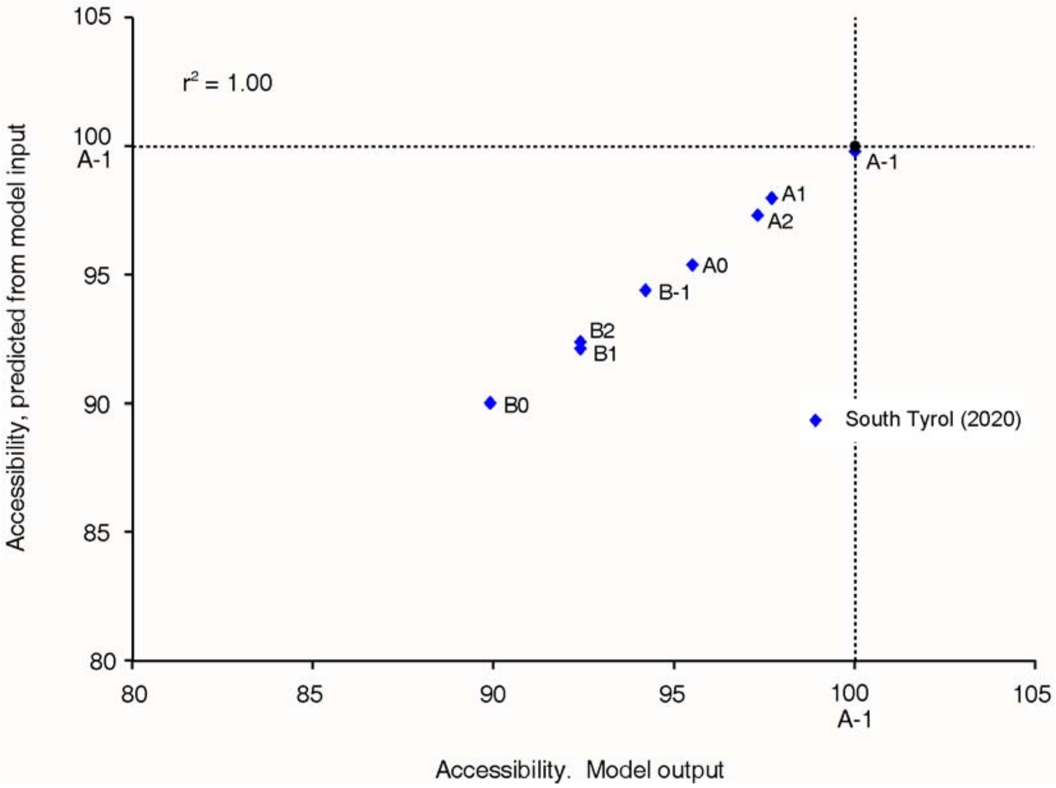
		Explanatory variables	Coefficient
7	acs	Average car speed (km/h)	0.14354
11	cc	Cost of car ownership per month (€)	-0.02430
13	ctcp	Car travel cost including road pricing (€/km)	-0.01480
		Constant	88.56318
Number of scenarios			14
F level			14.73489
Standard deviation of estimate			0.96466
Multiple correlation coefficient			0.95907
Coefficient of determination (r^2)			0.91982

Figure 17. Multiple regression of accessibility in Dortmund



		Explanatory variables	Coefficient
6	apts	Average public transport speed (km/h)	1.25206
7	acs	Average car speed (km/h)	3.06351
8	cptt	Cost of a public transport trip (€)	-0.31440
12	ctc	Car travel cost (€/km)	-0.12197
		Constant	-288.11292
Number of scenarios			8
F level			37.74638
Standard deviation of estimate			0.31412
Multiple correlation coefficient			0.99830
Coefficient of determination (r^2)			0.99661

Figure 18. Multiple regression of accessibility in Edinburgh



		Explanatory variables	Coefficient
6	apts	Average public transport speed (km/h)	0.15419
8	cptt	Cost of a public transport trip (€)	-0.31037
12	ctc	Car travel cost (€/km)	-0.48845
		Constant	164.26433
Number of scenarios			8
F level			204.47784
Standard deviation of estimate			0.23904
Multiple correlation coefficient			0.99853
Coefficient of determination (r^2)			0.99707

