Urban Studies, Vol. 44, No. 2, 339–355, February 2007

What Parameters Influence the Spatial Variations in CO_2 Emissions from Road Traffic in Berlin? Implications for Urban Planning to Reduce Anthropogenic CO_2 Emissions

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[Paper first received, August 2003; in final form, April 2006]

Summary. **The aim of this paper is to find major influencing factors of CO_2 emissions from road traffic in urban areas. The approach of the study involved a statistical analysis on the basis of the formerly 23 urban districts of the German capital of Berlin. Correlation and regression analyses of empirical data from the settlement structure, the traffic structure and income have found that the number of jobs per district and the share of the well-off population can best describe the CO_2 emissions from traffic in Berlin. Also the number of residents, the total built area, the number of cars and the amount of traffic area are positively related to the dependent variable. Therefore, the possibilities to reduce CO_2 emissions from road traffic for urban planners seem limited: a restriction of space dedicated to traffic and a change of transport means for commuting represent leverage points, according to the analysis. The other significant indicators are less able to be influenced by local and regional decision-makers—an alteration in the means of mobility to less CO_2 emitting alternatives is needed if CO_2 emissions from road traffic are extensively to be decreased.**

Introduction

This paper is about the driving forces of anthropogenic CO_2 emissions from road traffic in urban areas. Anthropogenic CO_2 emissions result from, for example, the burning of fossil fuels which are the common means to meet people's increasing energy needs. Nowadays, most people in Western societies live in urban areas (48.8 per cent in urban and 35.8 per cent in peri-urban regions in Germany at the end of 2003; Destatis, 2005); energy is mostly generated for their needs. Twenty per cent of the world's energy consumption is attributed to traffic: of this, 13 per cent is for passenger traffic and 7 per cent for freight traffic (Schafer and Victor, 1999). In Germany, the share for transport energy amounts to 28 per cent of the total energy use (in 2003; BMWA, 2005) and in the selected case study, the city of Berlin, the energy used by traffic amounts to 26.5 per cent, of which 13 per cent is used by passenger traffic (data for the year 2000; Senstadt, 2001b).

The peculiarities of the traffic sector in contrast to the sectors of trade, services, households and industry are, first, its strong reliance on fossil fuels. Alternative technologies such as engines with sunflower seed

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0042-0980 Print/1360-063X Online/07/020339–17
DOI: 10.1080/00420980601136588

oil or electric engines, have not been very successful on the market for various reasons. Secondly, throughout the 1990s, the transport sector was the only sector with increasing consumption rates of energy (year of investigation/data availability: 1995), in both Germany and Berlin. The consumption of motor fuel increased by 10 per cent from 1990 to 1999 for the whole of Germany (BMWi, 2000). Transport energy in Berlin rose by 16.4 per cent from 1990 to 2000 (Senstadt, 2001b). Whereas an increase in transport energy is in line with global and regional trends (brought about by, for example, increasing globalisation and just-in-time production) the special circumstances of Berlin's history are reflected in these figures too. After the reunification of Germany, increased opportunities for mobility of the formerly East German population increased the amount of transport energy used. Berlin was divided into two parts from 1961 to 1989: the one part restricted in growth by its state boundaries, the other half by a strong political will to keep the urban development tied and within existing boundaries. Since the reunification communication between the two parts, as well as between Berlin and its surroundings are adjusting to national trends. Nevertheless, in spite of the high growth rates in transport energy throughout the past decade, Berlin is not yet regarded as being a highly suburbanised city. Based on the low traffic figures of 1990, Berlin's growth rates in transport energy have been above average. With traffic-caused CO_2 emissions, the picture is similar: a 14 per cent increase in Berlin and a 12 per cent increase in Germany for the period 1990–2000 (affected by the same historical factors).

If we look at road traffic in particular, the emissions changed intensively: there was a 17 per cent increase for the whole of Germany during the 1990s. In the light of a projected global climate change which is to a great extent caused by man-made CO_2 emissions (IPCC, 2001a), this trend demonstrates the need to investigate subjects where urban transport and climate research meet.

Theoretical Approach

CO_2 is responsible for 83.3 per cent of the greenhouse effect in Germany compared with other greenhouse gases such as methane (CH_4). This substantial impact is not due to a high greenhouse potential but is caused by the enormous quantities of emitted CO_2. The contribution of CO_2 to global warming in Germany is demonstrated in Table 1, while similar relations can be assumed to apply to other First World countries too.

Globally, about 25 per cent of the anthropogenically induced CO_2 emissions can be attributed to land use changes (deforestation, rice harvesting, etc.) whereas about 75 per cent of the additional CO_2 emissions are caused by the burning of fossil fuels (IPCC, 2001a, p. 7). The increased use of fossil fuels results from higher energy demands, linked to higher living standards (higher income, smaller households, bigger flats and houses, more spare time compared with working hours), changing economic mechanisms (globalisation, specialisation in products and human labour) and a general increase in the traffic radii of people as well as the exchange rates of goods and services. However, energy use by the business sector has decreased substantially throughout the past decade in Germany, whereas personal energy use increased during that period (BMWA, 2005). The consumer sectors 'households' and 'traffic' cause the highest fractions of energy consumption in Germany (28.2 per cent and 30.0 per cent respectively for Germany in 2003; BMWA, 2005).

