

BEST OPTION FOR REDUCING ON-CAMPUS PRIVATE CAR-BASED CO₂ EMISSIONS: REDUCING VKT OR CONGESTION? (1)

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1. The proposed method and analysis included in this article are based on the MSc thesis study of Oruc Altintasi conducted at the Middle East Technical University.

INTRODUCTION

A sustainable transportation system has been defined as “one that satisfies current transport and mobility needs without compromising the ability of future generations to meet their own” (Black, 1997; Richardson, 1999). The success of sustainable transportation in urban regions depends on encouragement of non-motorized (pedestrian and cyclist) and shared-ride transportation modes instead of car-dependent travel. The level of sustainability in transportation can be simply assessed by calculating the corresponding carbon emissions value and comparing the shares of different travel modes. With today’s engine technology, carbon emissions of motorized vehicles is a function of fuel consumption, which is used to power the vehicle and is measured as Vehicle-Km-Travelled (VKT) or idle-running during waiting times (such as in congestion). Thus, a sustainable transportation policy that aims to effectively reduce CO₂ emissions will need to address VKT (especially from private cars) and traffic congestion.

Middle East Technical University (METU) in Ankara, Turkey has a fairly large campus that is spread over 220 hectares. This accommodates academic, cultural and dwelling units (dormitories for students and housing for personnel), research-and-development facilities known as Technopolis and educational services for the families of the personnel (nursery, elementary school and a high school). The campus has a daily population of 30,000 people; most of the population commutes from different parts of Ankara. A significant portion of these commuters use private cars, which generates approximately 14,000 trips per day. The campus area is bordered by two major arterials to the north and west which can be accessed from two main gates (A1 and A7). The third main gate to the east (A4) provides access to a nearby neighborhood, where a significant number of METU commuters reside (**Figure 1**). All the main gates are accessorized with a Radio Frequency Identification (RFID) system to prevent unauthorized vehicles from accessing the campus.

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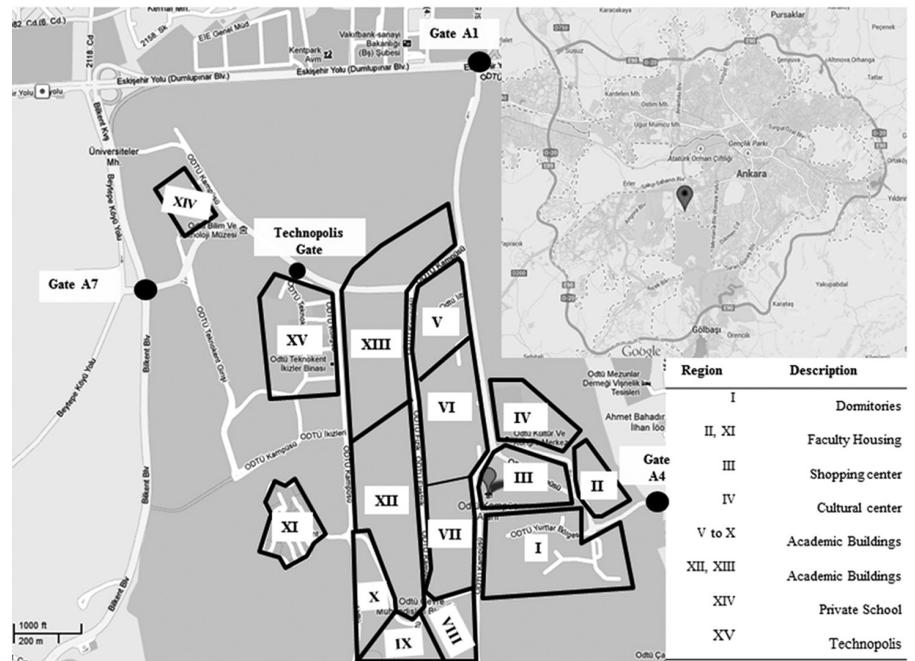


Figure 1. a) The layout and b) the location of METU campus in Ankara

The original design of the campus was pedestrian-friendly with academic units located in regions V to VII and dwelling units in regions I and II. However, over the years, further faculty buildings, dormitories and housing units were constructed to the west and north in regions VIII to XIII, which generated a set of non-walkable origin-destination (O-D) pairs. The Technopolis in Region XV also generates significant commuting and on-campus travel. It is a workplace for over 3000 people, whose vehicles are limited to accessing campus using only the A4 and A7 gates. Vehicle access to Technopolis further controlled via a minor gate. Most of the campus roadway was designed as undivided two lane roads that this causes congestion under high private car demand during peak hours.

As with other urban regions, it is possible to develop more sustainable transportation systems for a campus by decreasing private car usage and/or increasing shares of zero-emission modes (walking and biking) and public transit. These actions mainly aim to reduce private car vehicle-km-travelled (VKT) values and congestion (reflected as decrease in the average speeds), which are considered the two main factors in calculation of CO₂ emissions. The focus of this paper is to identify the major of the two parameters that has greater potential to reduce carbon emissions of METU campus transportation. To evaluate them, first, the current levels of carbon emissions for the campus were determined as the base case. A set of hypothetical scenarios were developed to reflect possible strategies for METU campus based on different sustainable transportation policies and their expected impact on the private car usage on campus. Emissions with and without congestion were compared for different hypothetical scenarios to identify the impact of VKT and congestion in reducing on-campus emissions at METU.

The layout of the paper is as follows: A comprehensive literature review is presented in Section 2 regarding sustainable campus transportation, vehicle emission calculations and traffic simulation literature. An evaluation methodology is described in Section 3, in which the limitations of the study

are also discussed. Numerical results are provided in Section 4. A summary of findings and recommendations for further studies are given in Section 5.

LITERATURE REVIEW

To better explain the contribution of this paper, a brief literature review on sustainable campus transportation is provided followed by a short review of how vehicle emissions are estimated. Use of PTV VISUM software in traffic assignment is also explained with examples of studies from the literature.

