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EXEMPLARY CALCULATIONS FOR NECESSARY TRAFFIC CHANGES THROUGH BEHAVIORAL CHANGES IN ORDER TO ACHIEVE EMISSION LIMITS USING THE EXAMPLE OF POTSDAM

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Abstract

Climate change, exceedances of pollutant thresholds, growing cities and the resulting increased traffic load are still global challenges. Despite the German Environment Agency's report that nitrogen dioxide loads at all measurement stations remained within the prescribed threshold values for the first time in 2024, further enhancements are imperative before the scheduled tightening of the threshold values in 2030. In the interdisciplinary project MaaS L.A.B.S., funded by the German Federal Ministry of Education and Research, a small group of test persons in Potsdam, near Berlin, were surveyed to determine what motivates them to switch to public transportation. A tracking application equipped with incentive features was used for this purpose. The feedback from the participants indicated that merely being aware of the amount of CO_2 saved by opting for low-emission modes of transport (public transport, bicycle, or walking) for a trip was sufficient to motivate them to refrain from using a car. This prompts the question of how many additional trips using alternative modes of transport are required to achieve a measurable change in emissions, particularly CO_2. Statistical data is used to estimate the number of persons who commute to Potsdam on a daily basis, as well as the used means of transport. This leads to the fundamental question how many persons need to be motivated to comply with the established CO_2 limits, and what is the subsequent impact on their travel times.

Keywords: CO_2-emission, public transport, emission reduction

1 Introduction

Similar calculations have been developed for metropolitan areas, whereby the model split is modified to incorporate lower-emission transport modes. Leroutier and Quirion [3] consider the greater Paris area and follow the "Shift-Avoid-Improve" model. Utilising scenarios, they investigate which car trips could be made by lower-emission modes of transport, which could be completely avoided, or which could be replaced by electric vehicles. The initial data was derived from transport surveys. They show that up to 20% of the cost produced by polluting emissions from car use could be reduced thanks to a modal shift (15%) and teleworking (5%). In order to achieve more significant results, a transition to electric cars is required. Viri and Mäkinen [8] modelled CO_2 emissions for the Tampere region in Finnland, utilizing scenarios that extend up to the year 2030. The findings show that while electrifying the private car fleet has a substantial impact (reduction of CO_2 emissions up to 44%), a drastic reduction in emissions also necessitates a reduction in total car trips with a switch to public transport, bicycle or walking (reduction of CO_2 emissions up to 60%). In this study, statistical data concerning commuters to Potsdam is analyzed; the option of commuting by bicycle or on foot is not considered.

Instead, it delineates a percentage of commuters who switch from cars to public transport and calculates a public transport route for them by using the timetable of the local transport association VBB. The study uses commuter trips from other municipalities into Potsdam, thus excluding inner-city traffic. Almost all trips exceed a distance of 10 kilometers on a single leg. Consequently, the utilization of bicycles is not a viable option, nor are footpaths. Commuters for whom reliance on a car is an indispensable aspect remain in the unconsidered share of car drivers.

2 The situation in Potsdam

With regard to fine dust (PM_{10}), nitrogen dioxide and ozone, the overall trend in the air quality is positive. However, over the past two years, on occasion the limit values for PM_{10} have been surpassed. The two official, traffic-related measurement stations in Potsdam are designated DEBB054 (Zeppelinstraße) and DEBB073 (Großbeerenstraße). In 2024, four instances were observed at both stations, and in 2025, there were seven occurrences in Zeppelinstraße and six in Großbeerenstraße [9]. This is significantly below the limit of maximum permissible limit of 35 days per year, with an average of more than 50 µg/m³ for the day, and the correlation to motorized individual traffic is not clearly evident. The situation regarding the targeted CO_2 limits is less than satisfactory. Despite the advances that have been made, Potsdam's objective is to achieve carbon dioxide neutrality by the year 2050 [1]. As stated in the city's 2023 climate report [2], the required reduction in energy consumption in transport in general, and in fossil fuels in particular, has not yet been achieved to a sufficient extent. In 2023, the city's greenhouse gas emissions amounted to approximately 695, 000 tons of CO_2 equivalent. However, to achieve the target scenario, they would have to reach 660, 000 tons by 2023 [2]. In the transport sector, energy consumption is only declining slightly. The traffic sector was responsible for 33% of CO2 emissions in 2023, including traction and driving current [2]. This equates to 229, 350 tons of CO_2 for the traffic sector. The present study calculates estimates to help determine how much CO_2 could be avoided if more commuters travelling to or from Potsdam switched to public transport, and how much more (or less) time they would need for their daily journeys. The underlying data is from 2023 because this is the year because this is the most recent year for which all required data is available.