Regarding CO_2 emissions (the relation to energy consumption is not straightforward[1]) households play a minor role compared with traffic. In Germany, traffic caused about 47 per cent more CO_2 emissions in 2002 than did households. It is the only sector with positive growth rates: CO_2 emissions by road traffic have increased continuously in recent decades in Germany, while CO_2 emissions from households have decreased (BMWA, 2005). Similarly, in Berlin, the CO_2 emissions caused by traffic increased by 14.4 per cent

Table 1. Greenhouse gas emissions in Germany, by gas and emitting group (million tons)

Greenhouse gas emissions	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
In total	1254	1201	1151	1135	1112	1105	1123	1086	1060	1024	1028	1039	1029
In total (without land use changes and forestry)	1247	1194	1145	1129	1107	1099	1117	1080	1054	1018	1014	1026	1015
CO_2 emissions	1023	984	936	927	912	907	929	898	890	863	874	888	878
CO_2 emissions (without land use changes and forestry)	1016	977	930	920	906	901	924	892	885	857	860	874	864
CH_4	140	129	125	120	116	109	105	101	96	92	87	83	81
N_2O	81	78	79	76	72	73	75	73	59	56	56	56	56
HFCs	4	4	4	5	5	6	6	6	7	7	7	8	8
PFCs	3	2	2	2	2	2	2	1	1	1	1	1	1
SF_6	4	4	5	5	6	7	6	6	6	4	4	3	4

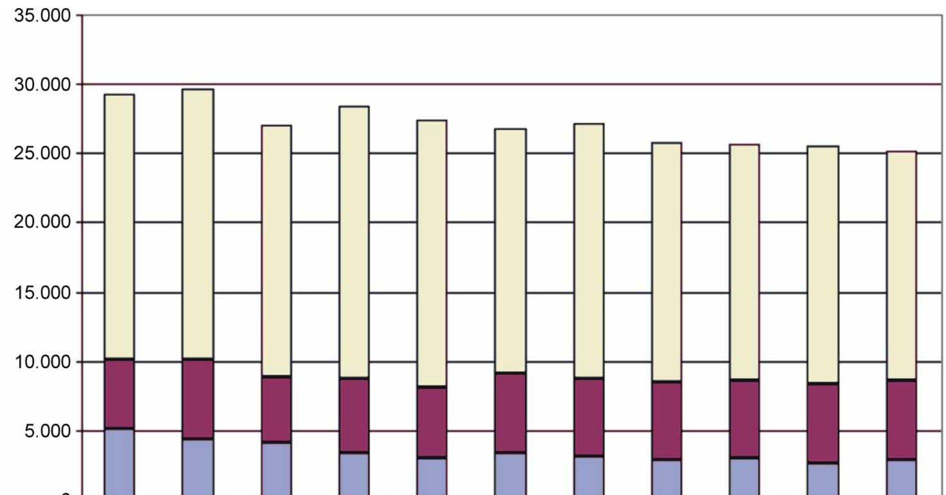
Source: Umweltbundesamt, after BMWA (2005).

from 1990 to 2000, whereas the emissions from households decreased by 13.4 per cent (Senstadt, 2001b). The latter is mainly due to the replacement of coal-fired ovens by gas or oil heating during the 1990s. Traffic CO_2 emissions amounted to 21.3 per cent of all CO_2 emissions in Berlin in 1995 and to 22.9 per cent in 2000 (Senstadt, 2005). Figure 1 pictures the CO_2 emissions in Berlin over time—traffic is the only sector with increasing CO_2 emissions. (Note: households and small consumers have the biggest share, although decreasing; this is caused by the combining of households and small businesses into one category.)

For the sake of completeness a short comparison of these CO_2 emissions will now be made with those from the energy-generating sectors. District heating stations and power plants are still the biggest originators. They emit 115 per cent more CO_2 than that caused by road traffic, the second-biggest sector (in 2002). Also important, but less so, are the emissions from industrial furnaces. Households rank fourth. Table 2 summarises the distribution of CO_2 emissions from consumer and energy-generating sources in Germany (BMWA, 2005). Again road traffic is the sole increasing category.

To combat CO_2 emissions, Berlin aims at a 25 per cent reduction in emissions per capita by 2010 compared with 1990. Suggestions on how to achieve this are manifold. Since the 1980s, planners have hoped to mitigate traffic volumes, fuel consumption and CO_2 emissions by, for example, the amelioration of public transport services and the arrangement of appropriate city structures. The catch-phrase ‘sustainable city planning’ was brought onto the agenda, a concept which comprises three important features: high density, mix of land uses and polycentric city structures. The overall intention is to limit city traffic and/or to change the focus of transport mode away from the strong orientation towards car use.

Therefore, we found it necessary to test the three factors of sustainable city planning—density, mix of uses and polycentrism—with respect to their influence on the CO_2



	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Sum	29.319	29.655	26.994	28.429	27.446	26.743	27.117	25.827	25.599	25.526	25.210
Households and small User	19.195	19.587	18.099	19.678	19.355	17.643	18.369	17.384	16.996	17.178	16.623
Traffic	5.037	5.694	4.837	5.340	5.152	5.690	5.664	5.624	5.651	5.768	5.764
Industry	5.087	4.374	4.058	3.411	2.939	3.410	3.084	2.819	2.952	2.580	2.823

Figure 1. CO_2 emissions for the city of Berlin, by sectors, 1900–2000. *Notes*: without temperature adjustments, including electricity imports and with flight traffic, in 1000t CO_2). *Source*: Senstadt (various years).