Sustainable Campus Transportation

Large university campuses can be regarded as small cities, due to their high student population, significant motorized traffic demand, different attraction-production zones (shopping, sport centers, teaching activities and so on). However, they have relatively small and closed transportation systems, where different traffic and demand management options can be implemented easily. Today, universities around the world are implementing many strategies to reduce car-dependent travel on their campuses. These strategies are gathered under the concept of "Transportation Demand Management", which has been defined as a "planning strategy to influence the travel behavior of people in a way that the congestion is reduced" (Meyer, 1997). These planning strategies are increasing the use of non-motorized modes, shared ride and public transit, and focused on reducing private car trips or at least single-occupancy in travel (Markowitz and Estrella, 1998).

On-campus transportation has also been the focus of more detailed studies. Balsas (2003) studied eight bike and pedestrian friendly campuses in the US to understand the reasons behind the success of non-motorized modes. Miralles-Guasch and Domene (2010) determined the travel pattern and transportation challenges of a university in Barcelona through an online survey with 5,525 participants, where lack of adequate infrastructure, marginal role of walking and cycling and longer time involved using public transport were detected as the main barriers to shift from private car to non-motorized modes. As an evaluation of parking management in a Chinese university, Huayan et al. (2007) focused on the problems of lack of parking lot capacity and increased on-street parking, which threatened pedestrian safety. Akar et al. (2012) also examined transportation choices and travel patterns of a campus community at Ohio State University via a web-based survey, which found that students were more likely to travel by alternative modes than faculty and staff members. Other campus studies focused on the travel behavior of students, as they are the target group with an easier modal shift chance towards adopting more sustainable modes. Limanond et al. (2011) studied the travel behavior of 130 students who live on campus in a rural university and found that males and females had similar travel pattern; students owning a car preferred driving and non-car owners preferred riding with a friend and using the bus. Zhou (2012) studied the commute behaviors of university students in Los Angeles. He found that improvement of a multimodal transportation system and discounts in public transit may greatly change the travel behavior of students. Eom et al. (2009) investigated the daily activity characteristics of university students in Carolina State University and confirmed that walking was the primary mode for on-campus residents.

Estimation of Vehicle Emissions

Estimation of carbon emissions generated on a university campus depends on the scale of the evaluation which may consider components such as heating, waste, transportation, etc. As an integrated tool to assess campus carbon emissions from different areas, "Clean Air-Cool Planet's University Carbon Calculator" program is used, mostly in the US. It is a Microsoft Excel-based program and can calculate future emissions trends and analyze the potential carbon emissions annually (Ferraro, 2008). However, this program requires very large and detailed data input regarding all the campus buildings, vehicle fleet data, fuel consumption data, etc. For university wide campus carbon emissions calculations, Clifford and Cooper (2012) calculated the carbon emissions from on-road vehicles for the University of Central Florida. Vehicle fleet data and gasoline consumption records kept by the university administration and the Motor Vehicle Emissions Simulator (MOVES) program was used to calculate the carbon emissions of both commuters (including faculty members, students, administrators) and visitors who were using campus shuttles, airlines, trains, cars, etc. The results showed that undergraduate students produced 71.6% of the total carbon emissions whereas faculty members only accounted for 4.0%. Mathez et al. (2013) also employed the MOVES program to calculate the travel related carbon emissions of McGill University in Montreal. Following a survey of commuters, emissions were categorized according to their mode split, and the age and gender of the commuters.

To accurately estimate motorized travel emissions, it is also necessary to consider vehicle engine types, fuel types, and average speed of vehicles. A means for calculating the relationship between vehicle speed and corresponding CO₂ emissions for private cars on freeways was provided by Barth and Boriboonsomsin (2008) in their study of road vehicle fleet data collected in 2005 in South California. Their purpose was to investigate the relation between average speed and corresponding emissions instead of specific vehicle categories. CO₂ emissions were found higher, if the speed was low (0-15 km/h), and optimal emissions were reached between 70km/h to 90 km/h, for which the latter was stated as the free flow speed for freeways. Any speed above the latter also produced additional CO₂ emissions. To reduce CO₂ emissions, the authors suggested congestion management strategies, such as ramp metering, incident management, enforcement, and using Intelligent Transportation System applications, as well as speed management strategies to avoid the exceeding of free flow speeds. Their analysis showed that CO₂ emissions would be reduced by 7-12%. The average speed and corresponding emissions was also discussed by Boulder et al. (2009). Average speed-emission curves were derived from European vehicle fleet data and the findings were very similar to the study by Barth and Boriboonsomsin (2008). Bigazzi (2011) investigated the traffic congestion effect on emissions, and used the MOVES program to derive an average speed-emissions model. Emissions rates were modeled using data for on-road vehicles, 52.8% of which were passenger cars powered by gasoline, measured in Portland, Oregon in 2010. Average speed and corresponding emissions were found to be slightly higher than those obtained by Barth and Boriboonsomsin (2008) and Boulder et al. (2009). Elsewhere, the Handbook of Emission Factors (HBEFA) emission calculation program is widely used in Germany, Austria and Switzerland as the program included vehicle fleet data from these countries (Boulder and Latham, 2009).

Traffic Assignment using PTV-VISUM

Traffic simulation in transportation engineering is crucial to better plan, design and to operate freeway junctions, arterial routes, roundabouts, whole city network, etc. PTV-VISUM is a macroscopic traffic simulation program that performs traffic analyses, forecasts and provides GIS-based data management (VISUM Basics, 2009). It can be used to model transport networks and travel demand to analyze the expected traffic flows on links and to develop advanced transport strategies and solutions. The network of traffic in PTV-VISUM can be defined as the traffic nodes, links, and zones and various traffic assignment procedures (user equilibrium, stochastic, dynamic assignment) are included to perform traffic flow analysis (VISUM Basics, 2009). Furthermore, for micro traffic simulation, PTV-VISUM is supported by PTV-VISSIM, which analyzes private and public transport operations under certain constraints such as, traffic composition, traffic signals and lane configurations (VISSIM User manual, 2009).

