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MODELING ENVIRONMENTAL IMPACT OF CYBERNETIC TRANSPORTATION SYSTEM

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Abstract

Cybernetic Transportation System (CTS) is a relatively new branch of the Intelligent Transportation System, which can provide flexible transportation services for university campuses, resorts, and industrial parks. The proposed simulation approach is suitable for a preliminary assessment of CTS-related environmental impact in real-world driving conditions. The model is built to allow performance prediction of a single cybercar or the whole CTS in a wide range of operational conditions. A simple formula is proposed to compare the environmental impact of CTS with that of conventional vehicles. Calculation techniques are developed to evaluate the effect of the relative receptor density and different fuel resources used for electricity generation on the environmental impact of the transportation system based on battery-electric vehicles.

Key words: cybernetic transportation system, electric vehicle, environmental impact, receptor density, total emission indicator

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1. Introduction

Road transport is responsible for a large and growing share of air pollution in most countries (Dragos et al., 2013; Hanganu et al., 2012; McCormick, 2007). New sustainable energy-efficient vehicle technologies and renewable automotive fuels are possible alternatives to conventional options. An electric vehicle (EV) is one of them (Hromadko and Miler, 2012).

Sustainability includes vehicle and engine technology aimed towards zero environmental impact, and the introduction of transport systems that are operated to provide mobility with optimized energy management and minimal emissions. Intelligent Transportation Systems (ITS) and in particular, urban Cybernetic Transportation Systems (CTS) play an important role here (Parent, 2007; Zvirin et al., 2009). These mostly consist of EVs, which have indeed zero tailpipe emissions, but for being truly sustainable, the energy sources used for the electricity production should be renewable. In the meantime, if the used energy sources are not renewable, care should be taken in decision-making on the implementation of CTS based on sociological and environmental parameters.

A viable approach for providing sustainable transportation to a city is, indeed, based on co-modal systems. This means specially-designed systems that combine the use of the individual car and the collective (public) transportation management system. If these are controlled to operate efficiently, they offer the combined advantages (e.g. comfort) of the former with those of providing sustainable overall mobility by the latter. CTS, which is clearly an Intelligent Transportation System is the promising example of such co-modal system (Awasthi et al., 2011). Several CTS types have started to appear in the last years of the 20th century. Some have been or are now under construction in various European locations, while others have been deployed in demonstrations, during R&D work in the field. CyCab developed by Robosoft, ParkShuttle of 2GetThere and ULTra of ATS Ltd can be mentioned

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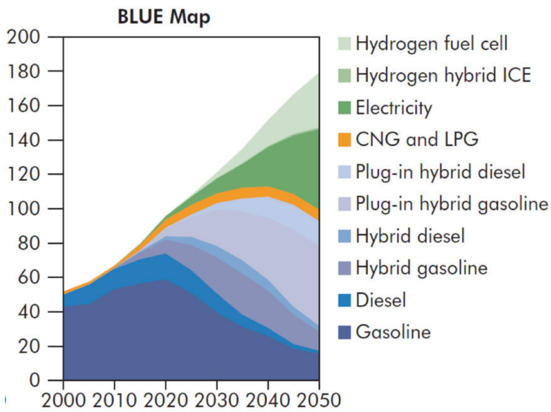
as typical examples (Boissé et al., 2007; Parent, 2007, 2010). CTS composed of road vehicles with fully automated driving capabilities has been proposed to address randomly arriving transportation demands and random conflicts between vehicles. Fleischmann et al., (2004) studied the framework of dynamic vehicles routing based on online traffic information. Wang et al. (2008, 2009) performed a simulation of a multi-agent based cybernetic transportation system, while Xia et al. (2010) described and analyzed a CTS intended for Chinese cities (CyberC3).