Table 2. Emissions of CO_2, for Germany, by emission groups (million tons)

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
In total	1023	984	936	927	912	907	929	898	890	863	874	888	878
Thereof energy related	989	954	906	896	880	876	900	868	860	832	835	851	841
Industrial processes	27	24	24	24	26	25	24	24	25	25	25	24	23
Road traffic	150	154	160	164	161	165	165	166	169	175	171	168	166
Remaining traffic	12	12	12	12	12	12	12	11	11	11	11	11	10
Households	129	131	123	134	128	129	142	138	132	120	117	131	120
Small consumers	62	61	55	53	50	53	63	54	53	49	46	50	47
Agriculture and forestry, fisheries	13	14	10	10	10	9	9	8	8	8	7	7	7
Industrial furnaces	196	173	159	148	149	150	144	144	139	135	136	133	132
District heating stations and generating plants	414	401	379	369	366	355	361	343	345	331	344	349	357
Others	12	8	6	5	5	4	3	3	3	3	2	2	2
Land use change and forestry	8	7	6	6	6	6	6	6	6	6	14	14	14

Source: BMWA (2005), after Umweltbundesamt.

emissions of urban traffic. Furthermore, what additional influencing factors of traffic CO_2 emissions in urban areas can be identified?

Newman and Kenworthy's (1989) empirical study on automobile(/car) dependence is often seen as the starting-point for a new, critical type of urban research. The main finding concerns the negative relationship between the density of a city and fuel consumption by cars, which has also been observed in other studies (Apel and Lehmbrock, 1998a, 1998b; Kutter, 1993). In the 1990s though, the strength of the relationship stated in their study was doubted (Lariviere and Lafrance, 1999; Holz-Rau and Kutter, 1995; Breheny, 1992). Density was and still is regarded as important, but not as the dominant factor influencing urban CO_2 emissions.

Measurements of urban CO_2 emissions in Phoenix, Arizona, underline the importance of urban density in terms of human activity but found the relation to CO_2 emissions in the opposite, negative direction. CO_2 emissions in the centre of Phoenix were up to 67 per cent higher than the emissions measured (at approximately 2 metres above ground level) in the outskirts of the city in the afternoon on five days in January along a number of transects (Idso *et al.*, 1998). The presence of an 'urban CO_2 dome' (Idso *et al.*, 1998, 2002) was indicated that showed especially high amounts of CO_2 emissions in the denser areas of the city centre. This and other studies also showed that CO_2 emissions vary significantly depending on the time of day (Nasrallah *et al.*, 2003; Idso *et al.*, 1998, 2002; Wentz *et al.*, 2002). Fluctuations were also found in weekly and annual cycles (Nasrallah *et al.*, 2003). Existing fluctuations of CO_2 emissions are not as important in our study and should be minimised in the regression analysis which uses the calculated total CO_2 emissions for one year, 1995. The total emissions for a long period such as one year allow a better conclusion for global climate change (GCC) and city planning measures which also apply to longer time scales. Nevertheless, the findings indicate that CO_2 emissions are highest in the denser areas of town.

The density of a city corresponds to different parameters—population and jobs for example. Wentz *et al.* (2002) found a close correlation between measured CO_2 emissions (also approximately 2 metres above ground level) and density of traffic, population and employment for Phoenix, Arizona. Different density parameters and their relation to the total annual CO_2 emissions will be tested on the urban area of Berlin.

The mix of land uses and polycentralism are also believed to contribute to a reduction of traffic, fuel consumption and CO_2 emissions (Topp, 1998; Sinz and Blach, 1994; Owens, 1986, 1992; Hüsler, 1992; Newman and Kenworthy, 1992; Rickaby, 1992). This opinion is widely shared, but authors differ with regard to the strength of the reduction potential.

The relationship between transport structure and CO_2 emissions from traffic has long been recognised (Newman and Kenworthy, 1989). Studies mainly focused on transport infrastructure such as length and width of roads, speed allowance, supply of car parks/parking spaces and car ownership, as well as the availability, reliability, frequency of and distance to public transport. The strength of the main influencing factor varies from region to region but today an overall consensus exists that a good supply of transport infrastructure drives its use. In the 1970s, however, the construction of new roads was still regarded as a solution to increasing traffic jams. Differences have been found in the acceptance of public transport (PT) and motorised individual traffic (MIT). Kutter (1999) describes changes in transport behaviour after the opening of the 'Spandau' underground railway line in Berlin. The additional supply of PT resulted in an increase in subway users of 7 per cent; 1 per cent of the growth was accounted for by former users of MIT and 6 per cent reflected a reduction in cyclists and pedestrians. This means that 84 per cent of the increased use of PT was accounted for by cyclists and pedestrians. They could cover longer distances in the same amount of time and thus chose to go to other locations for shopping and daily obligations. Deeper insight into people's behaviour with respect to travel patterns can be attained from an investigation in Zurich (Hüsler, 1992). Different cantons were examined regarding location to transport opportunities, mobility and income. The results demonstrate that people in the richer cantons are less motorised and have access to a better light/local railway system, whereas people in the poorer cantons are highly motorised and have good accessibility to a motorway/good road infrastructure. The overall finding is that a good traffic infrastructure (of whatever kind) induces its use.

The study undertaken in Zurich implies the importance of income in this context. The simplest approach is the investigation of the cost of mobility relative to income. Figure 2 mirrors the relation for fuel prices, absolutely and relative to net income in Germany. Over time, people have had to spend a smaller fraction of their income on the same amount of fuel, although the actual price of fuel has increased since the 1960s.