In the literature, Hui et al. (2010) developed a methodology to estimate time varying O-D matrix by using floating car data and remote traffic microwave sensors data from the Western 3rd Ring-Road corridor network in Beijing, China. The defined network was formed by using PTV-VISUM to get static O-D demand. Wong and Yu (2011) collected the data from 36 intersections and 26 road segments at the morning peak of a normal day and during the Macau Grant Prix event to determine the O-D matrix of the region. The network included 443 nodes, 1344 links, and 23 zones, and traffic assignment was performed to get traffic flows on links using PTV-VISUM. Finally, most critical links, trip lengths and travel times were evaluated. Elsewhere, Bustillos et al. (2011) used PTV-VISSIM to simulate University of Texas campus traffic dynamically. Parking surveys were undertaken with 80 faculty and staff to determine their destination trips. Traffic counts were classified for students, faculty, and staff members separately. Finally, O-D matrix and parking information were assigned to the PTV-VISSIM to evaluate the traffic performance. Fries et al. (2011) also evaluated the mobility impact of relocating parking at Clemson University campus in South Carolina using PTV-VISSIM. The network consisted of 742 nodes and 20,000 links and traffic data were collected by manual counts and video footage. The 44x44 O-D matrix they created was assigned to the network for 11 different traveler types (commuter student, faculty and staff, university service cars and so on), separately. They were then able to calculate the total network delay caused by private car users.

EVALUATION METHODOLOGY

The framework of the simulation-based methodology used to calculate the carbon emissions from private car usage on campus is shown in **Figure 2**. Existence of a sticker-based access policy for private car users and automated RFID control at all three campus entry locations made it possible to study the origin or destination of private car travelers at METU (Altintasi, 2013). Campus traffic data were collected from the RFID system and parking lot surveys (Step 1) simultaneously, which were used to obtain the daily activity profile at the campus gates. The data was further processed to estimate the current daily private car O-D matrix for the morning and evening peak periods, and off-peak hours separately (Step 2). The O-D matrix was assigned to the network (Step 3) using PTV VISUM simulation to get the VKT values and average speed on links, which were used in Step 4, to estimate current carbon emissions (called the base case

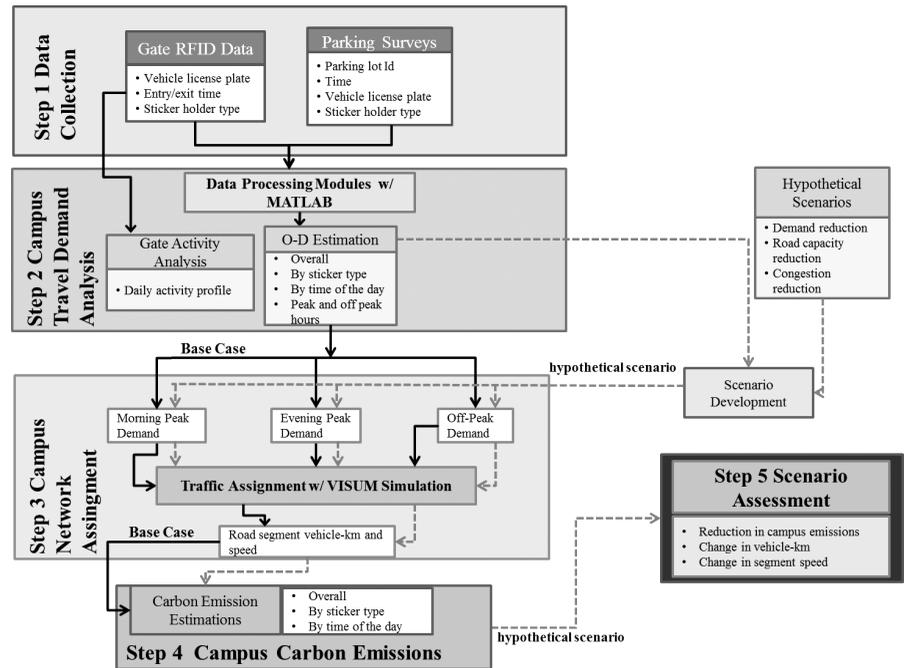


Figure 2. Framework of the simulation-based methodology for campus carbon emission assessment

scenario). To study congestion impact, the peak periods were assigned separately from the off-peak hours.

This framework was followed for each hypothetical scenario, as well, which proposed a change in the demand or the road network usage. The scenario assignments resulted in different VKT and speed values, thus different emissions. In the final step, Step 5, the changes between a scenario and the base case were evaluated from two perspectives: i) change in the total emissions, and ii) the share of congestion in the emissions. The latter is defined as the percentage of the emissions caused by slowed down traffic using the following formula:

$$\text{Congestion share} = \frac{\text{Emissions}(VKT, \text{assignment speeds}) - \text{Emissions}(VKT, \text{freeflow speeds})}{\text{Emissions}(VKT, \text{assignment speeds})} * 100$$

It should be noted here that a report by European Conference of Ministers of Transport (ECMT) in 2007 suggested that “the free-flow speeds should not be used as a direct benchmark to measure congestion policy outcomes”, as such an approach implicitly would suggest that successful policies deliver free-flow speeds. However, the report’s suggestion of “using median speeds” or a set of benchmark values such as “percentage of maximum legal speed or different speed bands” as alternatives were not discussed in further detail, either. In an urban network, we do not expect to have always free flow (or design) speeds as operating levels on METU campus roads, as discussed in the ECMT report. However, we can still define this “congestion share” by finding the difference in emissions from the “average speeds” and the “design speeds”. This would enable us to quantify the changes in emissions under different hypothetical scenarios to some extent. Further details of the methodology are given in the following subsections.