3 Estimation of the emissions

It is hypothesized that all vehicles will meet the Euro 4 standard, as a prerequisite for entry to the neighboring city Berlin, which has an environmental zone. The open-source software SUMO (see https://eclipse.dev/sumo/) was utilized in order to estimate the emissions of cars. In the context of SUMO, a number of emission models are at one's disposal. The calculation is performed using the HBEFA4 model, version 4.2, and the private car class with a petrol engine and Euro-4 standard. Moreover, typical traffic conditions for the area Berlin are assumed. The calculation for public transport vehicles used estimates given by the local public transport operator " ViP Verkehrsbetrieb Potsdam GmbH"., which were also employed in the MaaS L.A.B.S. project [7]. Given that per capita consumption is needed, it was necessary to establish a capacity utilization rate. The decision was taken to set it at 80% (higher than current values), as there are significantly more people using public transport in the calculated scenario. In the year 2023, the e-bus rate within the designated area was not yet substantial. Likewise, the share of renewable energies utilised for trams and light rail systems had not yet attained a level sufficient to significantly reduce their CO_2 emissions. The emissions are calculated as "g CO_2 / pkm" (pkm denotes passenger kilometres) with 18 g CO_2 / pkm for trains, 60 g CO_2 / pkm for buses and 12 g CO_2 / pkm for Tram trains.

The emissions of busses are higher because the rate of e-buses of the local transport associations was negligible in 2023. The deployment of additional vehicles due to the increased passenger volume has not yet been factored in. It is hypothesized that all commuters can be accommodated on the vehicles scheduled according to the timetable.

4 Calculation and results

To achieve the greatest possible savings potential, the main commuter flows are focused. Of the strongest commuters flows in 2023, 28, 286 commuters travelled from neighboring municipalities to work in Potsdam, while 28, 929 travelled from Potsdam to neighboring municipalities [5]. Figure 1 shows the five largest main commuter flows (in- and outgoing). Around 30% of all commuter trips in Berlin and the surrounding municipalities are made by public transport. At least 50% are made by private car, including commuters that are additional passengers in a car [4]. The proportion of commuters who use private cars increases the further they live from Potsdam and Berlin. For the calculations, the starting locations were distributed across residential areas of the start municipality and the destination locations across commercial, business and cultural areas of the destination municipality. Figure 2 shows the chosen locations for incoming commuters on a map. At least 50% travel by private car. Of these, 25% are expected to switch to public transport. The CO_2 savings will then be calculated and the changes in travel times compared. Trips start in the morning between 7 and 9 o'clock (with latest arrival time at destination being 9 a.m.). It is assumed that they will take the same route back in the afternoon. Time spent searching for a parking space is not included in travel times but the time spent walking to and from a public transport stops is.

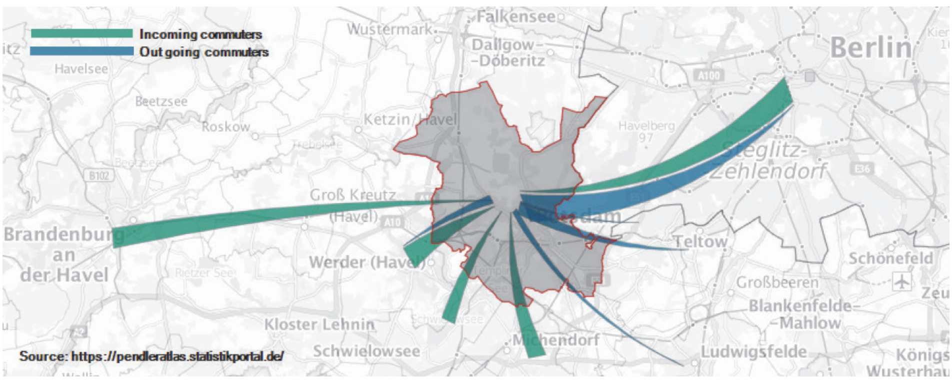

Figure 1 Commuter atlas for Potsdam 2023 (source pendleratlas.statistikportal.de)

Table 1 shows the size of the commuter flows per day and the percentage and absolute values of those switching to public transport. The average travel distance to Potsdam for one way is also listed.