This system was centrally controlled and was capable to operate in two different modes: the "shuttle mode" and the "on-demand mode". The control algorithm comprised three main modules responsible for scheduling, vehicle navigation and controlling a vehicle in real time. A similar CTS called CRISTAL was developed by the French enterprise LOHR (Parent, 2010). Research, development and demonstration activities of various CTS concepts are extensively supported by the European Commission in the framework of various FP5 – FP7 projects, such as: CyberCars, CyberMove, CityMobil, Cybercars-2, CityNetMobil, PICAV, CATS and CityMobil-2.

CTS is a system of road vehicles with automated driving capabilities (either fully or partially) based on feedback and feed-forward control. Its vehicle fleet is used for moving passengers or goods on a network of roads. It is under control of a computerized management system. The vehicles are used individually by the customers in a way similar to car sharing systems. Thus the CTS offers a link between the private car and the public transport modes. The CTS can be based on any type of vehicle, but usually EVs are used, in attempt to ensure that the system will be environmentally friendly. EVs offer a solution for the problem of urban air pollution, contributing also to fuel diversification and issues of energy supply security. A future increase of electricity production from renewable sources will certainly contribute to their public acceptance and further market penetration. For example, according to the "BLUE Map" scenario of the International Energy Agency (IEA) that is based on the development of new technologies by the year 2050, plug-in, hybrid and electric vehicles will account for more than two-thirds of all light-duty vehicle (LDV) sales, Fig. 1 (IEA, 2010).

Climate change concerns and a need in mitigation of greenhouse gas (GHG) emissions provide an important incentive for CTS development and introduction. It is important to note that transportation is responsible for a large part of the energy consumption worldwide (Chen et al., 2007; Ji and Chen, 2006; Ji et al., 2009). According to the International Energy Agency (IEA) data (IEA, 2010), about 26% of all energy-related GHG emissions in 2007 were caused by transportation. Economic growth and improving the welfare of population are leading inevitably to an increase in the demand for transportation. One of the best examples of this tradeoff is displayed in the data on car sales in China. According to the predictions made by Hao et al. (2011), car registrations in China would reach 91, 203 and 464 million in 2020, 2030 and 2050, respectively.



Energy Technology perspectives © OECD/IEA, 2010

Fig. 1. LDV sales by technology type – BLUE Map scenario (IEA, 2010)

Numerous studies are performed to evaluate and analyze hazardous and GHG emissions by the industry and transportation in China and worldwide, as well as to find ways of emissions mitigation (Chen and Qi, 2007; Ji and Chen, 2010). Various indicators such as pollution intensity, waste gas emission intensity, exergy of emission, etc. are proposed to analyze the adverse effects of air pollution on the environment (Dincer et al., 2010; Zhang et al., 2012).

An assessment of CTS environmental impact is required at very early stages of its development. Such assessment can be carried out based on available emission and energy consumption prediction models suited for different types of vehicle technologies under consideration. Modern road emission models, such as the ARTEMIS one, (Boulter and McCrae, 2007), make possible the assessment of energy consumption and emissions of transportation systems based on motor vehicles by using traffic conditions, route parameters and vehicle fleet data as an input. If a transportation system contains EVs, therefore an appropriate simulation tool should be applied for an assessment of additional emissions induced due to their activities.

It is well known that the environmental impact of EV and its attractiveness depend on technology and fuel mix used for electricity production in the region under consideration (Dincer et al., 2010; Granovskii et al., 2006). Therefore, this impact should be assessed for each considered case of EVs implementation. To allow adequate environmental impact assessment, energy and power requirements of electric vehicles or the whole transportation system should be appropriately predicted. Recent works dedicated to the modeling of energy consumption of electric vehicles were published by

Campanari et al. (2009), Lee et al. (2002), Szumanowski and Chang (2008), Yap and Karri (2010). Dual energy source schemes were discussed by Zvirin et al. (2004) that used analytical dependences of the battery and motor efficiencies on a depth of discharge (DOD) and load factor (PF), respectively.

