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?

Diana Meyer-Veden*
Maren Ewald**
Ottmar Edenhofer*
Matthias K.B. Lüdeke*

*Potsdam Institute for Climate Impact Research
PO 601203, 14412 Potsdam, Germany;
e-mail: meyer-veden@pik-potsdam.de
fax: 0049-(0)331-288-2640
edenhofer@pik-potsdam.de
luedeke@pik-potsdam.de
e-mail: maren.ewald@web.de
Weinbergstr. 41
64342 Seeheim-Jugenheim, Germany
Abstract
The aim of this paper is to find major influencing factors of CO2 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. A correlation and regression analysis on 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 CO2 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 CO2 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 our analysis. The other significant indicators are less of influence to local and regional decision makers - an alteration in the means of mobility to less CO2 emitting alternatives is needed if CO2 emissions from road traffic are extensively to be decreased.

Keywords: cities, traffic, CO2, urban policy, climate policy

Introduction
This paper is about the driving forces of anthropogenic CO2 emissions from road traffic in urban areas. Anthropogenic CO2 emissions result from the burning of fossil fuels which are the common means to meet people’s increasing energy needs. Nowadays most of the people in western societies live in urban areas (48.8% in urban and 35.8% in peri-urban regions for Germany in the end of 2003, Destatis 2005), energy is mostly generated for their needs. 20% of the world’s energy consumption is attributed to traffic: 13% account for passenger traffic and 7% for freight traffic (Schafer, 1999). In Germany the share for transport energy sums up to 28% of the total energy use (in 2003; BMWA, 2005) and in the selected case study, city of Berlin, the energy used by traffic amounts to 26.5%, from what a 13% accounts for passenger traffic (data for the year 2000, Senatsverwaltung für Stadtentwicklung Berlin [Senstadt], 2001).

The peculiarity of the traffic sector in contrast to the sectors of trade, services, households and industry is, first, its strong reliance on the energy supply by fossil fuels. Alternative technologies to those of the combustion engines of fossil fuels, e.g. engines with sunflower seed oil or with electric engines, have not been very successful on the market for various reasons. Secondly, the transport sector was the only sector with increasing consumption rates of energy compared to the other sectors throughout the 1990s (year of investigation/ data availability: 1995, see beneath), in Germany and in Berlin. The consumption of e.g. motor fuel increased by 10% from 1990 to 1999 for the whole of Germany (BMWi, 2001). Transport energy in Berlin rose by 16.4% from 1990 to 2000 (Senstadt, 2001). Whereas an increase in transport energy is in line with global and regional trends (brought about by e.g. increasing globalisation and just-in-time-production) the special circumstances in Berlin’s history are reflected in these figure too. The greater possibility for mobility of the formerly East German population after Germany’s reunification increase the
transport energy. 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 city’s development tied and within existing boundaries. Since the re-unification the exchange between the two parts as well as between Berlin and its surrounding is adjusting to national trends. Nevertheless the high growth rates in transport energy throughout the last decade, Berlin is not regarded a highly suburbanised city to the current date. According to the low figures of traffic in 1990 Berlin’s growth rates in transport energy are above average. With the traffic caused CO₂ emissions the picture is similar: 14% increase in Berlin and 12% increase in Germany for the same period between 1990 to 2000 (conditioned for the same historical reasons).

If we look at road traffic in particular, the emissions changed intensively: 17% 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 CO₂ emissions (IPCC, 2001a) this trend demonstrates the need to investigate subjects where urban transport and climate research meet.

**Theoretical Approach**

CO₂ is responsible for 83.3% of the greenhouse effect in Germany compared to other greenhouse gases as e.g. methane [CH₄]. Such substantial impact is not due to a high greenhouse potential but is caused by the enormous quantities of emitted CO₂. The share of CO₂ to global warming in Germany is demonstrated in table 1 (Umweltbundesamt, after BMWA, 2005) while similar relations can be assumed to apply to other first world countries too.