Based on this, Schäfer and Victor (1999) developed a number of ideas about the relationships between income, time and CO_2. An illustration is given in Figure 3. Their considerations are based on two assumptions. First, there exists a constant budget of time for mobility of about 1.1 hours/day. According to surveys this differs only slightly from cities to villages or between highly and less developed countries. Secondly, there is a constant budget of money spent on mobility that is approximately equal in countries with the same level of development. In highly developed countries, it amounts to 10–15 per cent of all expenditure, the highest fraction among all levels of economic development. This relationship was first postulated by Zahavi in 1979 (see Schäfer and Victor, 1999, p. 659) and was empirically confirmed by Schäfer and Victor (1999, 2000).

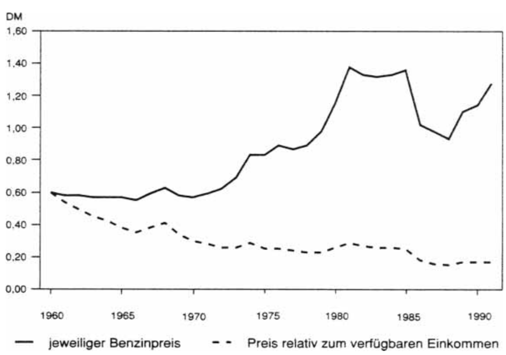


Figure 2. Trends in fuel prices in Germany, 1960–1990, absolutely (continuous line) and relative to the net income (pecked line). *Source*: Bergmann *et al.* (1993, p. 497).

Based on their assumptions, people increase their mobility, have different access to faster transport modes and go longer distances in a given amount of time when incomes rise. Thus, they use more energy and emit more CO_2 (when other influential parameters remain similar—for example, when the transport technology does not change radically and the energy sources remain the same). On this basis, Schäfer and Victor hypothesised that emissions of CO_2 from the transport sector are highly dependent on income.

Prices act as incentives to reduce costs as—for example, a study about travel costs in Singapore concludes (Eberlein, 1998). The study started when passengers travelling by car as single drivers during rush hours were levied a fee. The implementation of the fee in the afternoon rush hours only decreased the number of cars by 46 per cent. Another way of implementing financial incentives to reduce car use and fuel consumption is believed to be achieved by an increase in fuel prices. Simulations have shown that an increase in fuel prices to a level of about 2.5€ for diesel and 2.7€ for petrol would lower passenger kilometres by 20 per cent (cited in Eberlein, 1998, p. 229; Kuhfeld *et al.*, 1996; and Wegener, 1999), whereas the burden for economy and businesses would not exceed an increase in costs of 0.5 per cent (if bulk traffic were to be carried by alternative modes of transport)—an issue often brought up against such measurements. Model simulations by Wegener (1999) also proved the possibility of reducing motorised individual traffic by raising fuel prices. Here, a decrease in MIT of 30 per cent was

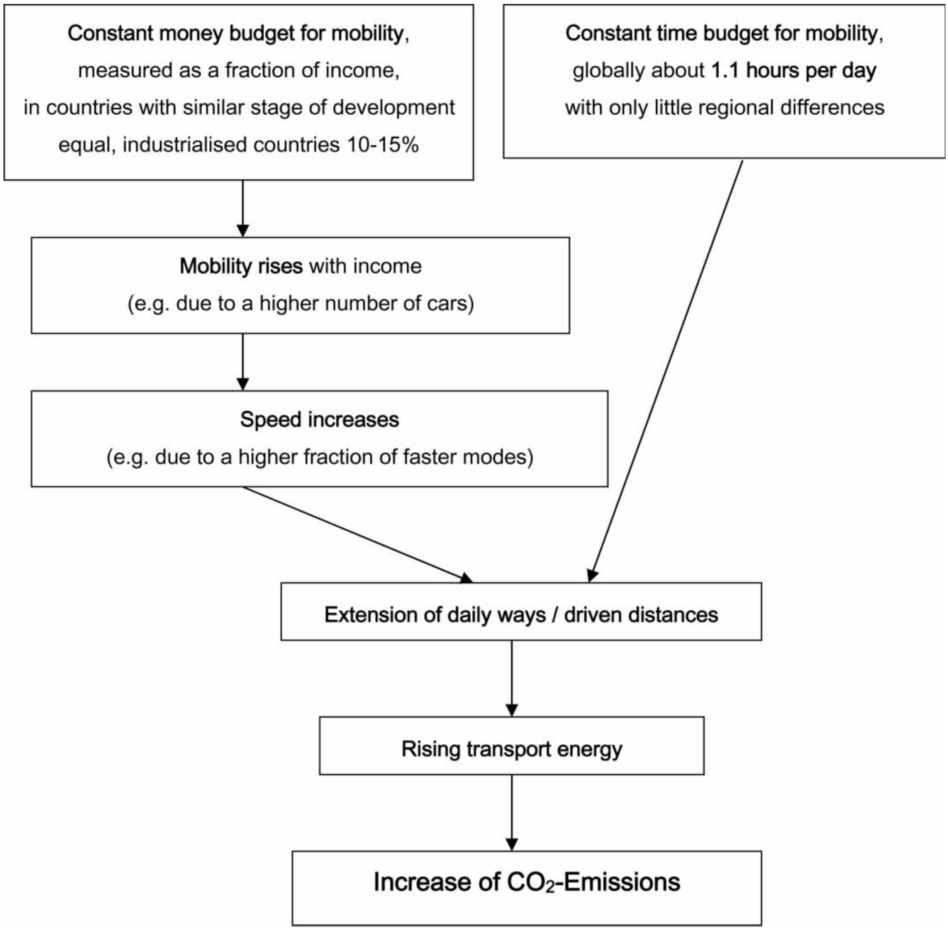


Figure 3. The relationships between income, time and CO_2 emissions. *Source*: authors' diagram, based on Schäfer and Victor (1999).

calculated, provided that public transport was simultaneously improved. It has been concluded that neither a reduction in mobility nor an increase in social disparities was visible in the model results. The reduced energy use and CO_2 emissions from transport resulted simply from a change in transport modes.