There are methods available that consider exposure pathways by applying detailed atmospheric dispersion models. These models require a great majority of input data, including meteorological conditions, surface terrain, etc., to simulate how pollutants in the ambient atmosphere disperse and how they react in the atmosphere. Between the most popular models the US EPA AERMOD (Cimorelli et al., 2004), CMAQ (CMAS, 2013), UK ADMS (CERC, 2013) may be mentioned. If all the required information is available, thus a more accurate prediction of the health effects of the transportation induced emissions is possible. In this case the DPSIR (Driver-Pressure-State-Impact-Response) approach considering interrelations between the environment and socio-economic activities can be applied (Agu, 2007). However, information needed to allow the application of the comprehensive DPSIR approach is not always available. In many cases a simplified analysis can be sufficient to perform a preliminary comparison between various transportation modes and their environmental impacts.

The main goal of this paper is to suggest a method of such simplified analysis and apply it for the examination of CTS environmental impact in comparison with conventional motor vehicles.

2. Methodology

We propose an assessment of the environmental impact of CTS based on EVs and compare it with conventional transportation modes by using the following procedure:

- Derivation of data on total emissions TEM_i released in the considered region during the process of electricity production;
- Derivation of data on total electricity supply TES in the considered region. Normally, the data on electricity production and emissions released as a result of electricity generation are published by the National or Regional Statistics Office or/and other responsible Governmental organizations.

Calculation of specific emission SEM_i values per unit of electrical energy consumed (Eq. 1), where i is a pollutant type, such as CO, NO_x, $PM_{2.5}$, etc.

$$SEM_i = TEM_i / TES \tag{1}$$

- Calculation of emission factors per person$\cdot$km released due to EV's activity (Eq. 2), where: E_{cons} is energy consumed by EV; PO is the vehicle passenger occupancy; L is route length. Values of E_{cons} can be measured or predicted by using one of the appropriate simulation models, such as TEVeS model (Kaparias et al., 2011) or any other, e.g. the model developed by Kim et al. (2013).

$$EM_i = E_{cons} \cdot SEM_i / (PO \cdot L) \tag{2}$$

Emission factors of a conventional transportation system based on motor vehicles can be assessed by application of a road emission model, e.g. ARTEMIS (Boulter and McCrae, 2007) or COPERT (EMISIA, 2013).
The values of emissions produced due to transportation activity are used to calculate a total emission indicator (*TEI*). *TEI* allows integral evaluation of pollutant emissions by any transportation system. According to Tartakovsky et al. (2013), *TEI* is calculated as the sum of normalized pollutant emission values (Eq. 3), where: TLV_i – threshold limit value for pollutant i.

$$TEI = \sum (EM_i / TLV_i) \tag{3}$$

Relevant TLV_i values can be found in the "Threshold Limit Value Occupational Exposure Guidelines and Biological Exposure Indices" of the American Conference of Governmental Industrial Hygienists (ACGIH, 2010). Table 1 shows some TLV_i values that were used in this work.

Table 1. Threshold limit values of some pollutants (ACGIH, 2010)

Pollutant	***TLV, mg m^{-3}***
Nitrogen dioxide NO_2 (NO_x normalization)	5.6
Carbon monoxide CO	28.5
1,3-Butadiene (HC normalization)	4
Sulfur dioxide SO_2 (SO_x normalization)	5.2
Particle matter PM2.5 (PM normalization)	3

Applying the normalization approach makes it possible to account for the relative health risk factors of various hazardous compounds emitted as a result of transportation activity by using widely available and validated information. The use of TEI for a comparison between various transportation modes is possible, if spatial distribution of the pollutant emission sources is similar: for example, in the case of a comparison between bus and passenger car emissions (Tartakovsky et al., 2013). A use of the TEI approach allows a big flexibility in the selection of pollutants that can be considered in the emissions comparison, because of a comprehensive list of TLV values that present in the data of ACGIH (2010).