License Plate	First Time	Source	Location	Movement	Second Time	Source	Location	Movement
01XY361	07:54	1	A1	1	08:30	0	70	0
01XY361	08:30	0	70	0	10:30	0	18	0
01XY361	10:30	0	18	0	12:00	1	A4	2
01ZW025	15:05	1	A4	1	15:30	0	30	0
01ZW025	15:30	0	30	0	19:49	1	A4	2

Table 1. An excerpt of the MATLAB code output

Determination of On-Campus Private Car Demand

While the RFID system provided data for one end of the on-campus trips, determination of the on-campus origin-destination (O-D) matrix required additional information on the other end. For this purpose, during the collection of gate RFID data, license plate surveys in all the campus parking lots were performed concurrently and multiple times (at 08:30-09:30, 10:30-11:30, 12:30-13:30, 16:30-17:30). Processing of these two sources of data jointly was performed via a MATLAB code developed by the authors. The code simply detected all the observation locations and time for every unique license plate, put them into time order, and generated basic information for each end of each trip for a vehicle (including observation time and location, data source and movement type). To explain the logic behind the code, a fictitious output excerpt is given in Table 1. Data "source" indicated whether the information was taken from the gates (source=1) or from parking lot (source=0). "Movement" indicated the type of vehicle movement (if it is "1," the movement is an entry; if it is "2," it is an exit; it is "0" if it is observed in a parking lot). For a vehicle (license plate "01XY361") first read by the RFID reader at the A1 gate entering the campus at 07:54 and observed at the Parking Lot 70 at 08:30, an on-campus trip was generated between the two locations. The same vehicle was also observed at the Parking Lot 18 at 10:30, which suggested another trip between the two parking lots. In its third observed trip, the same vehicle was read exiting the campus at 12:00 at A4 gate. Even though this code could not provide exact start/end times for the trips originating from/arriving to parking lots, the location information was reliable for O-D estimation. But, there is no guarantee about the number of unobserved on-campus trips. Thus, these two sources of data would provide a minimum number of trips made by each vehicle. Further details of the code and data processing can be found in (Altintasi and Tuydes-Yaman, 2014).

Vehicle Emission Estimation for METU Campus

METU has no recent travel survey data and the current study did not aim to calculate off-campus travel emissions. Thus, "Clean Air-Cool Planet's University Carbon Calculator" and MOVES programs were not suitable, since they require large and detailed input data sets. Instead, based on the finding by Barth and Boriboonsomsin (2008), a VKT and speed based approach was chosen by discretizing the CO₂ emissions versus speed graph into six speed intervals and the average CO₂/km values at the mid-interval speed values as follows:

- 5-15 km/h: an average of 0.609 (kg/km)
- 15-25 km/h: an average of 0.391 (kg/km)
- 25-35 km/h: an average of 0.279 (kg/km)
- 35-45 km/h: an average of 0.236 (kg/km)
- 45-55 km/h: an average of 0.218 (kg/km)

For METU campus, an average speed of 5 km/h limit was assumed for parking lots, while design and off-peak operating speeds on roads around the pedestrian activity zones (i.e. roads around core campus, dormitories and sports and cultural halls) were assumed as 30 km/h and 50 km/h for corridors connecting gates A1 and A7 to the core campus.

Scenario Development

For the development of the hypothetical scenarios that can either change the VKT or the congestion levels on campus roads, we have assumed different situations or cases that could affect the on-campus private car demand. In the process, for some scenarios we assumed different levels of impact on the O-D to see the sensitivity of the emissions to the demand levels. Scenarios were generated based on one or more of the following assumptions:

1. A potential change in pricing of car stickers on-campus
2. Possible strengthening of on-campus shuttle services
3. Potential reduction in road widths (thus, capacity) due to a proposed reserved bike lanes
4. Potential modal shift from private car to metro after the opening of the Çayyolu-Kızılay line
5. Possible peak hour entry gate restrictions for Technopolis workers

To develop a scenario based on the car sticker pricing (which is only the value of the magnetic card itself for the academic and administrative staff, and \$195 per year with 2012 prices for students), we based our assumptions on the fact that due to the lack of public bus services accessing the campus from the city, the university management would not consider a total ban, but rather discouragement (of students especially) via higher entry pricing. A low increase in car sticker prices was assumed to generate a 20% reduction in student private car demand in the first scenario (**Table 2**). However, improvement of on-campus shuttle services which carry the university community between the main gates and campus settlement, may contribute to a reduction in private car use among students in accessing the campus by up to 40%. Furthermore, the reduction could reach a level of 50% if bike lanes were created on campus roads (Scenario 3). Another easily controlled user group has been the Technopolis workers, who use separate permits already. As they have special agreements with the university, Technopolis workers could be further restricted in their use of campus during peak hours, by redirecting their permits to the A7 gate only (Scenario 4). While this would not change the total demand in any segment, it would ease peak hour congestion.

While the metro services are beyond the control of the campus administration, it can act to create a modal shift from different modes including the private car. In the absence of any study projecting the potential shift to metro among campus travelers, we generated different levels of reductions in the private car usage to quantify the potential impact on the campus emissions and their shares from VKT or congestion. With the existing feeder line and on-campus shuttle services from A1 gate providing connection to limited campus locations, first, a conservative level of 20% modal shift was assumed from private car to metro for all campus users (Scenario 5). If a low increase in the student car sticker prices were also implemented at the same time, we assumed a 40% reduction in the modal shift among students in Scenario 6. The modal shift among the private car user students could reach to 50%, if further on-campus shuttle

#	Scenario Description	% Reduction in private car demand			
		Student	Admin.	Acad.	Others
Student sticker pricing:					
1	Low price increase	20	---	---	---
2	High price increase, on-campus shuttle support, public transportation	40	---	---	---
3	High price increase, on-campus shuttle support, public transportation and reserved bike lanes	50	---	---	---
Peak hour entry gate restriction:					
4	Redirecting Technopolis workers to A7 during peak hours	---	---	---	---
Modal Shift due to the Metro line:					
5	A conservative modal shift assumption	20	20	20	20
6	Metro line opening w/ a low sticker price increase for students	40	20	20	20
7	Metro line w/ a low sticker price increase for students and a stronger shift in administrative personnel	40	40	20	20
8	Metro line w/ low sticker price increase for students, on-campus shuttle support, public transportation and reserved bike lanes	50	20	20	20

Table 2. Hypothetical scenarios and assumed reduction in private car demand for different travelers

support and biking services could be provided (Scenario 8). On the other hand, a stronger modal shift could be achieved among the administrative personnel, if further appropriate policy tools could be developed (not only by the university administration but by the municipality as well), such as better feeder systems, smart card applications with transfer options, etc. as devised in Scenario 7. We did not expect any strong modal shift among academic personnel and Technopolis workers as academic personnel were shown to have more flexible and complex arriving/departing time patterns (Altintasi, 2013), and Technopolis companies do not prefer shared shuttle rides due to work related privacy concerns.