<table>
<thead>
<tr>
<th>Year</th>
<th>CO₂ Emissions (without Land Use Changes and Forestry)</th>
<th>CO₂ Emissions</th>
<th>CH₄</th>
<th>N₂O</th>
<th>HFCs</th>
<th>PFCs</th>
<th>SF₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>1.024</td>
<td>1.016</td>
<td>140</td>
<td>81</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1991</td>
<td>1.029</td>
<td>1.037</td>
<td>129</td>
<td>77</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1992</td>
<td>1.016</td>
<td>1.032</td>
<td>125</td>
<td>79</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1993</td>
<td>1.024</td>
<td>1.037</td>
<td>120</td>
<td>76</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1994</td>
<td>1.012</td>
<td>1.032</td>
<td>116</td>
<td>72</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1995</td>
<td>1.001</td>
<td>1.032</td>
<td>110</td>
<td>72</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1996</td>
<td>0.990</td>
<td>1.029</td>
<td>105</td>
<td>72</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1997</td>
<td>0.978</td>
<td>1.026</td>
<td>101</td>
<td>72</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1998</td>
<td>0.966</td>
<td>1.023</td>
<td>99</td>
<td>72</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1999</td>
<td>0.955</td>
<td>1.019</td>
<td>92</td>
<td>72</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2000</td>
<td>0.944</td>
<td>1.015</td>
<td>92</td>
<td>72</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2001</td>
<td>0.933</td>
<td>1.011</td>
<td>92</td>
<td>72</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2002</td>
<td>0.922</td>
<td>1.007</td>
<td>92</td>
<td>72</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1: Greenhouse Gas Emissions in Germany per gas and emitting group; Source: Umweltbundesamt, BMWA, 2005
Globally about 25% of the anthropogenically induced CO₂ emissions can be attributed to land-use changes (deforestation, rice harvesting etc.) whereas about 75% of the additional CO₂ emissions are caused by the burning of fossil fuels (IPCC, 2001). The increased use of fossil fuels results from higher energy demands, firstly linked to higher living standards (higher income, smaller households, bigger flats and houses, more spare time compared to working hours), changing economic mechanisms (globalisation, regionalisation, 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. But energy use from the business sector has decreased substantially throughout the last decade in Germany, personal energy use increased during that period (BMWA, 2005). The consumer sectors ‘households’ and ‘traffic’ (28.2% and 30.0% respectively for Germany in 2003, BMWA, 2005) cause the highest fractions of energy consumption in Germany.

Regarding CO₂ emissions (the relation to energy consumption is not straightforward⁠)— households play a minor role compared to traffic. In Germany, traffic caused about 47% more CO₂ emissions in 2002 than households did. It is the only sector with positive growth rates: CO₂ emissions by road traffic increased continuously within the last decades in Germany while CO₂ emissions from households decreased (BMWA, 2005). Similar in Berlin, the CO₂ emissions caused by traffic increased by 14.4% from 1990 to 2000 (Senatsverwaltung für Stadtentwicklung Berlin, 2005), whereas the emissions from households decreased by 13.4% (from 1990 to 2000, Senatsverwaltung für Stadtentwicklung Berlin, 2005). The latter is mainly due to the substitution of coal-fired ovens by gas or oil heating during the 1990s. Traffic CO₂ emissions amounted to 21.3% of all CO₂ emissions in Berlin in 1995 and to 22.9% in 2000 (Senatsverwaltung für Stadtentwicklung Berlin, 2005). Figure 1 pictures the CO₂ emissions in Berlin over time - traffic is the only sector with increasing CO₂ emissions (note: households and small consumer have the biggest share, though decreasing - this is caused by the implementation of households and small businesses into one category).

---

¹ To calculate anthropogenic CO₂ emissions the consumption of energy as well as the emission factors of CO₂ 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 its specific emission factors. The combustion of e.g. unwrought lignite for one kWh of electric energy produces twice as much CO₂ emissions as compared to the combustion of natural gas. Either important is the consideration of CO₂ emissions caused outside of the region. Here, the emissions during the energy transportation 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.
Figure 1: CO2 Emissions for the city of Berlin in dependence on causing sectors (between 1900-2000, without temperature adjustments, including electricity imports and with flight traffic, in 1000t CO2); Source: Energiebericht 1997-2000, Senatsverwaltung für Stadtentwicklung Berlin