In cases where the spatial distribution of the pollutant emission sources is different (e.g. comparison of transportation modes based on electric and motor vehicles), a use of *TEI* as a comparison tool is impossible due to different pollutants dispersion in the atmosphere. When available input data does not allow the application of an atmosphere dispersion model, we suggest an approach which is based on the fact that the environmental impact of a transportation system is a function of not only emissions level, but it is also site dependent and determined by a number of people that are exposed to the polluted air. To account for this fact, we propose to introduce an environmental impact factor (*EIF*). The dimensionless *EIF* value is calculated as given by Eq. (4), where D_s is the receptor density in the site of consideration. Receptor density is calculated as the population per km^2 of the site area. *EIF* values can be used for a comparison of the environmental impact of CTS with other transportation modes.

$$EIF = TEI \cdot D_s \quad (4)$$

Because it is impossible to distinguish between various pollution sources that were involved in the additional electricity production due to EVs activity, as well as to account for pollutants dispersion and chemical conversions mechanism, the uniform background approach (Curtiss and Rabl, 1996) was applied to calculate *EIF* values for CTS or other EV based transportation modes. Certainly, this approach does not allow accounting for effects of meteorological conditions, pollutant release parameters or terrain data. If the world was homogeneous, the receptor density would have been uniform D_u. Receptor density D_s depends on the site. Sometimes it is not simple to determine the site area and, as a result, to calculate the receptor density D_s. In this case an application of the relative receptor density *f* can be useful, where *f* is defined as (Eq. 5).

$$f = D_s / D_u \quad (5)$$

Dependence of *EIF* on *f* is used in the present study to analyze the environmental impact of different transportation modes.

3. Model comparison with other available methods

Energy consumption values used in this work for environmental impact assessment were calculated based on the following models: ARTEMIS (Boulter and McCrae, 2007) for motor vehicles and TEVeS (Kaparias et al., 2011; Zvirin et al., 2004) for electric vehicles.

In order to assess the sensitivity of the results to the methodology of air pollutant emissions normalization, the method of impact weighted emissions (*IWE*) described by Granovskii et al. (2006) was applied and compared with the suggested method of Total Emission Indicator (*TEI*) calculation. The former is based on impact weighting coefficients of airborne pollutants from motor vehicles (0.017, 1, 0.64, 1.215, 1.3 for CO, NO_x, VOCs, PM and SO_x, respectively) that were obtained by the Australian Environment Protection Authority using cost-benefit analyses of health effects (Beer et al., 2006). For the comparison purpose we assessed emissions induced by an implementation of CTS in the Technion University campus and assumed a binary fuel mix used for electricity production, consisting of coal and natural gas (NG) only. The *TEI* and *IWE* values calculated for CTS were normalized by dividing them by their respective values calculated for the Euro-5 diesel bus running at the same driving route. Results of the comparison are shown in Fig. 2. As can be seen, the *TEI* method gives results that are quite close to those provided by the application of *IWE* methodology.

4. Results and discussion

The proposed approach to modeling environmental impacts of CTS and a comparison with other transportation modes is demonstrated for the example of a virtual driving route. Such a route may be applied for a city center, university campus or any other relevant site. The length of the simulated driving route was 1600 m; the absolute averaged value of the road gradients was 7.5%, and the basic average speed of the cybercar was 12.0 km h^{-1}.