To conclude, these investigations show that a very strong positive relationship exists between income, energy use and CO_2 emissions from transport. It is believed that the transport infrastructure is an important and positively correlated variable to CO_2 emissions. On the other hand, the different indicators from the settlement structure, such as population and job density, are not regarded as being very strong. The direction of influence of the population density of a settlement is somewhat unclear. It seems that denser settlements entail a smaller fuel consumption by cars at the local level, but that the denser inner-city areas feature higher CO_2 emissions at the sub-local level. The CO_2 emissions are highest where human activities are to be found. A combination of the variables from settlement structure, traffic structure and income is thought to have the strongest influence when it comes to reductions of CO_2 emissions in the traffic sector (Wegener, 1999; Würdemann, 1998, Rickaby, 1992). These relationships will now be investigated in the case study area of Berlin.

Materials and Methods

The main purpose of the investigation was the search for mitigation options of GCC at the sub-city to city level—in other words, the exploration of the main causes of urban traffic CO_2 emissions. By finding the most important driving forces of anthropogenic CO_2 emissions in urban areas, local politicians and planning authorities are given a means to plan for a sustainable city structure. The CO_2 emissions of the traffic sector in Berlin were analysed in relation to indicators from the settlement structure, traffic structure and income. The empirical part of the study focuses on the city area of Berlin with its 23 municipal districts (Figure 4).

The data refer to the year 1995—for this one year only, CO_2 emissions from traffic were calculated at a sub-city level. The procedure to process such data is very intensive so it was not repeated subsequently. This fact highlights the uniqueness of the data and the investigation described.

Another peculiarity concerns the political situation in the second half of the 20th century. The urban area of Berlin did not evolve under market conditions like those we see today. In the western part of the city ('West Berlin'), the area was restricted by the state boundaries of the west-German exclave, while in the eastern part the strict city planning under socialist conditions did not allow the city to expand outwards very much. These conditions resulted in high densities and a compact urban area in both parts without excessive sprawl at the urban

Figure 4. The former and the current municipal districts of Berlin. *Notes*: Since the new structuring of the urban area of the city on 1 January 2001, Berlin has been sub-divided into the 12 municipal districts indicated by the numbers 1–12: 1-Mitte, 2 Friedrichshain–Kreuzberg, 3 Pankow, 4 Charlottenberg–Wilmersdorf, 5 Spandau, 6 Steglitz–Zehlendorf, 7 Tempelhof–Schöneberg, 8 Neukölln, 9 Treptow–Köpenick, 10 Marzahn–Hellersdorf, 11 Lichtenberg, 12 Reinickendorf. Until the end of 2000, the city of Berlin was split in 23 urban districts shown by the white lines. *Source*: Statistical Office of Berlin.

fringes. Therefore, inner and outer city districts do not differ as much in population density as they do in other German cities. These very special historical conditions need to be kept in mind. Against this background of a relatively compact urban structure, it is interesting to look at the remaining possibilities of influence for urban planners in an envisaged reduction of urban CO_2 emissions from road traffic.

Data

The data on CO_2 emissions were provided by the Senate Department of Urban Development (Senatsverwaltung für Stadtentwicklung) and calculated on the basis of traffic censuses. Over a period of one year in 1993, daily road traffic flows as well as parked vehicles (cars, lorries) were monitored along the major roads in Berlin. Additionally, an extrapolation of the censuses helped in generating similar data for the minor roads in the city. Existing bus schedules were utilised to calculate the traffic flows by this kind of public road traffic. The traffic flows on the inner-city motorway were not measured but excluded. On this basis, the average car, bus and lorry traffic was calculated in terms of the number of vehicles/day for each of the main roads in Berlin. Additionally, the traffic exhaust and rub-off emissions for the flowing traffic as well as the emissions due to evaporation by parked traffic (including the vehicles filling up at fuel stations) were calculated. Combined with specific emission factors for the different fuel sources, the emissions of CO_2 from traffic were computed at the scale of the 23 municipal districts of Berlin.

Such detailed data at the municipal district level for Berlin are only available for this one year, which stresses the uniqueness and opportunities given by this analysis. There are, however, some drawbacks to the data. One methodological problem arises when the data calculation is eased by using average fuel consumptions. Furthermore, the cold running conditions are not included and the calculation for minor roads is based on assumptions—an extrapolation of the vehicle fleet. Another peculiarity of the data is that the *de facto* emissions monitored on the main roads do not give information about the driver's origin and/or end of journey. This means that the data about CO_2 emissions include a share of transit traffic. Probably not all car drivers counted on the roads will be residents of the same municipal district in which they were counted. This has to be kept in mind when interpreting the results. On the other hand, advantages result from the long time-span covered, so that the annual, weekly and diurnal variations of CO_2 emissions in urban areas (Nasrallah *et al.*, 2003; Wentz *et al.*, 2002; Idso *et al.*, 1998, 2002) could be ruled out.

The independent variables on traffic CO_2 emissions from the settlement structure (density of inhabitant and jobs; the share of certain land uses), the traffic structure (traffic area and length of infrastructure) and income categories (personal and household income in clusters) were collected by the Board of Statistics in Berlin (Statistisches Landesamt). They correspond to the respective time-period and sub-city level, the 23 municipal districts of Berlin. Further details of the independent variables and their indicators are given in Table 3.