One has to carefully analyze the proposed bike usage on the campus roads. While there are not many cyclists, or no declared details about a campus biking strategy, routes or systems, we studied this scenario at a basic level and mostly from the point of road network capacity requirement (which would directly affect the average speeds). As the literature suggests, the safest start point of a biking culture in a region requires designing reserved lanes. We are not capable of providing reserved bike lanes on those campus roads that have one lane capacity for each direction. For roads with 2 lanes in each direction shown in **Figure 3**, it is possible to redesign the roads to create a bike lane (up to 60 cm) by reducing the existing lane widths to 3m, which would further require reductions in the road capacities in the simulation. However, while biking along the north-south directions would be relatively easy; biking along the east-west roads would be very challenging due to the steep slopes in the campus geography (Gulluoglu, 2005). Nevertheless, this obstacle can be overcome by some means, such as the introduction of electric bicycles operated in a bike-sharing system.

Limitations of the Study

Despite the great efforts spent to combine different data sources, simulation based evaluation techniques, etc., there are certain limitations regarding this methodology. First, information about vehicle type and vehicle engine performance is necessary for accurately calculating carbon emissions, and were not used in this study. In the literature, such data was generally obtained via comprehensive travel surveys of different traveler groups. This study did not have the time or budget for conducting such surveys.

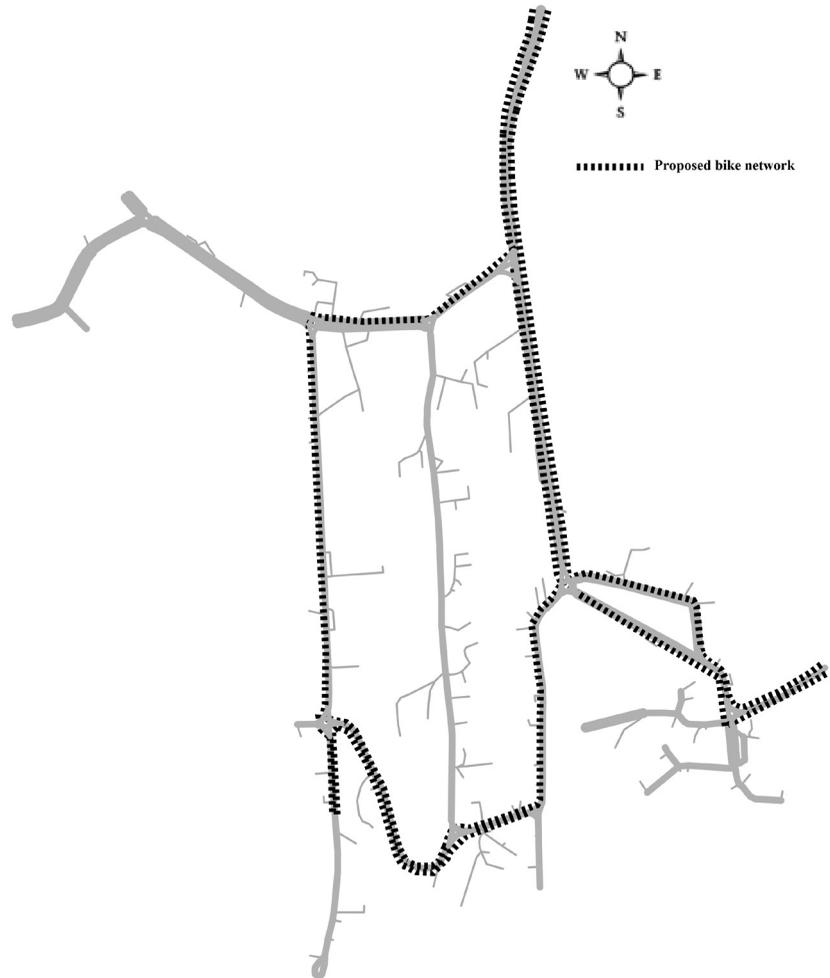


Figure 3. Roads facing capacity reduction due to assumed reserved bike lanes on METU campus

RFID system based data provided many details about private car usage and user but not for the vehicle type, fuel type and engine performance. However, use of average speed as a major indicator of the emissions was preferred in other studies, as well (Barth and Boriboonsomsin, 2008; Boulder et al., 2009; Bigazzi, 2011).

In most of the sustainable campus transportation studies, the emission calculations were not limited to passenger cars but also included other transportation modes. Furthermore, they focused on the emissions from whole length of commute travels starting from homes and connected household activities, not only on-campus emissions. However, such analyses required more data about the trip details as well as data about public bus fuel consumption (generally obtained from the municipality). Traditional travel surveys include many questions to understand the mode split distribution and VKT shares of a traveler in a day. Such an approach was not used in this study because there was no recent household survey data collected for the city of Ankara or campus users to analyze the traffic conditions beyond the campus limits. It was possible to collect private car commuter trip data from the campus entry gates and parking lots partially. As a result, we could obtain the O-D matrix for private car trips only. Scenarios had hypothetical demand level reductions purely selected to study sensitivity of the emissions to different demand (thus, VKT and

congestion) levels. The details of required policy and strategies to achieve such reduction levels were not considered in the scenario development stage. Despite the lack of a travel survey, these developed hypothetical emission reduction scenarios will give insight to the major component of the carbon emissions on METU campus.

NUMERICAL RESULTS

To support the assumed traveler behavior in the scenarios, first, a brief evaluation of the campus travel demand pattern is provided, followed by a short report on the campus network assignment input and results. On-campus private car based emissions are presented for all study periods in detail, which are later processed to estimate their congestion share.