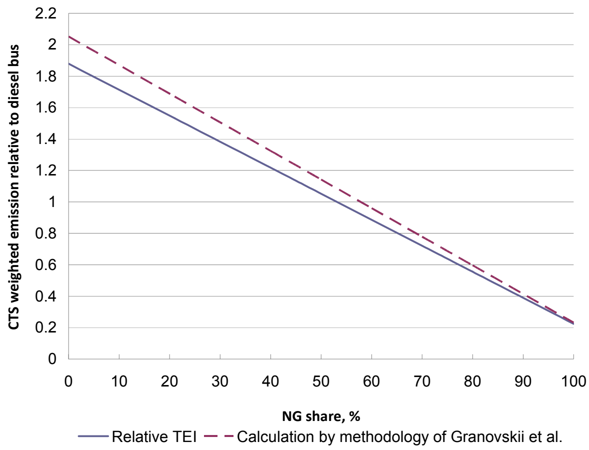


Fig. 2. Comparison of the *TEI* and *IWE* calculation methods

The virtual vehicle considered in this analysis was similar to the Yamaha-Europe cybercar. A comparison was performed between the cybercar and the electric minibus (E-bus) - Table 2.

Table 2. Main parameters of the simulated cybercar and E-bus

Parameter	*Cybercar*	*E-bus*
Gross vehicle weight (kg)	1250	7,700
Frontal area (m^2)	2.31	5,70
Battery type	Li-Ion	Li-Ion
Battery weight (kg)	355	1100
Maximal depth of discharge (DOD)	0.8	0.8

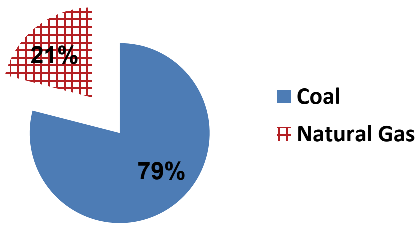
The conventional Euro-5 diesel minibus of Mercedes Benz Sprinter Traveliner type (gross vehicle weight 4000 kg, rated power 95 kW, number of seats 17, average passenger occupancy 12) was used in the comparison as a baseline. Energy consumption values of the simulated cybercar and E-bus (taken for the optimal productivity cases) are shown in Table 3.

Table 3. Energy consumption of cybercar, E-bus and diesel minibus

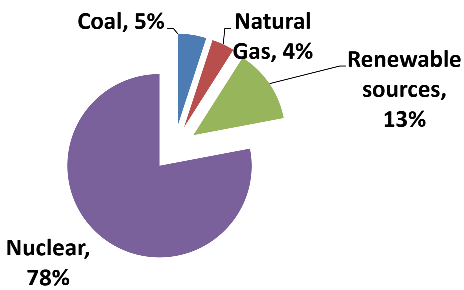
Parameter	*Cybercar*	*E-bus*	*Euro-5 diesel minibus*
Vehicle energy consumption (kWh km^{-1})	0.22	1.32	2.18
Vehicle occupancy (persons)	5	16	12
Specific vehicle energy consumption (kWh $person^{-1}km^{-1}$)	0.044	0.083	0.18

For the comparison purpose the measured fuel consumption data of a conventional diesel minibus shuttle running on the same driving route are provided, as well. The average measured fuel consumption value that has been received from the minibus shuttle operator is 4.5 km l^{-1}. The energy consumption of 2.18 kWh km^{-1} was estimated assuming a fuel density of 0.84 kg l^{-1} and a lower heating value of 42 MJ kg^{-1}. A comparison of the obtained values of the specific vehicle energy consumption shows a clear benefit of the cybercar with a reduction of energy consumption by a factor of 1.9 and 4 compared with E-bus and Euro-5 diesel bus, respectively.

The proposed methodology was applied to assess the CTS environmental impact for the two contrasting electricity production scenarios, where fossil fuels are used for 100% (Scenario 1) and less than 10% (Scenario 2) of the total electricity production – Fig. 3.



(a) Fossil fuel mix (Scenario 1)



(b) Renewable fuel mix (Scenario 2)

Fig. 3. Two scenarios of electricity production

The main intent to apply these very different scenarios was providing an insight into environmental benefits of CTS in a wide range of fuel mix compositions used for electric power generation.