Methodology

A statistical analysis, comprising both correlation and regression analyses, forms the basis of the methodological approach. CO_2 emissions from traffic/year/district form the dependent variable for each of the 23 municipal districts. The dependent variable is therefore a measure for the amount of CO_2 emitted from traffic in each district throughout the year (for data generation see above), due to both the resident population in the district and as from people driving by. The area of Berlin covers a distance of 38 km from north to south and 45 km from east to west (Statistisches Landesamt Berlin). Cutting through the centre at 'Potsdamer Platz', you have to cross 9 districts from north to south and 11 districts from east to west to reach the opposite boundaries (see Figure 4), which leads to an average diameter of 4.2 to 4.1 km per

Table 3. Results of the correlation and regression analyses: CO_2 emissions from traffic (tons/year) and the relationship to settlement structure, transport structure and income ($N = 23$) except for the districts with motorways ($N = 10$)

	Correlation		Regression			
	Coefficient	Significance p	*B*	Beta	Constant	R^2
Settlement structure						
Density						
Resident population (31 December 1995)	0.670	0.000	0.306	0.294		
Number of jobs	0.635	0.001	0.822	0.531		
Number of jobs in industry	0.670	0.000	—	—		
Total built area [ha]	0.564	0.005	0.215	0.376	20 796.511	0.747
Mix of land uses						
Area: mixed uses [ha]	0.235	0.280	—	—		
Area: residential use [ha]	0.313	0.146	—	—		
Area: business use [ha]	0.224	0.304	—	—		
Transport structure						
Traffic area [ha]	0.785	0.000	79.726	0.400		
Street length [m]	0.546	0.007	—	—		
Length of highways [m]	0.192	0.595	—	—	22 051.158	0.714
Total number of vehicles	0.806	0.000	1.429	0.496		
Income						
Total net income/month (average income/person * number of residents)	0.720	0.000	—	—		
Number of residents with net income < 700€/month	0.449	0.031	—	—		
Number of residents with net income 700– < 1250€/month	0.414	0.050	—	—		
Number of residents with net income >1250€/month	0.862	0.000	2.078	0.843	46 407.839	0.711
Number of household with net income <1250 €/month	0.488	0.018	—	—		
Number of household with net income 1250–2000 €/month	0.679	0.001	—	—		
Number of household with net income >2000 €	0.761	0.000	—	—		
Combined analysis						
Resident population (31 December 1995)	0.670	0.000	—	—		
Number of jobs	0.635	0.001	0.512	0.331		
Total built area [ha]	0.564	0.005	—	—		
Traffic area [ha]	0.785	0.000	—	—	16 328.883	0.834
Total number of vehicles	0.806	0.000	—	—		
Number of residents with net income >1250€/month	0.862	0.000	1.757	0.723		

district. Calculations from the DIW (German Institute for Economic Research) have shown that 30.8 per cent of all commuters (commuter traffic as an indication for the distances covered) travel less than 5 km and 56.4 per cent travel less than 10 km. Of the population of Berlin, 46.7 per cent use MIT for the journey to work; 39.1 per cent chose PT. The latter comprises road traffic (buses) and non-road traffic (S-Bahn, U-Bahn and trams). Therefore, one can assume that the majority of journeys to work will be covered by road traffic. In this case, the figure from the DIW can serve as an indication for the distances travelled by car. It shows that most of the road traffic counted in a district will probably be transit traffic (about 70 per cent, if we assume the figures for commuting to be similar for other kinds of road traffic or the means of it). However, quite a significant share, about 30 per cent, will also be generated by people living in the respective district.

The CO_2 emissions are tested against independent parameters formed by indicators derived from the settlement structure, transport structure and income (see Table 3). The correlation analysis forms the first part of the statistical analysis. It is used to derive information about a possible relation of the dependent variable to the independent indicators as well as about the direction of this relation. The analysis is based on the Pearson correlation coefficient. All indicators chosen have been analysed in respect to the significance (p) and tested at the following levels: $p > 0.05$: not significant; $p \leq 0.05$: significant; $p \leq 0.01$: very significant.

Indicators that are at least significantly related were included in a regression analysis which forms the second part of the statistical analysis. A regression analysis investigates the kind of relationship between the variables—a functional dependency is assumed where the independent indicators describe the dependent one. A stepwise inclusion of the parameters was chosen—the method that reiterates the analysis by each parameter in turn and independently considers the inclusion or exclusion of the parameters with every step (the criterion to enter is a probability of $F \leq 0.05$; the criterion to remove: a probability of $F \geq 0.1$). A multicollinearity test is included by the significance check of each of the independent parameters within the regression analysis. In the case of multicollinearity, the standard error of the independent parameters would exceed a certain number so that the significance check would fail—the indicator is taken out of the regression.

Results

In Table 3, one will find the parameters included in the analysis as well as the outcome of the calculations. The dependent variable is CO_2 emissions from road traffic in tons/year. It is investigated with respect to several independent parameters as indicators for the settlement structure, the transport structure and income. In row 2, the correlation coefficients are all positive, indicating a positive relationship.