Campus Travel Demand Analysis

RFID system data collected at the three main campus gates (A1, A4, and A7) provided detailed information about a vehicle (its license plate, sticker type, entry and/or exit time, etc.) for a 24-hour period. A full working week data (November 21-25, 2011) from 3 gates showed that a regular weekday total activity profile (of total entries and exits) in METU campus followed the typical urban travel demand profile (**Figure 4**); a sharper morning peak was observed around 8 a.m. and a more dispersed evening peak between 5p.m.-7p.m. with limited activity after 10p.m.to 7a.m. Thus, the daily traffic assignments were performed for the demand between 7a.m. and 10p.m. Total entry and exit data was obtained from all the RFID sticker owners which included students, academic and administrative staff, and the Technopolis workers.

Figure 4. Total activity profile of METU campus during the control week (from A1, A4 and A7)

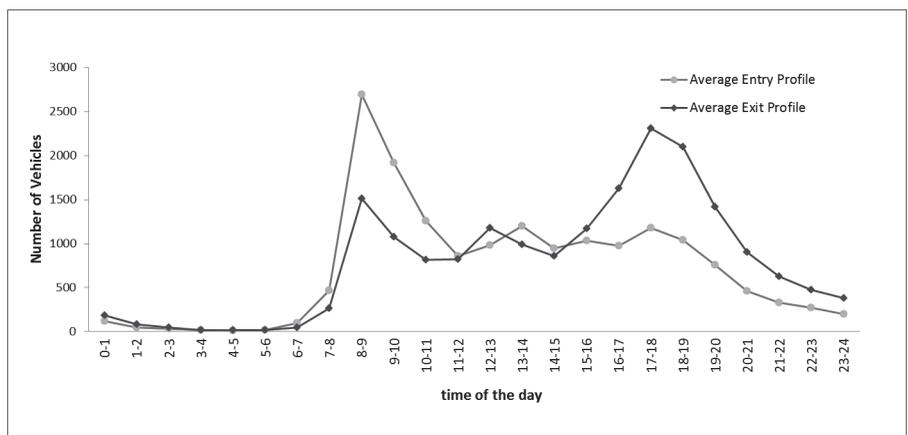


Figure 5. Total activity profile of major traveler groups by time of the day

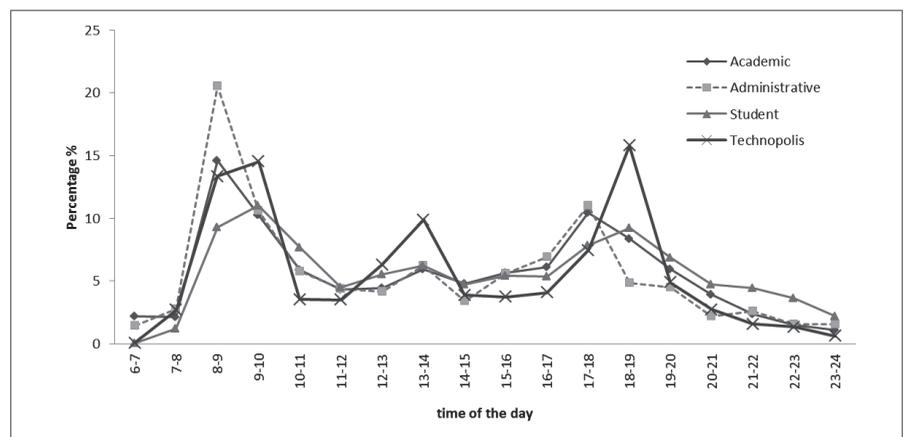


Figure 5 represents the total activity profiles of major traveler groups; administrative personnel showed a sharper morning arrival and evening departure times that represented the more definite working hours, scheduled between 8:30 a.m. to 5:30 p.m. Academic personnel had also a sharp morning arrival peak, but their evening departures had a more scattered pattern extending to 7-8 p.m. Students with cars had a lagged and a smaller peak between 9 a.m.-10 a.m., and exited the campus much later than the others. Technopolis workers were more active in morning hours starting from 7 a.m. to 10 a.m. and a small noon peak was seen at 13 p.m. Also, they had a scattered exiting pattern during the evening.

Campus Daily Traffic Assignment

Matching the unique license plate numbers from the gate RFID data and multiple campus-wide parking lot surveys on the same day enabled estimation of a private car O-D matrix for the 14 campus analysis regions, Technopolis (Region XV) and the three main gates. As shown in **Table 3**, 21,047 private car trips were estimated on May 4, 2011. Further analysis of the trip details by Altintasi (2013) revealed that academic and administrative personnel trips constituted 19.8 % and 8.9 %, respectively, while students share was 29.4 % and Technopolis workers had 6.7%. Out of the 1,132 on-campus trips (trips between Regions I-XIV in Table 3), students and academic personnel shares were 39.1% and 27.8%, respectively, while administrative and Technopolis workers only accounted for the 4.1% and 0.4%, respectively.

To obtain more precise network assignment results using PTV VISUM software, the 15 campus analysis regions were represented with a total of 40 smaller assignment zones, which represent the major parking lot areas and gates (**Figure 6**). To represent commute behavior, a user equilibrium principle was selected, though it would not create major differences in the results due to the limited number of alternative paths in the METU campus network. The O-D matrix of four traveler groups (academic and administrative personnel, students and others) were created separately for each assignment interval and assigned to the network together. From the results of the PTV-VISUM assignments (e.g. the morning peak assignment shown in **Figure 6**), it was possible to obtain both the total number of vehicles (volume) passing through a link with the average expected speed at this volume. The directionality of the traffic in the morning flowing from main gates towards the core campus can be seen by the volume difference of two adjacent links representing the two sides of a road segment.