Figure 19. Multiple regression of accessibility in South Tyrol

Conclusions

The experience with the meta analysis has shown that the models applied in STEPs are in reasonable agreement about the major behavioural responses and environmental effects of the energy trends and policies examined: Higher fuel prices will have a significant effect on trip distances and modal choice, reductions in car distance will significantly reduce air pollution, greenhouse gas emissions, traffic accidents and traffic deaths, and reductions in car use will have negative effects on accessibility unless public transport is significantly improved.

If one considers that the scenarios differ not only in their assumptions about fuel prices but also in their policies in the fields of technology, infrastructure and demand regulation, this result supports the hypothesis that car travel cost, or more specifically fuel price, is indeed the most important policy variable and that all other policies fields, such as alternative vehicles, traffic regulation (in particular travel speed), but also land use policies, are of lesser importance – a result in accordance with those of EU empirical and modelling studies, such as the PROPOLIS project (Lautso et al., 2004).

For future studies there is considerable potential for improving the validity and transferability of model results with respect to scenario specification, model mechanism and model output indicators by a cross-validation of the results with respect to important output indicators as standard practice. Such a meta analysis would contribute much to establishing the credibility of the models and to improve their policy relevance and acceptance of their results in the policy arena.

The experience with the meta analysis has also shown that there exists a demand for more research. Forecasting energy price increases seems to be more difficult than forecasting their effects. Research should therefore address the issue of market responses to energy price shocks. Related to this, and not taken into account in the setting of the scenarios (and so in the modelling), are the political reactions to the changes that these scenarios forecast. This would also be a fruitful source of research, building on the STEPS modelling results.

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Annex

Tables A1 to A7 in the Annex contain the values of the 27 selected input and output indicators of the ASTRA, Brussels, Dortmund, Edinburgh, Helsinki and South Tyrol models collected for the meta analysis.

Table A1. ASTRA data for meta analysis 2030

			Indicator	**A-1**	**A0**	**A1**	**A2**	**B-1**	**B0**	**B1**	**B2**
Input	1	gdpc	GDP per capita (€)	36617	35204	37636	30361	35999	34805	37474	30803
	2	fcpl	fuel cost for car users including taxes (€ per l)	1.15	1.17	1.15	2.02	1.78	1.81	1.73	2.60
	3	twrk	non-telework (% of jobs)	100.0	100.0	100.0	92.8	100.0	100.0	100.0	92.8
	4	luc	land use control (1=none, 2=weak, 3=strong)								
	5	devl	developed land per capita (sqm)								
	6	apts	average public transport speed (km/h)	16.3	16.8	18.7	17.5	16.5	17.1	19.0	17.7
	7	acs	average car speed (km/h)	28.3	28.6	28.7	29.1	28.8	29.0	29.0	29.4
	8	cptt	cost of a public transport trip (€)	2.27	2.10	1.95	1.45	2.23	2.08	1.94	1.43
	9	afcc	average car fuel consumption (l per 100 km)	10.1	9.2	7.5	9.3	10.2	9.2	7.4	9.2
	10	palt	share of alternative vehicles (%)	11.8	11.8	21.0	11.6	17.2	17.2	34.2	16.2
	11	cc	cost of car ownership (€ per car per month)								
	12	ctc	car travel cost (€/km)	0.116	0.107	0.086	0.188	0.182	0.166	0.127	0.241
	13	ctcp	car travel cost including road pricing (€/km)	0.116	0.107	0.086	0.188	0.182	0.166	0.127	0.241
Output	14	tdpc	total distance travelled per capita per day (km)	38.3	38.8	39.3	38.3	38.1	38.6	39.1	38.2
	15	cdpc	distance travelled by car per capita per day (km)	22.4	22.2	20.9	19.7	21.8	21.5	20.5	18.9
	16	adt	average distance per trip (km)	17.1	17.4	17.6	17.2	17.0	17.3	17.5	17.1
	17	adct	average distance per car trip (km)	20.2	20.3	19.6	20.7	20.7	20.8	19.9	21.0
	18	swct	share of walking and cycling trips (%)	31.0	30.6	29.6	31.1	31.9	31.4	30.1	31.7
	19	sptt	share of public transport trips (%)	16.6	17.6	19.2	22.0	18.4	19.3	20.4	23.8
	20	sct	share of car trips (%)	49.7	48.9	47.8	42.8	46.9	46.4	46.1	40.3
	21	fcpc	car fuel consumption per capita per day (l)	1.95	1.79	1.28	1.82	1.95	1.78	1.17	1.83
	22	co2	CO_2 emissions by transport per capita per day (kg)	4.31	4.27	3.89	3.79	4.09	4.05	3.63	3.63
	23	nox	NO_x emissions by transport per capita per day (g)	13.04	12.72	12.22	11.62	11.89	11.70	10.94	11.07
	24	pm	PM emissions by transport per capita per day (mg)								
	25	cown	car ownership (cars per 1,000 population)	617	617	628	444	470	470	479	347
	26	tdpm	traffic deaths per million population per year	135.0	129.0	121.8	111.1	128.9	122.9	116.2	107.1
	27	acc	accessibility								

