TRANSPORT PROBLEMS 2021 Volume 16 Issue 2
PROBLEMY TRANSPORTU DOI: 10.21307/tp-2021-029

Keywords: energy intensity; transport modes; Warsaw; CO_2 emission intensity

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ENERGY AND CO_2 EMISSION INTENSITIES OF VARIOUS MODES OF PASSENGER TRANSPORT IN WARSAW

Summary. This article presents the results of the calculation of energy and CO_2 emission intensities in relation to the unit of passenger transport activity for various modes of public transport, cars and motorcycles for Warsaw in 2015. The results are compared with similar information from other countries and regions that comes from international comparisons and are summarized in this article. The results for Warsaw show that intensity indicators are comparable to other cities, with noteworthy low-intensity indicators for city public transport buses. An important achievement of the author is calculation of the energy and CO_2 emission intensities for various modes of transport in Polish conditions and for a single city: Warsaw.

1. GHG EMISSIONS AND TRANSPORT ENERGY INTENSITY

Enrgy use in transport has become one of the most studied topics since the 1970s and first oil peak. Gradually, technologies and laws were upgraded, so that cars, trains and other modes of transport could become less energy-consuming and, at the same time, more environmentally friendly. In fact, initially, energy efficiency of vehicles was enforced by the air pollution regulations, which started with the 1970s USA Clean Air Act. Europe followed with regulations in this respect in the early 1970s with United Nations Economic Commission for Europe (UNECE) Regulation 15 amendments. Since the 1990s, this trend has increased with acceleration of climate change and the need to mitigate emissions of greenhouse gases (GHGs). The emissions of greenhouse gases, especially CO_2, usually go hand in hand with the energy consumption of a given mode of transport; therefore, this led to an additional boost to increase the energy efficiency of transport and further to minimize the energy intensity of various modes of transport. Nowadays, some of the most important indicators of transport environmental performance are energy and GHG emission intensities. Many times, GHG emission intensity is limited only to CO_2, which, for most modes of transport, except aviation [15], contributes the most toward GHG emissions. To fill the gap in calculations of such indicators, the main aim of this article is to show the results of energy and CO_2 emission intensity calculations for various modes of transport in the Warsaw transportation system in 2015.

1.1. Energy and CO_2 emission indicators

There are many ways to calculate the energy performance of various modes of transport. In various studies, results of these kinds of calculations can be found, shown as energy used divided by different factors such as GDP [19], vehicle use factor (vehicle-km) [3], mass of the transport mode (kilograms) [4, 21], unit of transport activity (passenger-km or ton-km) [11, 21], load factor (passenger, ton) [24] and population (number of inhabitants) [7, 17]. Leaving the discussion about the relevancy of the indicators aside, probably the most widely used are indicators showing the energy and GHG (or CO_2) emissions divided by the unit of transport activity – energy or GHG emission intensity indicators.

This kind of view is characteristic for the transport policy assessments of a given area, be it a city, a region or a country. It assesses not only the energy efficiency or emissions of modes of transport but also provides a broader view of a system because it also depends on other factors, especially:

- transport distances and
- vehicle occupancy [3, 11].

Therefore, when carefully analyzed and used, a comparison of these kinds of indicators can aid in the formulation of recommendations that are not only focused on technology but also on the organization and performance of the transport system.

1.2. Energy intensity of modes of transport – international overview

Energy intensity indicators can be found in publications of energy efficiency comparisons [2] and separate calculations for various transport systems [3]. The most general comparison of various modes of transport is presented by the International Energy Agency [11]. Data from this source are reproduced in fig. 1. This figure is regularly updated by the IEA; however, it shows calculations for the year 2018. The graph is not specifically focused on city transport. Nevertheless, it shows the level of expectancy that energy efficiency can be achieved by various modes of transport. Rail and two-wheelers may have the lowest indicators of energy intensity, while cars and aviation have the highest indicators of energy intensity. Bus transport is in the middle range however, in some conditions bus transport can be more energy intensive than private car transport [11]. Unfortunately, the sources of the data used for the IEA graph are not described in detail.

Very similar results on energy intensity with some more detailed categorizations of different modes of transport have been obtained for different countries. A comprehensive study of energy intensity has been presented by Kalenoja [13] for the conditions in Finland in the early 1990s. The calculations have been shown for both energy and CO_2 emissions. Both have also been subjected to a life cycle analysis, but with the possibility to follow different elements of the calculations. For calculations considering energy only for the transport process, local trains are the most efficient modes of transport, followed by trams, metro and city buses and mopeds. The least efficient are passenger cars.

In the United States of America, the U.S. Department of Transportation [27] probably has the largest dataset of energy intensity data, calculated for various modes of transport on the basis of US statistics. However, the data are given in American measurement units (BTU/passenger-mile); it can be seen that the results are only slightly different from those of the IEA and Finland datasets. Trains are the most efficient, followed by motors and buses, and passenger cars are the least efficient. More insight into this statistic is provided by Chester [3], who calculated detailed indicators of energy and GHG emission intensities for selected US cities (Chicago, San Francisco, New York). Calculations for cities are unfortunately provided only on the basis of personal and public modes of transport and not by different modes of transport.