May 4, 2011	Regions I –XIV	Region XV	Gates		
			A1	A4	A7
Parking Lots in Regions I –XIV	1132	165	4107	3650	1808
Region XV (Technopolis)	108	0	7	165	19
A1	3654	93	0	0	0
Gates A4	3457	450	0	0	0
A7	1819	413	0	0	0
Total=21047 private car trips					

Table 3. Daily on-campus private car O-D matrix of METU campus

		Morning Peak Emissions				Evening Peak Emissions			
		From assignment		From free flow speeds		From assignment		From free flow speeds	
Speed (km/h)	CO ₂ (kg/km)	VKT	CO ₂ (kg)	VKT	CO ₂ (kg)	VKT	CO ₂ (kg)	VKT	CO ₂ (kg)
0-5	0.714	287	204.9	145.1	103.6	126.7	90.5	126.7	90.5
5-15	0.609	1023.1	623.1	678.4	413.1	796.6	485.1	509.7	310.3
15-25	0.391	967.5	378.3	---	---	821.6	321.2	---	---
25-35	0.279	1407.9	392.8	2861.9	798.5	1226.3	342.1	2334.9	651.4
35-45	0.236	1683.3	397.3	---	---	1149.1	271.2	---	---
45-55	0.218	496.9	108.3	2180.3	475.3	646.9	141.0	1795.9	391.5
Total		5865.7	2104.7	5865.7	1790.5	4767.2	1651.2	4767.2	1443.8
Congestion share 14.9%					Congestion share 12.6%				
		Off- Peak Emissions				Daily Emissions			
		From assignment		From free flow speeds		From assignment		From free flow speeds	
0-5	0.714	869.2	620.6	869.2	620.6	1282.9	916	1141.0	814.7
5-15	0.609	3443.9	2097.3	3443.9	2097.3	5263.6	3205.5	4631.9	2820.7
15-25	0.391	688.2	269.1	---	---	2477.3	968.6	0.0	0.0
25-35	0.279	14839.7	4140.3	15527.9	4332.3	17473.9	4875.2	20724.7	5782.2
35-45	0.236	---	---	---	---	2832.4	668.5	0.0	0.0
45-55	0.218	11573.6	2523.0	11573.6	2523.0	12717.4	2772.3	15549.9	3389.8
Total		31414.6	9650.4	31414.6	9573.3	42047.5	13406.3	42047.5	12807.6
Congestion share 0.8%					Congestion share 4.5%				

Table 4. Estimated on-campus VKTs and carbon emission results (base case)

campus VKT, not so much congestion. So, any emission reduction strategy must aim to reduce the private car VKT primarily, instead of managing congestion directly such as, increasing capacity, speed management techniques, traffic management or signalization.

Emission Results of Scenarios

The reductions in the total VKT and daily emissions for every scenario (with respect to the base case) are tabulated in Table 5. Student demand reductions in Scenarios 1 to 3 showed a potential reduction up to 16.0 % in CO₂ at the highest discouragement plan in Scenario 3. Scenario 4, which assumed redirecting the Technopolis workers to use city road to reduce congestion on campus roads during peak hour, had a significant impact on reducing emissions up to 5.9 % during morning peaks, with reducing the VKT by only 4.9 %. Since the peak hour VKT and emissions constituted a very small percentage of daily values, this scenario ended up having around 1.5 % reduction in daily emissions. The analysis of the conservative modal shift to metro service in Scenario 5, suggested a potential reduction of almost 21.0 % in VKT and CO₂. The potential can be further improved to 28.3 %, by a low increase in student private car sticker prices in Scenario 6.

Scenario	Morning Peak		Evening Peak		Off-peak		Total	
	VKT	CO ₂	VKT	CO ₂	VKT	CO ₂	VKT	CO ₂
Scenario	Change (%)							
1	-2.5	-2.5	-4.9	-5.9	-7.1	-7.8	-6.2	-6.8
2	-6.5	-6.5	-9.6	-11.4	-13.6	-14.4	-12.2	-13.0
3	-8.1	-8.9	-12.4	-14.4	-17.0	-17.9	-15.2	-16.0
4	-4.9	-5.9	-1.7	-2.7	--	--	-0.9	-1.3
5	-20.0	-20.5	-18.7	-22.6	-21.5	-22.0	-21.1	-21.8
6	-23.9	-25.4	-24.7	-29.6	-28.0	-28.5	-27.1	-28.3
7	-26.2	-27.9	-26.8	-31.8	-29.8	-30.2	-28.9	-30.0
8	-25.5	-27.9	-27.5	-31.9	-31.4	-32.0	-30.1	-31.4

Table 5. VKT and carbon emission reductions of the scenarios with respect to the base case

Ultimately, a reduction of 31.4 % in VKT and CO₂ emissions was observed in Scenario 8.

The congestion share in emissions of the eight hypothetical scenarios was calculated, as well (**Table 6**). Accordingly, our hypothetical scenarios were able to reduce the congestion share during the morning peak hour to 12.9%. Thus, during the morning peak hour, at current levels of 5,865.7 vehicle-km producing 2,104.7 kg CO₂ (base case) and 313.6 kg CO₂ (14.9%) of this due to congestion in the network; in the most successful hypothetical scenario (Scenario 8), the morning peak VKT and emissions were reduced to 4,368.8 vehicle-km and 1,517.6 kg CO₂, respectively; and only 195.8 kg CO₂ (12.9%) was produced due to congestion. This shows that the scenarios decrease both VKT and inherently congestion, thus it is more important to deal with

Table 6. Congestion share in the daily emissions for the developed scenarios

	Base case	Scenarios							
		1	2	3	4	5	6	7	8
Morning Peak									
VKT	5865.7	5718.3	5484.7	5391.6	5580.8	4693.1	4462.0	4331.4	4368.8
CO ₂ (kg)	2104.7	2052.4	1967.2	1916.9	1980.3	1674.2	1569.7	1518.2	1517.6
Congestion share (%)	14.9	15.0	14.9	14.9	14.3	14.4	13.2	12.9	12.9
Evening Peak									
VKT	4767.2	4527.9	4307.3	4175.0	4682.3	3871.5	3590.6	3490.7	3457.2
CO ₂ (kg)	1651.2	1553.2	1463.0	1413.4	1605.8	1279.3	1162.8	1126.3	1124.4
Congestion share (%)	12.6	11.8	11.0	9.7	11.9	9.9	6.7	6.4	6.1
Daily									
VKT	42047.5	39433.7	30919.5	35639.9	41669.1	33220.2	30670.6	29891.1	29368
CO ₂ (kg)	13406.3	12499.7	11693.3	11255.1	13236.5	10479.2	9634.2	9380.6	9201.6
Congestion share (%)	4.5	3.9	3.9	3.8	3.6	3.5	2.9	2.8	2.8

VKT than congestion. In the evening peak, it was possible to reduce the congestion share in the emissions to 6.1 %. Overall, congestion share in the daily emissions could be decreased from 4.5% to 2.8%.