Table A2. Brussels data for meta analysis 2020

			Indicator	**A-1**	**A0**	**A1**	**A2**	**B-1**	**B0**	**B1**	**B2**
Input	1	gdpc	GDP per capita (€)								
	2	fcpl	fuel cost for car users including taxes (€ per l)	1.41	1.29	1.23	1.80	2.34	1.71	1.55	2.21
	3	twrk	non-telework (% of jobs)	100	100	100	100	100	100	100	100
	4	luc	land use control (1=none, 2=weak, 3=strong)	2	2	2	2	2	2	2	2
	5	devl	developed land per capita (sqm)								
	6	apts	average public transport speed (km/h)								
	7	acs	average car speed (km/h)								
	8	cptt	cost of a public transport trip (€)	1.57	1.57	1.57	1.57	1.57	1.57	1.57	1.57
	9	afcc	average car fuel consumption (l per 100 km)	7.8	7.1	6.4	7.1	7.8	7.0	6.1	7.0
	10	palt	share of alternative vehicles (%)								
	11	cc	cost of car ownership (€ per car per month)								
	12	ctc	car travel cost (€/km)	0.109	0.092	0.079	0.128	0.182	0.119	0.094	0.155
	13	ctcp	car travel cost including road pricing (€/km)	0.109	0.092	0.079	0.128	0.182	0.119	0.094	0.155
Output	14	tdpc	total distance travelled per capita per day (km)								
	15	cdpc	distance travelled by car per capita per day (km)	21.2	22.4	23.0	16.2	11.3	16.9	18.2	11.7
	16	adt	average distance per trip (km)								
	17	adct	average distance per car trip (km)	28.7	30.1	30.8	23.2	17.4	24.0	25.5	18.0
	18	swct	share of walking and cycling trips (%)	0.6	0.6	0.6	0.7	0.9	0.7	0.7	0.9
	19	sptt	share of public transport trips (%)	33.6	32.4	31.7	40.7	47.0	40.0	38.4	47.8
	20	sct	share of car trips (%)	65.9	67.1	67.7	58.5	52.0	59.3	60.9	38.5
	21	fcpc	car fuel consumption per capita per day (l)	1.63	1.57	1.45	1.14	0.87	1.16	1.10	0.81
	22	co2	CO$_2$ emissions by transport per capita per day (kg)	6.78	6.39	6.38	4.60	3.66	4.89	4.99	4.69
	23	nox	NO$_x$ emissions by transport per capita per day (g)	2.38	2.53	2.41	1.87	7.64	2.00	1.92	1.43
	24	pm	PM emissions by transport per capita per day (mg)								
	25	cown	car ownership (cars per 1,000 population)	540	540	544	457	457	457	457	386
	26	tdpm	traffic deaths per million population per year								
	27	acc	accessibility								

Table A3. Dortmund data for meta analysis 2030 (1)