The European Environmental Agency [9] has historical statistics of this kind for the European Union. The statistics show that historically (1970-1995), the most efficient modes of transport were trains and buses, followed by cars and airplanes. Quite a similar picture was found for Australia [16, 17], where buses are usually the most efficient, followed by trains and trams, while passenger cars perform the worst.

This international comparison shows that the energy intensity of modes of transport is a well-established indicator for whole states or regions, but can be separately calculated also at the local level.

1.3. GHG or CO_2 emission intensity results – international overview

In terms of GHG or CO_2 emissions, research in the literature has been compiled comprehensively and is presented in Table 1, where GHG or CO_2 emission intensity indicators from various sources have been gathered. Usually, CO_2 is 97-99% of the share of transport GHG emission intensity, as it is for Italy [1] and Great Britain [26].

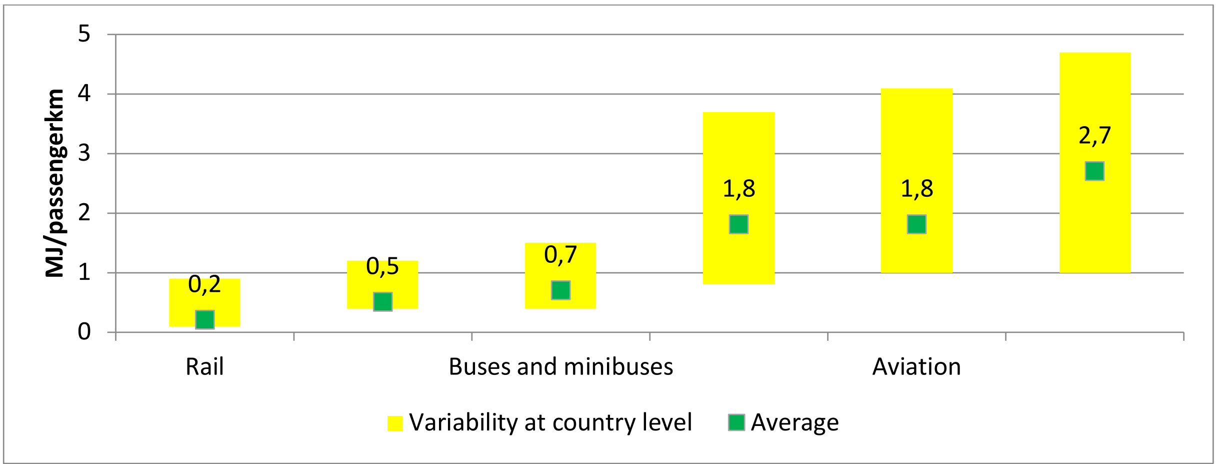

Fig. 1. Energy intensity of modes of passenger transport by IEA (2018), Source: [11]

Table 1

GHG* or CO_2 emission intensity (gCO_2eq/p-km* or gCO_2/p-km) for various modes of transport – international review. Sources: Great Britain (GB) [20], France (FR) [22], Germany (DE) [25], Australia (AU) [16, 17], Spain (ES) [10], Italy (IT) [1, 29], the Netherlands (NL) [28], Finland (FI) [13] and Switzerland (CH) [30]

Modes of Transport	Country GHG* or CO_2 emissions (gCO_2eq/pkm* or gCO_2/pkm)								
	GB* (2018)	FR* (2018)	DE* (2018)	AU* (1999)	ES (1992)	IT (2005)	NL (2000)	FI (1994)	CH (2010)
City buses	105	93,2	31	N/A	31,5	72	80-130	67	25
Suburban Buses	N/A	N/A	N/A	149	N/A	N/A	N/A	62	105
Trams	35	2,8	58	129	N/A	32	45-75	9,2	25
Metro	31	3,4	58	N/A	45,8	21,3	45-60	3,9	N/A
Suburban trains	41	5,4	57	169	37,5	35	N/A	2,7	5-10
Cars	29-235	152-166	147	208-238	124,8	105	135-280	194	65-195
Motors and mopeds	84-135	N/A	N/A	N/A	71,3	80	50-65	N/A	25-108

* Data with this symbol relate to GHG emission intensity and data without this symbol relate only to CO_2 emission intensity.

At the international level, by 2014, the European Energy Agency [8] was reporting CO_2 emission data for modes of passenger transport under the name TERM-21 indicator. Only four very general modes of transport were presented, such as air, inland navigation, road and rail. Among these, the rail was usually the least emitting mode, even 3 times better than road transport and 8 times better than air or inland navigation. These data were shown as the average for the whole EU-28, but data collection stopped in 2014.