For the sake of completeness a short comparison of the above described CO$_2$ emissions of the consumer sectors with those from the energy generating sectors seems comprehensible. District heating stations and power plants are still the biggest originators. They emit 115% more CO$_2$ than what has brought about by road traffic, the second biggest sector (2002). Also, but less important are the emissions from industrial furnaces. Households rank four. Table 2 summarises the distribution of CO$_2$ emissions from consumer and energy generating sources in Germany (BMWA, 2005). Again road traffic is the solely increasing.
Table 2: Emissions of CO₂ for Germany in emission groups; Source: Umweltbundesamt, BMWA, 2005

To combat CO₂ emissions, Berlin aims at a 25% reduction of the emissions per capita by 2010 compared to 1990. Suggestions on how to achieve this are manifold. Since the 1980s planners have hoped to mitigate traffic volumes, fuel consumption and CO₂ emissions by e.g. 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 means 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 polycentralism - with respect to their influence on CO₂ emissions of urban traffic. Furthermore, what additional influencing factors of traffic CO₂ emissions in urban areas can be identified?

Newman & Kenworthy’s empirical study on automobile/(car) dependence is often seen as the starting point for a new, critical type of urban research (Newman & Kenworthy, 1989). 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 & Lehmbrock, 1998; Kutter, 1993). In the 1990s though, the strength of the relationship stated in their study was doubted (Lariviere & Lafrance, 1999; Holz-Rau, 1995; Breheny, 1992). Density was and still is regarded as important, but not as the dominant factor influencing urban CO₂ emissions.

Measurements of urban CO₂ emissions in Phoenix, Arizona, underline the importance of urban density in terms of human activity but found the relation to CO₂ emissions in the opposite, negative direction. CO₂ emissions in the centre of Phoenix were up to 67% higher than the emissions measured (at approximately two metre above ground) in the outskirts in the afternoon on five days in January along a
number of transects (Idso et. al. 1998). The presence of an “urban CO₂ dome” (Idso et. al. 1998, Idso et. al. 2002) was indicated that showed especially high amounts of CO₂ emissions in the denser areas, the city centre. This and other studies also showed that CO₂ emissions vary significantly dependent on the time of the day (Nasrallah et. al. 2003, Idso et. al. 2002, Wentz et. al. 2002, Idso et. al. 1998). Fluctuations were also found in weekly and annual cycles (Nasrallah et. al. 2003). Existing fluctuations of CO₂ emissions are not as important in our study and should be minimised in the regression analysis which uses the calculated total CO₂ 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 CO₂ emissions are highest in the denser areas of town.

The density of a city corresponds to different parameters as e.g. population, jobs etc. Wentz et. al. (2002) found close correlation of measured CO₂ emissions (also approximately 2m above ground) to density of traffic, population, and employment for Phoenix, Arizona. Different density parameters and their relation to the total annual CO₂ emissions will be tested on the urban area of Berlin.

The mix of land uses and polycentrism are also believed to contribute to a reduction of traffic, fuel consumption and CO₂ emissions (Topp, 1998; Sinz & Blach, 1994; Owens, 1992; Hüsler, 1992; Newman 1992; Rickaby, 1992; Owens, 1986). This opinion is widely shared, but authors differ with regard to the strength of the reduction potential.

The relationship between transport structure and CO₂ emissions from traffic has long been recognised (Newman, 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 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. Whereas in the 1970s the construction of new road infrastructure 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 describes changes in transportation behaviour after the opening of the “Spandau” underground railway line in Berlin (Kutter, 1999). The additional supply of PT resulted in an increase in subway users of 7%: 1% of the growth was accounted for by former users of MIT and 6% reflected a reduction in cyclists and pedestrians. This means that the increased use of PT was to 84% 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 the people’s behaviour towards travel patterns can be attained from an investigation in Zurich (Hüsler, 1992). Different cantons were examined regarding location to transportation 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 structure.
The overall consensus is that a good traffic infrastructure (whatever kind) induces its use.

The study undertaken in Zurich implies the importance of income in this context. A 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.