			Indicator	**A-1**	**A0**	**A1**	**A2**	**B-1**	**B0**	**B1**	**B2**
Input	1	gdpc	GDP per capita (€)	100	98.5	99	97.2	97.5	59.9	96.5	94.9
	2	fcpl	fuel cost for car users including taxes (€ per l)	1.51	1.71	1.71	3.16	3.15	3.55	3.55	6.56
	3	twrk	non-telework (% of jobs)	0.93	0.93	0.93	0.86	0.93	0.93	0.93	0.86
	4	luc	land use control (1=none, 2=weak, 3=strong)	1	1	1	2	1	1	1	2
	5	devl	developed land per capita (sqm)	39.8	39.7	39.7	35.9	39.8	39.7	39.7	35.9
	6	apts	average public transport speed (km/h)	100	108	131	108	100	108	131	108
	7	acs	average car speed (km/h)	38	36.7	37.5	33.5	39.8	36.6	37.1	32.9
	8	cptt	cost of a public transport trip (€)	100	122	122	65	100	122	122	65
	9	afcc	average car fuel consumption (l per 100 km)	7.5	7.5	4.8	7.5	7.5	7.5	4.8	7.5
	10	palt	share of alternative vehicles (%)	2.1	11.8	19.3	11.8	2.1	11.8	19.3	11.8
	11	cc	cost of car ownership (€ per car per month)	345	421	721	421	345	421	721	421
	12	ctc	car travel cost (€/km)	0.113	0.128	0.082	0.237	0.236	0.266	0.170	0.492
	13	ctcp	car travel cost including road pricing (€/km)	0.113	0.178	0.132	0.367	0.236	0.316	0.220	0.622
Output	14	tdpc	total distance travelled per capita per day (km)	28.5	23.6	22.4	21.2	24.1	21.1	20.7	20.6
	15	cdpc	distance travelled by car per capita per day (km)	21.6	15.4	13.6	7.2	15.2	10.1	9.7	3.7
	16	adt	average distance per trip (km)	11.6	10.4	11.1	9.5	10.1	9.4	10.4	9.4
	17	adct	average distance per car trip (km)	13.6	11.7	12.1	8.8	10.9	9.4	10	6.8
	18	swct	share of walking and cycling trips (%)	25.6	30.7	31.5	41.5	29.7	36.8	35.2	48.8
	19	sptt	share of public transport trips (%)	10.3	11.8	13.3	22.7	12.7	15.6	16.5	27.5
	20	sct	share of car trips (%)	64.1	57.5	55.2	35.8	57.6	47.6	48.3	23.7
	21	fcpc	car fuel consumption per capita per day (l)	1.36	0.98	0.56	0.45	0.95	0.64	0.40	0.23
	22	co2	CO_2 emissions by transport per capita per day (kg)	7.92	6.39	5.73	3.50	5.80	4.39	4.30	2.14
	23	nox	NO_x emissions by transport per capita per day (g)	21.7	20.2	18.1	11.9	16.5	14.4	14.1	8.0
	24	pm	PM emissions by transport per capita per day (mg)	1015	970	909	661	816	752	751	510
	25	cown	car ownership (cars per 1,000 population)	715	612	432	596	675	592	417	604
	26	tdpm	traffic deaths per million population per year	42.0	30.5	27.3	14.0	31.1	20.4	20.0	6.7
	27	acc	accessibility	61.1	59.1	59.0	56.3	59.6	57.8	57.7	55.7

Table A4. Dortmund data for meta analysis 2030 (2)