The considered scenarios differ by energy sources used for electric power generation, and are typical for the national electricity production fuel mix in Israel - Scenario 1 (Israel Central Bureau of Statistics, 2011a) and France - Scenario 2 (DGEMP, 2007). The fuel mix data shown in Fig. 3 is based on the published statistics on electricity generation in the mentioned above countries with some simplification to reduce the number of energy sources. As can be seen from Fig. 3, in Scenario 1 about 80% of the total electricity is produced by using coal - the most polluting fossil fuel. In Scenario 2 more than 90% of the total electricity is generated by using energy sources with zero end-of-pipe emissions of criteria pollutants and GHG.

The driving route and the driving cycle were kept unchanged for both scenarios. Emission factors for the considered electricity production scenarios were calculated based on the published data on emissions from electricity generation (CITEPA, 2011; DGEMP, 2007; Israel Central Bureau of Statistics, 2011a, 2011b). They are listed in Table 4.

Table 4. Emissions from electricity generation

Electricity production scenario	*Emission factor (g $kW^{-1}h^{-1}$)*				
	CO_2	*CO*	*NO_x*	*PM*	*SO_2*
Fossil fuel mix (scenario 1)	710	0.18	2.0	0.10	1.9
Renewable fuel mix (scenario 2)	39	0.090	0.17	0.0081	0.12

HC emission factors of electricity generation are very low and neglected. It should be noted that the life cycle assessment (LCA) allows evaluating all environmental impacts associated with a given product or service at all stages of its lifetime from resource extraction and processing, through construction, manufacturing and retail, distribution and use, repair and maintenance, disposal/decommissioning and reuse/recycling.

All electricity generation technologies emit greenhouse gases and pollutants at some point in their life cycle. In electricity generation with fossil fuels most emissions are produced during plant operation. However, renewable electricity generation also consumes materials and extra nonrenewable energy and inevitably causes a certain amount of emission from the perspective of life cycle analysis (Chen et al., 2011a, b; Yang et al., 2013). In case of using nuclear and renewable energy sources for electricity production, most emissions are caused indirectly, for instance during the construction phase (Bauduin et al., 2011). Pollutants are dispersed into the atmosphere at both local and regional levels.

However their real impact on the environment and health varies according to a number of factors. For electricity generation technologies, the results of an analysis will be influenced by the specific characteristics of the site chosen compared to others in its category, the manufacturing and design characteristics, the lifetime and the operating conditions. It is therefore difficult to transfer results from one country to another or one generation unit to another (Bauduin et al., 2011). So the data of life cycle analysis must be interpreted carefully. Special care should be undertaken, if a comparison of LCA environmental impacts of electricity produced and motor vehicle emissions is performed. In this work end-of-pipe/tailpipe emissions were considered.

As anticipated, the beneficial electricity production fuel mix in Scenario 2 resulted in the very low emission factors compared with those for Scenario 1. Based on the energy consumption data and emission factors presented in Tables 3 and 4, specific emissions (g $(person \cdot km)^{-1}$) released due to CTS and E-buses system activities were calculated. The results are summarized in Table 5.

For the comparison purposes specific emissions by the conventional diesel minibus of Euro-5 technology equipped by a diesel particulate filter (DPF) were calculated and shown in Table 5 too. The emissions from a diesel bus were assessed with the aid of ARTEMIS model (Boulter and McCrae, 2007) and based on the measured driving behavior data. SO_2 emissions by diesel buses are very low and neglected in these calculations. CO_2 emissions by the conventional Euro-5 diesel minibus were calculated based on the measured fuel consumption data (Zvirin et al., 2009). CTS specific emissions were compared also with a predicted level of airborne pollutant emissions by a bus of the Euro-6 technology implemented in Europe from 2013. This assessment was carried out based on the forecasted values of bus emission factors made by Wilson and Dixon (2009). Following findings of Hausberger et al. (2009), emission factors of CO, HC and CO_2 are supposed to remain unchanged. The estimated values of specific emissions for Euro-6 diesel minibus (g $(person \cdot km)^{-1}$) are shown in Table 5, as well.