The indicators from the settlement structure have been classified under two variables: those associated to urban density and others describing a certain kind of land use. One can see that the resident population, the total number of jobs as well as the number of jobs from the industrial sector, and the total built-up area, all show a positive significant correlation to the dependent variable. As indicators for the density of an urban district, the outcome reveals that the CO_2 emissions from road traffic might increase with urban density and especially with respect to the parameters mentioned. They are significant at the 0.01 level. In contrast, the indicators that relate to the land use of urban areas have not been found significantly related to the CO_2 emissions from road traffic in Berlin. The chosen indicators are important aspects with a direct influence from urban planning, but presumably with no significant power when it comes to the prediction of the CO_2 emissions from road traffic. If one includes all the correlating indicators from the settlement structure into a regression analysis to predict the CO_2 emissions from road traffic, the indicator 'jobs in industry' is taken out of the model. It appears that the jobs in industry are highly correlated to the total number of jobs and lose relevance in the prediction of the dependent variable as to the other indicators. In turn, the urban districts with high population figures, many jobs and large built-up areas show high CO_2 emissions from road traffic in Berlin. The regression model with density parameters yields an R^2 of 0.747 which is fairly good for a model with 3 indicators. It explains 74.7 per cent of the dependent variable.

Another aspect, the traffic infrastructure for MIT, will be looked at in detail. The correlation analysis yields a significant positive connection to the traffic area, the street length and the total numbers of vehicles in Berlin. The significance is valid at the 0.01 level for all three indicators. From this study, one can conclude that an increase in designated traffic area and in street length seems to result in rising CO_2 emissions from road traffic in Berlin. The increase in car ownership seems to have an identical result, but is less susceptible to influence by the planning authorities. The indicator 'length of highways' has not been proved to be significantly related to the dependent variable. Additionally, if one runs a regression analysis on the significantly correlated parameters, the street length is also taken out. It cannot significantly contribute to a prediction in CO_2 emissions from road traffic when the traffic area and the number of vehicles per district are taken into account. A comparison of the different parameters from the transport structure in Berlin reveals that the amount of traffic area and the number of vehicles per district can best describe the CO_2 emissions from road traffic. The regression model shows an R^2 of 0.714 which is quite good, especially as the model contains only two parameters.

The third variable, the relation of CO_2 emissions from road traffic to income, will now be discussed for the case study area. Indicators have been chosen that relate to total amount of net income generated in a district (assigned the average net income per person in the respective district multiplied by the resident population), to single persons and to the household level.[2] Table 3 shows that all the chosen parameters have a positive correlation to the dependent variable. There is not much difference between the parameters referring to a per capita basis and those relying on a household basis. This would imply that an increase in each parameter would predict a rise in the CO_2 emissions from road traffic in Berlin. However, the correlations are not equally strong. The two lower income clusters/head as well as the lowest income category/household are significant at the 0.05 level. In comparison, the correlation with people and households from the upper income cluster reveals significance at the 0.01 level. This means that it is more certain that people and households with a well-established financial background will impact on the CO_2 emissions from road traffic than it is for the lower income clusters. Again, a regression analysis was performed with the significantly correlated parameters and only one indicator remains in the model: the cluster of people with high income. The regression model on the income parameter gains an R^2 of 0.711. It is lower than the R^2 found so far but attains this value with only one parameter. The number of high-income households can explain a considerable amount of the CO_2 emissions from road traffic in the case study.

The combined analysis shown at the bottom of Table 3 is aiming to discover the most important predictors of CO_2 emissions from road traffic in Berlin if one considers jointly the significant indicators of all the former regression models. It can serve as an expression for the prediction of CO_2 emissions from road traffic if one aspires to implement more than one strategy. From the formerly six parameters included, two remained. The number of jobs and the number of high-income residents form the combined regression model. The other indicators lose relevance in comparison with these two; they are not significantly predicting the dependent variable and accordingly are taken out. Thus it can be concluded, that the urban districts featuring a high number of jobs as well as with high numbers of well-off residents have the highest CO_2 emissions from road traffic in the case study area. The model yields an R^2 of 0.834 which is high.

In a comparison of all models performed, one can see that the R^2 of the combined analysis is the highest comprising two parameters. With respect to the other models, the difference is small. The R^2 is a little higher in models with more parameters and a little smaller in those with fewer parameters. The implication for politics and planning is, therefore, that it might be possible to effect a reduction in CO_2 emissions from road traffic by using appropriate strategies.

Discussion and Conclusion

The investigation of traffic CO_2 emissions in the 23 districts of Berlin has shown that a regression model with the variables 'number of jobs' and 'number of people from the highest income cluster' can best describe the CO_2 emissions from road traffic when different parameters of density, land uses, the transport structure and income are combined. Urban districts with numerous work places and well-off residents are associated with large amounts of CO_2 emissions from road traffic.

Most of the traffic encountered in the districts has to be assumed to be transit traffic although a significant share is also generated by people from the district. If one takes the commuter traffic as an indication of the average distances travelled on Berlin's roads (assuming that the distances for other kinds of road traffic are equal or equalling out; for example, with shopping and leisure trips) calculations from the DIW allow an insight into the relation between district-based and cross-district traffic: in Berlin, 30 per cent of all commuters travel less than 5 km, while 55 per cent drive between 5 km and 10 km. On average, Berlin's districts have a diameter of 4.2 km, although the variance is large, as can be seen in Figure 4. Therefore, the share of transit traffic might be especially high in the inner, smaller districts of the city and lower in the larger, outer ones. This is important in the correlation to the income clusters. Our analysis cannot prove whether the high-income residents drive more, it can only say that there seems to be more traffic in the districts with high shares of affluent residents. This can either be caused by the respective residents or by through traffic. As the richer districts (Wilmersdorf, Zehlendorf, Steglitz, Tempelhof and Reinickendorf) are in the outer areas, they are especially large—it can be assumed that a relatively high share of traffic in these districts is generated by the local population. Yet this cannot be stated with certainty. A higher amount of transit traffic might also be caused by commuters from outside Berlin, coming from the surrounding areas of Brandenburg. On the south-western border of Berlin, there is situated the city of Potsdam, whose people might account for some commuter traffic. However, and as mentioned before, Berlin is not regarded as being a strongly suburbanised city of the type where one would expect considerable transit traffic. Berlin's unusual history did not allow for much spatial extension, although some limited suburbanisation has taken place since reunification. Our analysis does not allow us to determine the relative volumes of local and cross-district traffic. As a result of the discussion, we assume that the transit traffic will be similar throughout the urban districts as different parameters level out each other. Against this background, one can assume that the well-off residents drive more than the less affluent. This is underlined by the fact that the richer districts are situated in the west of the city, the former West Berlin. Although large urban districts exist in the east of Berlin with possibly the same share of through traffic as their western counterparts, the amount of CO_2 on these roads is much less. The income of residents does seem to relate to the CO_2 emissions of road traffic in the respective districts.