			Indicator	**A-1**	**A3**	**B3**	**C-1**	**C0**	**C1**	**C2**	**C3**
Input	1	gdpc	GDP per capita (€)	100	98.3	96.1	94.8	94.3	95.4	89.4	90.7
	2	fcpl	fuel cost for car users including taxes (€ per l)	1.51	3.16	6.56	6.41	5.70	5.70	21.93	21.93
	3	twrk	non-telework (% of jobs)	0.93	0.86	0.86	0.93	0.82	0.88	0.73	0.73
	4	luc	land use control (1=none, 2=weak, 3=strong)	1	2	2	1	1	1	3	3
	5	devl	developed land per capita (sqm)	39.8	35.9	35.9	39.7	39.7	35.7	35.6	35.6
	6	apts	average public transport speed (km/h)	100	131	131	100	108	131	108	131
	7	acs	average car speed (km/h)	38	33.7	33.1	39.4	36.6	37.1	25	26.2
	8	cptt	cost of a public transport trip (€)	100	65	65	100	122	122	100	100
	9	afcc	average car fuel consumption (l per 100 km)	7.5	4.8	4.8	7.5	7.5	3.7	7.5	3.7
	10	palt	share of alternative vehicles (%)	2.1	19.3	19.3	2.1	14.2	35.2	14.2	35.2
	11	cc	cost of car ownership (€ per car per month)	345	721	721	345	421	721	421	721
	12	ctc	car travel cost (€/km)	0.113	0.152	0.315	0.481	0.428	0.211	1.645	0.811
	13	ctcp	car travel cost including road pricing (€/km)	0.113	0.282	0.445	0.481	0.428	0.211	1.835	1.001
Output	14	tdpc	total distance travelled per capita per day (km)	28.5	21.2	20.8	21.1	20.1	20.8	18.7	18.7
	15	cdpc	distance travelled by car per capita per day (km)	21.6	6.1	3.4	8.1	7.4	10.1	0.4	0.7
	16	adt	average distance per trip (km)	11.6	10.7	10.4	9	9	10.4	8.3	9.5
	17	adct	average distance per car trip (km)	13.6	9	7.2	8.1	8.2	10.2	2.4	3.7
	18	swct	share of walking and cycling trips (%)	25.6	40.3	46.1	39.6	41.7	34.6	62.8	59.2
	19	sptt	share of public transport trips (%)	10.3	26.4	31.0	18.6	18.4	16.1	29.5	31.7
	20	sct	share of car trips (%)	64.1	33.3	22.9	41.8	39.8	49.2	7.8	9.1
	21	fcpc	car fuel consumption per capita per day (l)	1.36	0.25	0.14	0.51	0.46	0.32	0.02	0.02
	22	co2	CO_2 emissions by transport per capita per day (kg)	7.92	3.10	2.05	3.32	3.42	4.17	1.00	1.07
	23	nox	NO_x emissions by transport per capita per day (g)	21.7	10.7	7.7	10.4	11.8	13.1	4.7	4.9
	24	pm	PM emissions by transport per capita per day (mg)	1015	624	503	590	658	719	383	391
	25	cown	car ownership (cars per 1,000 population)	715	420	420	660	589	417	606	414
	26	tdpm	traffic deaths per million population per year	42.0	12.0	6.3	16.3	14.7	20.8	0.3	0.7
	27	acc	accessibility	61.1	55.8	55.7	57.7	57.1	57.9	54.8	54.0