The results of the predictions show that greenhouse CO_2 emissions (Table 5) released due to the CTS operation are significantly lower compared with the other considered transportation options for both electricity production scenarios. However, the level of GHG reduction that can be achieved depends heavily on the fuel mix used for electricity production. In the case of Scenario 1, GHG emissions are reduced by 30% compared with a conventional diesel bus. For the Scenario 2 case, GHG emissions are reduced by a factor of 26. Data on air pollutant emissions do not show the similar unambiguous trend. Together with lower CO and NO_x emissions, substantially higher PM emissions are predicted to be released due to the CTS operation for the fuel mix of Scenario 1. Specific emissions of all air pollutants to be released in Scenario 2 due to CTS operation are significantly lower than those of the Euro-5 diesel bus. However, the predicted PM emissions are still higher by 33% compared with the Euro-6 bus.

To assess an integral pollutants emission that will be a result of CTS implementation, *TEI* values were calculated for each transportation option. The results are summarized in Table 6. The CTS' *TEI* value for Scenario 1 is higher by a factor of 13 compared with Scenario 2. For the reference purpose *TEI* values of Euro-5 and Euro-6 buses are provided as well. Different scenarios of NG gradual penetration to the electricity production market based on fossil fuels were analyzed. This was done to find a coal-NG fuel mix that will provide a level of CTS added emissions, which will be lower compared with the conventional Euro-5 and Euro-6 diesel buses. Fig. 4 shows the CTS *TEI* values (calculated relative to Euro 5 diesel *TEI*), as were predicted for different shares of NG in the electricity fuel mix.

Emissions added due to CTS implementation become to be lower compared with the conventional Euro-5 diesel buses when the value of natural gas share in the electricity fuel mix exceeds 53% (point A). If the combustion of coal is completely replaced by NG (point B), the *TEI* value of CTS will be lower by a factor of 4.5 in comparison with a Euro-5 diesel bus. This analysis leads to the conclusion that, if all the electricity will be produced with NG at today's efficiency of production, the emissions of air pollutants due to CTS activities will only become equal to that of a Euro-6 bus – Fig. 4. Therefore, the lower level of CTS emissions can be achieved only, if renewable or nuclear sources will become a part of the electricity production mix, and coal use will be fully eliminated. A comparison of environmental impact factors (*EIF*s) calculated for different values of the relative receptor density f was performed for CTS, Euro 5 and Euro 6 diesel buses. D_u values for Scenarios 1 and 2 were assessed for the examples of Israel (358 person per km^2) and France (114 person per km^2), respectively, using published data from the Israel Ministry of Foreign Affairs (2011) and the US Department of State (2011). The results are presented in Fig. 5.

Table 5. Specific emissions of CTS, E-bus and conventional diesel minibus

Transportation system	***Specific emission (g person^{-1}km^{-1})***					
	CO_2	***CO***	***NO_x***	***PM***	***SO_2***	***HC***
CTS, scenario 1	31	0.0079	0.088	0.0044	0.084	-
CTS, scenario 2	1.7	0.0040	0.0073	0.00036	0.0052	-
E-buses system, scenario 1	59	0.015	0.17	0.0083	0.16	-
Euro-5 diesel minibus (with DPF)	44	0.012	0.12	0.00081	-	0.00077
Euro-6 diesel minibus	44	0.012	0.024	0.00027	-	0.00077