Table 1 Incoming commuters switching to public transport by municipality

Municipalities of incoming commuters	Commuters in numbers	Commuters [%]	Switchers (1/4 of 50%)	Average distance to Potsdam [km] (one way)
Berlin	18, 132	64	2267	26.0
Werder (Havel)	3, 751	14	469	15.6
Brandenburg (City)	2, 370	8	296	58.0
Michendorf	2, 092	7	261	16.0
Schwielowsee	1, 944	7	243	13.7
Sums	28, 286		3, 536	

4.1 Results for incoming commuters from Berlin

Route calculations and emission estimates were performed for the car trips of 2267 commuters, consisting of two trips per day, one in the morning and one in the afternoon. Table 2 shows the results for CO_2 emissions, travel times and travel distances, presenting both absolute and average per capita values.

Table 2 Results for Berlin showing average per capita values

	CO_2 [t]	CO_2 p.c. [kg]	time [h]	time p.c. [h]	length [km]	length p.c. [km]
PT	2.933154927	1.294	4, 633	2.04	114, 187	50.369
Cars	23.391037826	10.318	1, 983	0.87	117, 823	51.973
Diff	-20.457882899	-9.024	+2, 650	+1.17	-3, 636	-1.604

More than 20 tons of CO_2 could be saved in one day if 2,267 commuters from Berlin chose public transport over driving (under the aforementioned assumptions and conditions). The total distance travelled would be slightly less too: 3, 636 km less, or 1.6 km per person and day. This might be plausible because there are several direct/straight train connections from south-west Berlin to Potsdam. As expected travel times increase. On average, each commuter needs an extra hour per day, which equates to a 134% increase in travel time.

4.2 Results for incoming commuters from Werder

Route calculations and emission estimates were performed for car trips of 469 commuters, consisting of two trips per day, one in the morning and one in the afternoon. Table 3 shows the results for CO_2 emissions, travel times and travel distances, presenting both absolute and average per capita values.

Table 3 Results for Werder showing average per capita values

	CO_2 [t]	CO_2 p.c. [kg]	time [h]	time p.c. [h]	length [km]	length p.c. [km]
PT	0.856751070	1.827	956.78	2.04	17, 075	36.408
Cars	3.318405372	7.075	344.21	0.73	14, 607	31.146
Diff	-2.461654302	-5.249	+612.57	+1.31	+2, 468	+5.262

The average per capita emission savings are lower because the average trip distances are shorter (40%) but the average additional travel time per capita is higher than that of the Berlin commuters: plus 18 minutes - an increase of nearly 180%. The additional distance also increases by an average of 5.3 km.

4.3 Results for incoming commuters from Brandenburg (City)

Route calculations and emission estimates were performed for car trips of 296 commuters consisting of two trips per day, one in the morning and one in the afternoon. Table 4 shows the results for CO_2 emissions, travel times and travel distances, presenting both absolute and average per capita values.

Table 4 Results for Brandenburg showing average per capita values

	CO_2 [t]	CO_2 p.c. [kg]	time [h]	time p.c. [h]	length [km]	length p.c. [km]
PT	1.043412293	3.525	725.24	2.45	27, 916	94.311
Cars	5.415374357	18.295	367.07	1.24	25, 643	86.633
Diff	-4.371962065	-14.770	+358.17	+1.21	+2, 273	+7.678

The distance between Brandenburg and Potsdam is 40 km longer than that between Werder and Potsdam. This results in the greatest emissions savings per capita. The additional travel time per person for public transport users is even shorter than for commuters from Werder, but still 97% longer than for car users, while the additional distance travelled per person compared to a private car trip is the longest of all the example calculations: over seven kilometers.

4.4 Results for incoming commuters from Michendorf

Route calculations and emission estimates were performed for car trips of 261 commuters consisting of two trips per day, one in the morning and one in the afternoon. Table 5 shows the results for CO_2 emissions, travel times and travel distances, presenting both absolute and average per capita values.