CONCLUSIONS AND FURTHER RECOMMENDATIONS

METU campus travel demand showed a regular urban travel demand profile with two major peak periods in the morning and the evening, and a small one during noon. The majority of motorized travel was carried out by campus private car commuters, which was the targeted group of travelers in this study. The rather low demand between on-campus zones showed that people mostly used cars to reach campus; consequently, the campus network observed congestion only during peak hours. The campus emissions were estimated by the total VKT on a network and average speed of a link from a campus network assignment in PTV-VISUM. Determination of the net impact of congestion and VKT on reducing emissions was the main contribution of this paper. The emission component due to congestion on campus roads was determined separately, and was found to be 14.9 % in the most severe case of the morning peak. In addition to the base case, 8 hypothetical scenarios were evaluated and the main source of emissions was found as total VKT, not congestion. Thus, policies that would aim to reduce private car VKT has to be developed to push METU campus transportation towards more sustainable levels. This study found that a 30% reduction could be achieved, if commuters would shift to using the metro supported by an adequate on-campus shuttle bus service. VKT reduction also inherently reduced the congestion share from 4.5 % to 2.8 % daily.

Campus transportation management is relatively simpler compared to urban regions, however the challenges of creating such a modal shift from car to shared-ride or non-motorized trips remain the same. If METU campus, or any university campus, faces more severe congestion levels similar to those in metropolitan regions, in addition to reducing VKT, congestion management tools, such as traffic signal optimizations, traffic incident management, etc. can be more influential in reducing private car emissions.

In this study, only carbon emissions from private cars were studied. As a second stage, the emissions cost of public transit use should be calculated to find the average emission value per traveler for METU campus. In this way, we can produce more scenarios that would consider modal shift from private car to on-campus shuttles and public transit; following that we can calculate the net change of modal shifts in terms of emissions. Furthermore, in the literature, campus carbon emissions were calculated from home to campus and required comprehensive travel surveys, which should be undertaken in future. Such undertakings will enable the development of more sustainable transportation strategies. To divert travelers from private car usage, a more comprehensive public transportation planning study should be undertaken with the municipality.

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BEST OPTION FOR REDUCING ON-CAMPUS PRIVATE CAR-BASED CO₂ EMISSIONS: REDUCING VKT OR CONGESTION?

Reducing carbon emissions, especially that of private car use, is an inevitable goal of sustainable transportation policies. This study focuses on i) determination of the current level of CO₂ emissions from private cars on the Middle East Technical University (METU) campus and ii) evaluation of the impact of different emission reduction scenarios. Such scenarios were based on hypothetical conditions that can either reduce Vehicle-km-travelled (VKT) or congestion on campus, which are defined as the two major factors governing vehicle emission levels with today's engine technology. To produce a quantitative evaluation, first, as a base case, current private car travel demand was derived from the joint analysis of Radio Frequency Identification (RFID) data and parking lot surveys. In the scenarios, this demand was modified according to the assumptions made. All network assignments were performed using PTV-VISUM software, which produced average speed and number of vehicles on campus roads. The daily assign-

ment was carried out in three parts, as a morning and an evening peak, and an off-peak assignment. Emissions due to congestion were determined separately, as a percentage. The results showed that carbon emissions produced by private cars on METU campus were primarily a function of VKT; thus, could not be reduced by congestion management alone. They could be reduced by 30% if commuters would shift to the metro service that is supported by a strong on-campus shuttle services.

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Anahtar Sözcükler: Sürdürülebilir ulaşım; Trafik ataması; Trafik sıklığı; Karbon emisyonları; Trafik Simülasyonu

KAMPÜS İÇİ ÖZEL ARAÇ KAYNAKLI KARBON EMİSYONLARININ AZALTILMASINDA EN UYGUN SEÇENEK: TAŞIT-KM VEYA TRAFİK SIKIŞIKLIĞI AZALTILMASI?

Karbon emisyonların, özellikle de özel araç kaynaklı kısmının, azaltılması sürdürülebilir ulaşım politikalarının vazgeçilemez hedefidir. Bu çalışma i) Orta Doğu Teknik Üniversitesi (ODTÜ) kampüsünde özel araç kaynaklı karbon emisyonlarının mevcut değerlerinin belirlenmesine ve ii) farklı emisyon azaltma senaryolarının etkilerinin değerlendirilmesine odaklanmıştır. Senaryolar varsayım dayalı olup, bugünkü motor teknolojisiyle emisyon katkısı en yüksek iki faktör olan taşıt-km değerini ya da trafik sıklığını azaltacak şekilde geliştirilmiştir. Sayısal bir değerlendirme yapabilmek için öncelikle, mevcut durum için, kampüs içi özel araç yolcularının başlangıç-bitiş matrisi, Radyo Frekansı ile Tanımlama Sistemi (RFID) verisi ve otopark sayım verisinin birlikte analizi sonucu elde edilmiştir. Her senaryo için, yapılan kabuller doğrultusunda, farklı bir başlangıç-bitiş matrisi oluşturulmuştur. Bütün analizlerde, trafik ağ ataması PTV-VISUM simülasyon programı kullanılarak yapılmış, kampüs yol kesimlerindeki ortalama hız ve geçen araç sayıları belirlenmiştir. Günlük trafik ataması, sabah ve akşam zirve saatleri ve zirve olmayan saatler olmak üzere 3 aşamada gerçekleştirilmiştir. Trafik sıklığı kaynaklı emisyon, toplam emisyonun yüzdesi olarak ayrıca hesap edilmiştir. Sonuçlar, ODTÜ kampüsündeki özel araç kaynaklı karbon emisyonların, temel olarak taşıt-km değerine bağlı olduğunu göstermektedir; bu yüzden, sadece trafik sıklığı yönetimi ile azaltılamazlar. Senaryo analizleri, kampüs içi ring servisi ile desteklenmiş metro sisteminin teşvik edilmesi sağlandığında, kampüs içi özel araç kaynaklı emisyon değerlerinde %30 azalma sağlanabileceğini göstermiştir.

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