![Figure 2: Development of fuel prices (absolutely and relatively to the net-income between 1960 and 1990); Source: Bergmann, Eckhard, et. al.: Raumstruktur und CO₂-Vermeidung, (IzR), 8/1993, p.497](image)

People over time have had to spend a smaller fraction of income on the same amount of fuel, although the actual price of fuel has increased since the 1960s. Based on this, Schafer & Victor (1999) introduced a concept about the relation between income, time and CO₂. An illustration is given in Figure 3.
Mobility rises with income (e.g. due to a higher number of cars)

Speed increases (e.g. due to a higher fraction of faster modes)

Extension of daily ways / driven distances

Rising transport energy

Increase of CO₂-Emissions

Figure 3: Flowchart to the study of SCHAFER & VICTOR; Source: own draft

Their considerations contain two assumptions. First, there exists a constant budget of time for mobility of about 1.1 hours/day. It differs only slightly from cities to villages or between highly and less developed countries. Second, 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% of all expenditure, the highest fraction among all levels of economic development. This relationship was first postulated by Zahavi (1979) and was empirically confirmed by Schafer & Victor (1998, 2000).

Based on their assumptions people increase 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 CO₂ (when other influential parameters remain similar, e.g. the transport technology does not change radically and the energy sources remain the same). On this basis Schafer & Victor
hypothesised that emissions of CO₂ from the transport sector are highly dependent on income.

Prices act as incentives to reduce costs as e.g. a study about travel costs in Singapore concludes (Eberlein, 1999). 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 amount of cars by 46%. 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 of fuel prices to a level of about 2.5 € for diesel and 2.7 € for petrol would lower passenger kilometres by 20% (German Institute for Economic Research, see Kuhfeld et. al., 1996; see also Wegener, 1999), whereas the burden for economy and businesses would not exceed an increase in costs of 0.5% (if bulk traffic were to be carried by alternative modes of transport – an issue oftenly 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 of the MIT of 30% was calculated, provided that the Public Transport were to be simultaneously improved. It has been concluded that neither a reduction in actual mobility nor an increase in social disparities was visible in the model results. The reduced energy use and CO₂ emissions from transport resulted simply from a change in transport modes.

Concluding: These investigations show that a very strong positive relationship exists between income, energy use and CO₂ emissions from transport. It is believed that the transport infrastructure is an important and positively correlated variable to CO₂ emissions. On the other hand the different indicators from the settlement structure, as e.g. 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 on the local level but, that the denser inner city areas feature higher CO₂ emissions on the sub-local level. The CO₂ emissions are highest where the human activities are to be found. A combination of the variables from the settlement structure, traffic structure and income is thought to have the strongest influence when it comes to reductions of CO₂ emissions in the traffic sector (Wegener, 1999; Würdemann, 1998, Rickaby, 1992). These relationships shall be investigated on the case study area of Berlin.

**Materials and Methods**

The main purpose of the investigation was the search for mitigation options of GCC on a sub-city to city level, in other words: the exploration of the main causes of urban traffic CO₂ emissions. By finding the most important driving forces of anthropogenic CO₂ emissions in urban areas local politicians and planning authorities are given a means to plan for a sustainable city structure. The CO₂ emissions of the traffic sector in Berlin were analysed in relation to parameters 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).
Figure 4: The former and the current municipal districts of Berlin;

Note: after the new structuring of the urban area of the city on the 01.01.2001 Berlin is subdivided into 12 municipal districts shown by brown lines and indicated by numbers from 1 to 10 with 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. Before the end of 2000 the city of Berlin was split in 23 urban districts which are circulated by the light grey lines.

Source: Statistical Office of Berlin

The data refer to the year 1995 - for this one year only CO₂ emissions from traffic were calculated on a sub-city level. The procedure to process such data is very intensive so that it has not been repeated in the following years. This fact mirrors 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 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 without excessive sprawl at the urban 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 CO2 emissions from road traffic.

Data
The data on 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 autobahn were not measured but excluded. On this basis, the average car, bus and lorry traffic was calculated in amount 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 the evaporation for 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 CO2 from traffic were computed at the scale of the 23 municipal districts of Berlin.