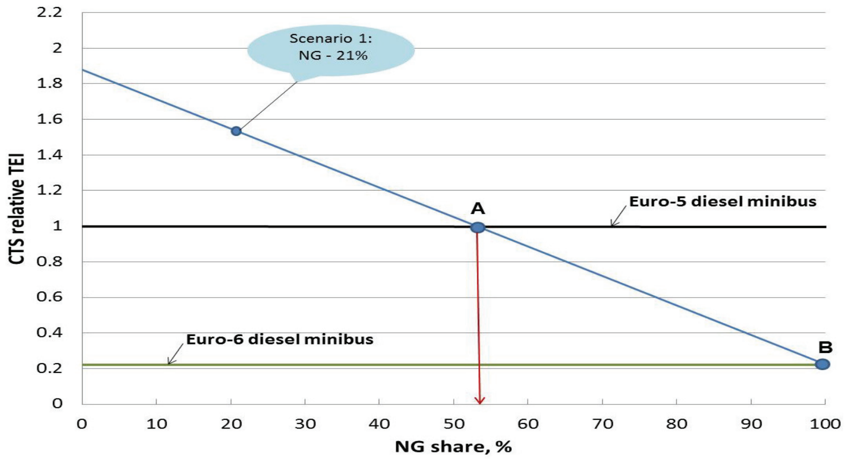


Fig. 4. Dependence of CTS TEI on NG share in the electricity fuel mix

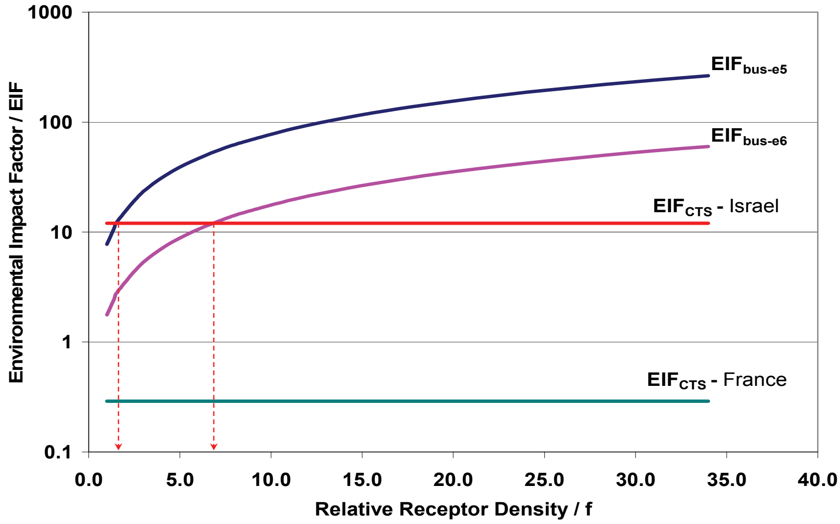


Fig. 5. Effect of relative receptor density on environmental impact factor value for different transportation modes

As can be seen, the EIF_{CTS} value for Scenario 1 is becoming lower than *EIF* values of Euro 5 and Euro 6 diesel buses at the relative receptor densities of 1.5 and 6.8, respectively. This means that for the considered case of CTS application it will be environmentally beneficial over the conventional Euro 6 diesel bus, if implemented at sites with a receptor density of 2430 person per km^2 or higher. The results show that for Scenario 2 EIF_{CTS} is always lowers than that of the Euro 6 diesel bus at any receptor density. The difference between them becomes higher as the relative receptor density increases.

Table 6. Total Emission Indicator values for different transportation modes

Transportation system	*TEI (km^{2}person^{-1})*
CTS, scenario 1	0.034
CTS, scenario 2	0.0025
E-buses system	0.064
Euro-5 diesel minibus (with DPF)	0.022
Euro-6 diesel minibus	0.0050

5. Conclusions

A modeling approach is suggested and applied for the evaluation of CTS environmental impact and a comparison between various transportation modes. We propose the dimensionless environmental impact factor (*EIF*) as a tool of simplified environmental impact assessment. The dependence of *EIF* on the relative receptor density *f* is suggested to be used for environmental impact analysis.

Testing the proposed approach for the two very different electricity production scenes showed that we have a simple and convenient tool for evaluating the effect of variations in the relative receptor density and electricity fuel mix on the environmental impact of the considered transportation system.

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