Moreover, one can see that the correlations between the dependent variable and the smallest income cluster of people does not reveal a negative sign. Less income does not reflect on the mobility patterns of MIT in Berlin—or, in other words, the less affluent do not make economies by reducing their car use. However, the correlation is less clear and the coefficient is stronger in the positive relation to the high-income residents. With it, our results support the theory of Schäfer and

Victor (1999, 2000). Financial issues have a strong influence on traffic volumes and respective CO_2 emissions.

In turn, the implementation of monetary incentives does promise an impact on the traffic volumes and envisaged reductions of CO_2 emissions. The possibilities for local planners to influence urban CO_2 emissions thus seem limited at first sight as this is not under their direct influnence. The finding of jobs being such a strong parameter in the combined regression model might strengthen this impression.

With a closer look, however, one can see that the regression models on the other variables (settlement and transport structure) also show comparably high R^2 values and when compared with the income and combined analysis. As mentioned earlier, small differences need to be evaluated in terms of the numbers of parameters included. One can assume that an aspired reduction of CO_2 emissions from road traffic can be obtained with strategies aiming to impact, for example, the transport infrastructure. Two parameters remain in this regression model. One, the number of vehicles, can be understood as an additional expression of wealth and is out of the direct influence of the planning boards. The second, the traffic area, remains a promising parameter of traffic CO_2 emissions which is under the direct influence of the local and regional planning boards. The traffic area should be restricted if one wants to achieve a reduction in CO_2 emissions from road traffic in Berlin. With additional means, such as supporting the PT, one could assume that the CO_2 emissions from road traffic could be decreased.

The frequently mentioned parameter 'density of inhabitants'—in contrast to other studies in different regions—was not found to be contributing to a reduction in traffic CO_2 emissions; the sign of the correlation is not negative but positive. The urban districts with numerous people face more traffic and more CO_2 emissions. Hence, one could not easily conclude that higher population densities would result in a reduction of CO_2 emissions from road traffic in Berlin, as reported from other studies. One possible reason is the high population densities of European cities (like Berlin), compared with those, for example, in the US and Australia. Furthermore, Berlin has a relatively compact urban structure with smaller differences in population density across its area compared with other cities and without much sprawl at its fringes. As explained earlier, this is due to the historical peculiarities in the second half of the 20th century. It seems also that a denser building structure, as found in some districts, still allows a considerable volume of traffic to occur on the roads in Berlin. Thus, the success of potential planning measures via an increase in densities might be smaller than expected—the density of inhabitants does not account for a possible reduction in traffic CO_2 emissions in Berlin.

Our results are similar to those of Wentz *et al.* (2002). They measured the highest CO_2 emissions in the urban centre of Phoenix, Arizona, as an indicator for human activity corresponding to the density of traffic, population and employment. Against this background, some urban researchers argue in favour of a compression of the urban fringes instead of a general increase of density (for example, Wegener, 1999; Würdemann, 1998). Such a strategy seems promising to ease the problems of central-city traffic congestion, air pollution and CO_2 emissions. However, this would only minimise the emissions in the central parts of the settlements and not decrease the total emissions for the whole of the area.

Concluding, the power of local and regional planning to foster the reduction in anthropogenic CO_2 emissions seems smaller than indicated in the literature. The only significant parameter falling under the direct influence of the planning authorities is the amount of space dedicated to traffic. It has been shown that a further significant relation exists to the number of jobs provided in a district, indicating that people prefer to commute by cars. The analysis shows that the application of traditional city planning instruments would probably be insufficient to lessen CO_2 emissions from traffic. Instead, the implementation of financial incentives might bring achievements.

Nonetheless, for a considerable reduction of urban CO_2 emissions from road traffic and a sustainable future development, it seems that one approach is indispensable: education about the effects of possible climate change and the related need for the alteration of people's transport habits.

Notes

1. To calculate anthropogenic CO_2 emissions, the consumption of energy as well as the emission factors of CO_2 per energy source are of importance. The energy use is calculated locally by counting the consumption of its end users, whereas the supply of energy refers to a regional or wider process and has to include the share of different energy sources and their specific emission factors. The combustion of, for example, unwrought lignite for 1 kWh of electric energy produces twice as much CO_2 emissions as compared with the combustion of natural gas. Also important is the consideration of CO_2 emissions caused outside the region. Here, the emissions during energy transport in the case of coal, oil and gas as well as the emissions produced at the place of energy generation in case of electricity import need to be kept in mind.
2. The categories for income clusters per head and income clusters per household are taken from the division according to the Boards of statistics Berlin Statistisches Landesamt Berlin.

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