Such detailed data on the municipal district level of Berlin are only available for this time period, 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 at the main roads do not give information about the origin and/or end of the journey of the driver. It means that the data about CO2 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 CO2 emissions in urban areas (Nasrallah et.al. 2003, Wentz et.al. 2002, Idso et.al. 2002, Idso et.al. 1998) could be ruled out. The independent variables on traffic CO2 emissions from the settlement structure (density of inhabitant and jobs; the share of certain land uses, see further down), 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 to the independent variables and their indicators are given in table 3.
Methodology

A statistical analysis, comprising both correlation and regression analysis, forms the basis of the methodological approach. CO₂ 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 CO₂ emitted from traffic at place throughout the year (for data generation see above) either by the resident population in the district as well as from people driving by. The area of Berlin covers a distance of 38km in north-south and 45 km in east-west direction (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 borders (see figure 4) which leads to an average diameter of 4.2 to 4.1km per district. Calculations from the DIW (German Institute for Economic Research) have shown that 30.8% of all commuters (commuter traffic as an indication for the distances covered) travel less than 5 km while 56.4% pass less than 10km. 46.7% of the population in Berlin use MIT for the journey to work, 39.1% chose PT. The latter compiles 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%, 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%, will also be generated by people living in the respective district.

The CO₂ 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 proven to be related on a level of p>0.05: not significant, p<=0.05: significant, p<=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 analyses 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 one by one parameter and independently considers the inclusion or exclusion of the parameters with every step (the criterion to enter is the probability of <=0,05, the criterion to remove: probability of F >=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 CO2 emissions from road traffic in tons/year. It is investigated with respect to several independent parameters (see row 2) as indicators for the settlement structure, the transport structure and income (see row 1). In row 4, the signs of the correlation coefficient indicate the direction of influence with a plus indicating a positive and a minus representing a negative relation.

### CO2 emissions from traffic [t/year] and the relation to the settlement structure

| Variable | Indicators | Sample | Correlation | Regression | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Coefficient | Significance p | Coefficient | B | Beta | Constant | R² |
| Density | Resident population (31.12.1995) | 23 | 0,670 | 0,000 | 0,306 | 0,294 | | | |
|  | Number of jobs | 23 | 0,635 | 0,001 | 0,822 | 0,531 | | | |
|  | Number of jobs in industry | 23 | 0,670 | 0,000 | - | - | - | - | |
|  | Total built area [ha] | 23 | 0,564 | 0,005 | 0,215 | 0,376 | 20796,511 | 0,747 |

### CO2 emissions from traffic [t/year] and the relation to the transport structure

| Variable | Indicators | Sample | Correlation | Regression | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Coefficient | Significance p | Coefficient | B | Beta | Constant | R² |
| Transport structure | Traffic area [ha] | 23 | 0,785 | 0,000 | 79,726 | 0,400 | | | |
|  | Street length [m] | 23 | 0,546 | 0,007 | - | - | - | - | |
|  | Length of highways [m] | 10 | 0,192 | 0,595 | - | - | - | - | |
|  | Total number of vehicles | 23 | 0,806 | 0,000 | 1,429 | 0,496 | 22051,158 | 0,714 |

### CO2 emissions from traffic [t/year] and the relation to income

| Variable | Indicators | Sample | Correlation | Regression | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | Coefficient | Significance p | Coefficient | B | Beta | Constant | R² |
| Income | Total net income/ month | 23 | 0,720 | 0,000 | - | - | 46407,839 | 0,711 |
|  | (Average income/person * number of residents) | | | | | | | |
|  | Number of residents with net income < 700€/ month | 23 | 0,449 | 0,031 | - | - | - | - | |
|  | Number of residents with net income 700-<1250€/ month | 23 | 0,414 | 0,050 | - | - | - | - | |
|  | Number of residents with net income >1250€/ month | 23 | 0,862 | 0,000 | 2,078 | 0,843 | | | |
|  | Number of household with net income <1250 €/month | 23 | 0,488 | 0,018 | - | - | - | - | |
|  | Number of household with net income 1250-2000 €/month | 23 | 0,679 | 0,001 | - | - | - | - |
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 number of total jobs as well as the number of jobs from the industrial sector, and the total built 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 CO₂ 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 CO₂ 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 as it comes to the prediction of the CO₂ emissions from road traffic. If one includes all the correlating indicators from the settlements structure into a regression analysis to predict the CO₂ 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 comprising high population figures, many jobs and large amounts of built-up areas show high CO₂ emissions from road traffic in Berlin. The regression model with density parameters yields an R² of 0.747 which is fairly well for a model with 3 indicators. It explains 74.7% of the dependent variable.