Table A5. Edinburgh data for meta analysis 2030

			Indicator	A-1	A0	A1	A2	B-1	B0	B1	B2
Input	1	gdpc	GDP per capita (€)								
	2	fcpl	fuel cost for car users including taxes (€ per l)	1.21	1.46	1.33	3.48	1.62	1.86	1.50	3.77
	3	twrk	non-telework (% of jobs)								
	4	luc	land use control (1=none, 2=weak, 3=strong)								
	5	devl	developed land per capita (sqm)								
	6	apts	average public transport speed (km/h)	19.6	20.6	21.5	21.1	19.8	20.8	21.6	21.2
	7	acs	average car speed (km/h)	32.7	32.6	32.7	32.5	32.8	32.7	32.7	32.7
	8	cptt	cost of a public transport trip (€)	2.19	2.65	2.64	1.32	2.19	2.65	2.64	1.31
	9	afcc	average car fuel consumption (l per 100 km)	5.49	5.5	5.24	5.27	5.42	5.42	5.26	5.19
	10	palt	share of alternative vehicles (%)	13.6	13.6	30.6	14.0	25.7	25.7	48.9	24.2
	11	cc	cost of car ownership (€ per car per month)								
	12	ctc	car travel cost (€/km)	0.066	0.080	0.070	0.183	0.088	0.101	0.079	0.196
	13	ctcp	car travel cost including road pricing (€/km)	0.075	0.089	0.078	0.268	0.096	0.109	0.088	0.281
Output	14	tdpc	total distance travelled per capita per day (km)	14.4	14.5	14.7	13.0	14.4	14.4	14.6	13.0
	15	cdpc	distance travelled by car per capita per day (km)	11.7	11.8	12.0	9.3	11.6	11.7	11.9	9.2
	16	adt	average distance per trip (km)	5.3	5.3	5.3	4.3	5.3	5.2	5.3	4.3
	17	adct	average distance per car trip (km)	6.7	6.7	6.8	6.1	6.7	6.7	6.7	6.1
	18	swct	share of walking and cycling trips (%)	22.7	23.1	22.8	31.5	23.2	23.6	23.1	32.0
	19	sptt	share of public transport trips (%)	12.9	12.7	12.7	17.4	13.3	13.0	12.8	17.9
	20	sct	share of car trips (%)	64.3	64.2	64.5	51.1	63.5	63.4	64.1	50.1
	21	fcpc	car fuel consumption per capita per day (l)	0.39	0.40	0.31	0.29	0.33	0.33	0.23	0.25
	22	co2	CO_2 emissions by transport per capita per day (kg)	2.36	2.37	2.01	1.82	2.25	2.26	1.79	1.74
	23	nox	NO_x emissions by transport per capita per day (g)	1.98	1.99	1.61	1.53	1.72	1.73	1.25	1.35
	24	pm	PM emissions by transport per capita per day (mg)	115	116	95	87	100	101	73	77
	25	cown	car ownership (cars per 1,000 population)	530	530	531	499	517	517	521	462
	26	tdpm	traffic deaths per million population per year								
	27	acc	accessibility	2676	2577	2800	2626	2614	2523	2777	2647

Table A6. Helsinki data for meta analysis 2020

			Indicator	A-1	A0	A1	A2	B-1	B0	B1	B2
Input	1	gdpc	GDP per capita (€)	30949	30949	30949	30949	30949	30949	30949	30949
	2	fcpl	fuel cost for car users including taxes (€ per l)	1.16	1.16	1.14	1.71	1.64	1.64	1.60	2.165
	3	twrk	non-telework (% of jobs)	85.8	85.7	85.8	86.4	85.8	85.8	86.0	86.5
	4	luc	land use control (1=none, 2=weak, 3=strong)								
	5	devl	developed land per capita (sqm)								
	6	apts	average public transport speed (km/h)	20.1	21.0	24.4	21.6	19.9	20.9	24.8	21.8
	7	acs	average car speed (km/h)	52.0	52.3	54.1	55.8	52.8	52.3	54.1	54.7
	8	cptt	cost of a public transport trip (€)	1.47	1.61	1.63	1.17	1.43	1.59	1.64	1.18
	9	afcc	average car fuel consumption (l per 100 km)	8.5	8.6	8.3	8.3	8.5	8.3	8.5	8.0
	10	palt	share of alternative vehicles (%)	5.65	5.65	10.53	5.71	8.01	8.01	16.31	7.76
	11	cc	cost of car ownership (€ per car per month)								
	12	ctc	car travel cost (€/km)	0.098	0.100	0.095	0.142	0.139	0.136	0.136	0.173
	13	ctcp	car travel cost including road pricing (€/km)	0.098	0.100	0.095	0.142	0.139	0.136	0.136	0.173
Output	14	tdpc	total distance travelled per capita per day (km)	53.2	51.2	53.2	55.5	49.7	48.2	51.2	53.6
	15	cdpc	distance travelled by car per capita per day (km)	22.4	20.8	20.0	16.5	19.0	18.4	17.5	14.3
	16	adt	average distance per trip (km)	13.4	12.9	13.4	13.7	12.5	12.1	13.0	13.2
	17	adct	average distance per car trip (km)	16.1	15.5	15.9	15.8	14.7	14.0	14.1	14.0
	18	swct	share of walking and cycling trips (%)	8.9	9.7	8.4	7.3	9.1	10.0	8.6	7.50
	19	sptt	share of public transport trips (%)	5.2	5.1	5.4	6.1	5.2	5.2	5.5	6.27
	20	sct	share of car trips (%)	3.9	3.9	3.8	3.2	3.9	3.8	3.6	2.97
	21	fcpc	car fuel consumption per capita per day (l)	1.53	1.38	1.25	1.00	1.46	1.19	1.49	0.88
	22	co2	CO_2 emissions by transport per capita per day (kg)	6.52	6.16	5.49	5.11	5.60	5.47	4.57	4.59
	23	nox	NO_x emissions by transport per capita per day (g)	3.71	3.51	2.98	3.00	3.24	3.17	2.47	2.73
	24	pm	PM emissions by transport per capita per day (mg)	1973	1922	1904	2000	1870	1851	1868	1979
	25	cown	car ownership (cars per 1,000 population)	508	508	510	444	443	443	446	384
	26	tdpm	traffic deaths per million population per year	58.8	58.9	52.2	46.7	49.6	48.7	47.1	42.2
	27	acc	accessibility								