Table 5 Results for Michendorf showing average per capita values

	CO_2 [t]	CO_2 p.c. [kg]	time [h]	time p.c. [h]	length [km]	length p.c. [km]
PT	0.377622343	1.447	447.98	1.72	8, 700	33.334
Cars	1.855157674	7.108	161.91	0.62	8, 437	32.327
Diff	-1.477535331	-5.661	+286.07	+1.10	+263	+1.007

Since the distances travelled are similar to those from Werder, the average per capita saving of CO_2 emissions are also similar. The municipality of Michendorf is very compactly structured with few remote districts and has a regional train station in the town center. Although the trip lengths are only slightly longer than car routes, the average additional travel time per capita increases by 177%.

4.5 Results for incoming commuters from Schwielowsee

Route calculations and emission estimates were performed for car trips of 243 commuters consisting of two trips per day, one in the morning and one in the afternoon. Table 6 shows the results for CO_2 emissions, travel times and travel distances, presenting both absolute and average per capita values.

Table 6 Results for Schwielowsee showing average per capita values

	CO_2 [t]	CO_2 p.c. [kg]	time [h]	time p.c. [h]	length [km]	length p.c. [km]
PT	0.333226473	1.371	404.06	1.66	7, 117	29.286
Cars	1.446927746	5.954	147.38	0.60	6, 674	27.466
Diff	-1.113701273	-4.583	+256.68	+1.06	+442	+1.820

Commuters from Schwielowsee have the lowest average per capita CO_2 savings (and also make the shortest trips). However, their average daily travel time is increasing by 177%.

5 Conclusion

In addition to the absolute values shown in the previous tables, figure 2 illustrates the ratio of car and public transport emissions for the calculated commuter groups. Not only could the incoming commuters from Berlin save the highest absolute amount of CO_2, they are also the most efficient.

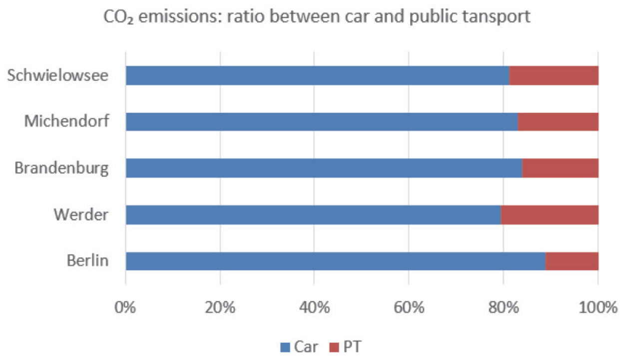

Figure 2 CO_2 emissions as ratio of car and public transport (incoming commuters)

This study does not calculate the values for outgoing commuters. If the same logic is applied as for the incoming commuters, the total number of switchers among the outgoing commuters is similar (only additional 80 persons), but only 16% do not commute to Berlin, table 7.

Table 7 Overview outgoing commuters by municipality

Municipalities (outgoing commuters)	Commuters in numbers	Commuters [%]	Switchers (1/4 of 50%)
Berlin	24, 347	84	3043
Teltow	1, 475	5	184
Werder (Havel)	1, 223	4	153
Ludwigsfelde	951	4	119
Kleinmachnow	933	3	117
Sums	28, 929		3616

There are at least 260 working days in a year (Monday to Friday). In Germany, there are around 10 public holidays, some of which fall on working days. Taking into account holiday, sick leave, and other reasons for not commuting, the number of working days can be estimated at 200. The calculations show that 29.882735870 tons of CO_2 could be saved per day if half of the incoming commuters travelling by car switched to public transport (all statistic data based on 2023). Multiplying this by 200 days results in 5, 976 tons of CO_2 emissions saved. This is 17% of the 35, 000 tons of excess CO_2 emitted in Potsdam in 2023 [2]. Assuming that the calculations for outgoing commuters, which are a similar number of people (table 7), save comparable amounts, one third of the surplus mentioned in chapter   could be saved through changed travel behavior alone. Of course, these calculations are estimates and rely on some assumptions and simplifications. They do also not take into account that not all of the savings would take place within the city limits of Potsdam. Nevertheless, the calculations demonstrate that changes in traffic behavior can lead to significant improvements concerning emission reduction. Using energy from renewable sources for electric buses and trains would further increase this effect. The examples also show that switching to public transport results in longer travel times. This makes it difficult to motivate commuters to switch. If travel time could be used effectively, public transport could become more appealing. However, this would require a certain level of comfort on public transport trips.

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