As 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 with all three indicators. Drawn from this study one can conclude, that an increase in designated traffic area and in street length seems to result in rising CO₂ emissions from road traffic in Berlin. The increase in car ownership seems to
result in identical matters but is less of influence from the planning authorities. The indicator ‘length of highways’ has not been proven significantly related to the dependent variable. Additionally, if one runs a regression analysis on the significantly correlated parameters, also the street length is taken out. It can not significantly contribute to a prediction in CO₂ 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 CO₂ emissions from road traffic. The regression model shows an R² of 0.714 which is quite good, especially as the model contains only two parameters. As the third variable the relation of CO₂ emissions from road traffic to income shall be illuminated 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. Table 3 portrays that all chosen parameters show 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 of each parameter would predict a rise in the CO₂ emissions from road traffic in Berlin. However, the correlations are not equally strong. It comprises a significance on the 0,05 level with the two lower income clusters/head as well as with the lowest income category/household. In comparison, the correlation with people and households from the upper income cluster reveals a significance on the 0,01 level. This means, it is more certain that people and households with a well-established financial background will impact on the CO₂ emissions from road traffic than the same could be stated 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 a R² of 0.711. It is the lower than the R² found so far but attains this value with only one parameter only. The number of high income households can explain a considerable amount of the CO₂ 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 CO₂ emissions from road traffic in Berlin if one considers jointly the significant parameters of all former regression models. It can serve as an expression for the prediction of CO₂ emissions from road traffic if one aspires to implement strategies from more than one resorts. From the formerly 6 parameters included 2 remained. The number of jobs and the number of high-income residents form the combined regression model. The other indicators lose relevance in comparison to these two, they are not significantly predicting the dependent variable and are taken out accordingly. This concludes, that the urban districts featuring high number of jobs as well as with high numbers of well-off residents characterise the

---

2 The categories for income clusters per head and income clusters per households are taken from the division according to the Statistisches Landesamt Berlin.
highest CO₂ emissions from road traffic in the case study area. The model yields an R² of 0.834 which is high.

In a comparison of all models performed, one can see that the R² of the combined analysis is the highest comprising two parameters. With respect to the other models performed the difference is little. The R² is little higher in models with more parameters and little smaller in those with fewer parameters. The implication for politics and planning is therefore, that an effect on the reduction of CO₂ emissions from road traffic might be possible by strategies from the various resorts tested here.

**Discussion and Conclusion**

The investigation of traffic CO₂ 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 CO₂ 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 characterise large amounts of CO₂ emissions from road traffic.