Table A7. South Tyrol data for meta analysis 2020

			Indicator	A-1	A0	A1	A2	B-1	B0	B1	B2
Input	1	gdpc	GDP per capita (€)								
	2	fcpl	fuel cost for car users including taxes (€ per l)								
	3	twrk	non-telework (% of jobs)	100.0	100.0	100.0	95.6	100.0	100.0	100.0	95.6
	4	luc	land use control (1=none, 2=weak, 3=strong)								
	5	devl	developed land per capita (sqm)	74.6	74.6	74.6	74.7	74.6	74.6	74.6	74.7
	6	apts	average public transport speed (km/h)	26.0	25.9	32.0	26.4	26.1	26.0	32.1	26.47
	7	acs	average car speed (km/h)	62.8	63.0	63.0	64.4	63.7	63.8	63.9	65.16
	8	cptt	cost of a public transport trip (€)	0.63	0.70	0.73	0.52	0.64	0.70	0.74	0.52
	9	afcc	average car fuel consumption (l per 100 km)								
	10	palt	share of alternative vehicles (%)	6.3	6.3	8.5	6.5	6.7	6.7	10.1	6.5
	11	cc	cost of car ownership (€ per car per month)								
	12	ctc	car travel cost (€/km)	0.108	0.110	0.109	0.126	0.119	0.122	0.121	0.137
	13	ctcp	car travel cost including road pricing (€/km)	0.108	0.110	0.109	0.126	0.119	0.122	0.121	0.137
Output	14	tdpc	total distance travelled per capita per day (km)	49.1	48.7	49.4	47.8	48.0	47.8	48.5	47.0
	15	cdpc	distance travelled by car per capita per day (km)	42.6	42.4	41.8	39.9	41.2	41.1	40.5	38.5
	16	adt	average distance per trip (km)	29.5	29.6	29.6	29.8	29.8	29.8	29.8	30.1
	17	adct	average distance per car trip (km)	29.5	29.7	29.4	29.3	29.6	29.7	29.4	29.2
	18	swct	share of walking and cycling trips (%)								
	19	sptt	share of public transport trips (%)	13.2	13.0	14.6	15.0	13.9	13.7	15.2	15.7
	20	sct	share of car trips (%)	86.8	87.0	85.5	85.0	86.1	86.4	84.8	84.3
	21	fcpc	car fuel consumption per capita per day (l)								
	22	co2	CO_2 emissions by transport per capita per day (kg)	5.4	5.4	5.1	4.7	5.1	5.2	4.8	4.4
	23	nox	NO_x emissions by transport per capita per day (g)	6.3	6.2	6.0	5.9	6.1	5.9	5.9	5.6
	24	pm	PM emissions by transport per capita per day (mg)	581	578	665	558	561	573	741	534
	25	cown	car ownership (cars per 1,000 population)								
	26	tdpm	traffic deaths per million population per year								
	27	acc	accessibility	100.0	95.5	97.7	97.3	94.2	89.9	92.4	92.4