Most of the traffic encountered in the districts has to be assumed to be transit-traffic though a significant share is also generated by people from the respective one. If one takes the commuter traffic as an indication for the average distances travelled on Berlin’s roads (assuming that the distances for other kinds of road traffic are equal or equalling out, e.g. 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% of all commuters pass less than 5km while 55% drive between 5km an 10km. On average, Berlin’s districts have a diameter of 4.2km though 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 assure that there seems to be more traffic in the districts with high shares of affluent. 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 autochthonous population. Yet this cannot be stated with certainty. A higher amount of transit-traffic might also be caused by commuters from outside of 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 a strongly suburbanised city which would make conceivable extended transit-traffic. The particular history did not allow for a spatial extension much although suburbanisation took place after the reunification yet on a limited scale. Our analysis does not allow to solve this indeterminacy between autochthonous 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 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 its western counterparts, the amount of CO₂ exhausted on these roads is much less. The income of residents seems to reflect on the CO₂ 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: less affluent do not save in the mobility with cars. 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 SCHAFTER & VICTOR (1998, 2000). Financial issues have a strong influence on traffic volumes and respective CO₂ emissions. In turn, the implementation of monetary incentives does promise a strong impact on the traffic volumes and envisaged reductions of CO₂ emissions. With it the possibilities for local planners to influence urban CO₂ emissions seem limited at first sight. The finding of jobs being such a strong parameter in the last regression model might strengthen the impression. On a more closer look however, one can see that the regression models to the other variables (settlement and transport structure) show comparable high R² as well and compared to 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 CO₂ emissions from road traffic can be obtained with strategies aiming to impact, e.g., 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. Second, the traffic area remains a promising parameter of traffic CO₂ emissions under direct influence of the local and regional planning boards. It should be restricted if one wants to achieve a reduction of CO₂ emissions from road traffic in Berlin. With additional means, e.g. supporting the PT, one could assume that the CO₂ 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 of traffic CO₂ emissions, the sign of the correlation is not negative but positive. The urban districts with numerous people face more traffic and respective CO₂ emissions. In turn, one could not conclude easily that higher population densities would result in a reduction of CO₂ emissions from road traffic in Berlin as reported from other studies. One possible reason are the high population densities of European cities (like Berlin), compared to those, e.g., in the US and Australia. Furthermore, Berlin features a relatively compact urban structure without as great differences in population density as compared to other cities and without much sprawl at its fringes. This is due to the historical peculiarities in the second half of the last century (see above). It seems that also a denser building structure, as found in some districts, still allows a considerable part of traffic to occur on the roads in Berlin. With it, 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 (e.g. Wegener, 1999; Würdemann, 1998). Such a strategy seems promising to ease 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 direct influence of 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 preferably 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 one issue indispensable: education about the effects of a possible climate change and the respective alteration of people’s transport habits.

**Acknowledgements**
We would like to thank Henning Rust for the fruitful discussions and the statistical advice.
References

Apel D, Lehmbrock M (1998a) „Konzepte für eine verkehrssparende Stadtentwicklung“, http://www.difu.de/publikationen/difu-berichte/2_97/artikel02.shtml, 29.11.00

Apel D, Lehmbrock M, 1998b, „Die zukünftige Stadt: kompakt, mobil, urban“, http://www.difu.de/publikationen/difu-berichte/1_98/index.shtml, 29.11.00

Bergmann E et. al. (1993) „Raumstruktur und CO2-Vermeidung“, Informationen zur Raumentwicklung (iZr) 8 pp 489-567

Bundesministerium für Wirtschaft (BMWi) (2000) „Energiedaten 2000“ (Cd-Rom); Berlin


Kutter E (1993) „Eine Rettung des Lebensraumes Stadt ist nur mit verkehrsintegrierender Raumplanung möglich“, Informationen zur Raumentwicklung (IzR) 5./6., pp 283-294
Kutter E (1999) „Die Region ist die Stadt – aber hierfür fehlen die Mobilitätskonzepte“, Verkehr und Technik 12, pp 495-506
Statistisches Bundesamt – Destatis: http://www.destatis.de/presse/deutsch/pm2005/p2370021.htm,
Statistisches Landesamt Berlin (2001), Board of Statistics- Federal State of Berlin 
http://www.statistik-berlin.de, 05.10.2005,
Sinz M, Blach A (1994) „Pendeldistanzen als Kriterium siedlungsstruktureller Effizienz“, 
Informationen zur Raumentwicklung (IzR) 7/8, pp 465-480
Stadtentwicklung - Impulse, Projekte, Perspektiven, Eds Walcha H, Dreesbach PP, 
Stuttgart: Kohlhammer, pp 160-184
Umweltbundesamt (1998) http://www.umweltbundesamt.de/uba-info- 
daten/daten/klimagase/htm, 18.09.2001
Wegener M (1999) „Die Stadt der kurzen Wege: Müssen wir unsere Städte umbauen ?“, 
IRPUD (Dortmund), Berichte 43/1999, pp 1-52; http://www.raumplanung.uni-
dortmund.de/irpud/pub/ber.htm#ber43, 06.10.2005
Würdemann G (1998) „Handlungsfelder der räumlichen Planung für eine lebenswerte 
und verkehrssparsame Stadt und Region“, Informationen zur Raumentwicklung (IzR) 
6, pp 351-368