It is also worth mentioning that the International Energy Agency [12] also has a record of the GHG emission intensity factor, which is reported on their website. In fact, the IEA data include only energy-related CO2 emission intensities for most modes of transport, except aviation. They provide a general view of the issue because the data from various countries are summarized in one picture. The picture shows that usually, rail has a lower intensity of emission among the various modes of transport, followed by two-wheelers and buses. Cars and planes always have the highest emission intensities. Keeping this general consensus in mind, this article presents calculations of similar indicators for Warsaw.

2. METHOD AND DATA USED

Energy and CO_2 emission intensity indicators can be calculated in different ways. There are Life Cycle Analysis approaches, which take into consideration all kinds of factors that may affect a single trip [e.g., 3, 5, 13, 18]. There are also approaches that measure only part of the picture, e.g., energy use during the transport process (vehicle operation), vehicle manufacturing or other factors. This paper presents indicators relevant only for the transport process (vehicle operation).

Calculation of energy and CO_2 emission intensity indicators for Warsaw was not an easy task, because it required data that are currently not commonly available for transport systems and require special research. For calculation of both indicators, there is a need to have information about energy use in the transport system, as well as transport performance, but both these need to be separately calculated from more detailed datasets, also with categorization of different modes of transport. Calculation of CO_2 emissions also requires detailed categorization of data of different modes of transport on the basis of the fuel used. In 2015, all of the data needed for these kinds of calculations were available for Warsaw.

To calculate the energy use and emissions of CO_2, all data available were combined in a model prepared at the Institute for Sustainable Development Foundation. The model was initially used to calculate energy use and emission of GHGs in Polish municipalities for the purpose of formulation of local climate and energy policies [23]. Gradually upgraded, the model used for the currently described calculations included data obtained from the following sources:

- COPERT IV European vehicle pollution and energy use database, as well as other relevant local transport energy use information from local public transport providers and the literature;
- Polish Statistical Office vehicle fleet information as well as other relevant local fleet data from local public transport providers and the literature;
- Data on road traffic levels and intensity from Warsaw Traffic Research, Warsaw Road Transport yearly measurements and General Polish Traffic Research; and
- Polish National Centre for Emissions Management CO_2 emission factors for different kinds of fuels as well as electric energy in the national grid.

The details of the model with the equations used and a general description of the main results have been described in a separate paper [23]. Table 2 shows only the most important results of the model that were used to calculate indicators that are the main topic of this article.

In the tables and figures that show the results, indicators are shown in the categorization by modes of transport, which are given under the following names:

1. Cars – relate to all kinds of private and public passenger cars. The numbers do not relate to any goods transport.
2. Motors and mopeds – relate exactly to motors and mopeds.
3. Metro – relate exactly to functioning of existing metro lines in Warsaw. In 2015, two metro lines were already active in Warsaw; however, the second line was partly under construction.
4. Trams – relate exactly to functioning of tram lines existing in Warsaw.
5. City buses – relate only to buses that provide service within the management of the Warsaw Public Transport Authority.
6. Suburban trains – relate to suburban trains that are operated only by the Fast City Railway (Szybka Kolej Miejska) company of Warsaw City. This company operates 4 lines serving Warsaw and cities close to Warsaw. The more extensive suburban train system is operated by Mazovia Trains and was not taken into account in this calculation because of lack of proper data.

7. Suburban buses – relate only to buses that operate in Warsaw and suburbs not under the management of the Warsaw Public Transport Authority.

Table 2

Energy use and CO_2 emissions by modes of transport in Warsaw in 2015, Source: Own study

Modes of transport	Yearly energy use (MWh)	Yearly CO_2 emissions (Mg)
City buses	446624	118260
Suburban buses	152426	40628
Trams	124139	98915
Metro	102668	81760
Suburban trains	33364	26645
Cars	3713212	1030196
Motors and mopeds	25853	6445

For the transport performance, additional data had to be used. Warsaw Traffic Research [14] did not calculate the transport performance in passenger-kilometers because it lacked the data on the length of singular trips by different modes of transport. In 2015, the Polish Statistical Office carried out, for the first time in its history, a national mobility research, which obtained this kind of information from the inhabitants of Warsaw [6]. Unfortunately, not all of the information from this research was available specifically for Warsaw. The author tried to obtain more information about the data for Warsaw from Polish Statistical Office, but did not succeed.

Therefore, indicators of the average distance traveled with one trip by users of various modes of transport are not always specific for Warsaw. This is especially true in the case of trams, buses and suburban trains. For these modes of transport, the average distance is assumed from the research data presented publicly [6]. For trams and buses, it is assumed that the distance traveled is the same as for public transport generally. For suburban trains, which, in this specific calculation, relate only to the trains of fast city railway (Szybka Kolej Miejska), it is assumed that the distance traveled is the same as that for the metro line. Distances for cars, motorcycles and suburban buses in Warsaw were publicly available [6].

Distance traveled combined with the relevant data on the number of passengers in public transport or car occupancy allowed for calculation of the transport performance for Warsaw in 2015. Table 3 shows the most important transport data used for further calculations of energy and CO_2 emission intensity indicators.

After completion of the mentioned dataset, further calculations have been carried out using the following equations for each mode of transport:

(1) $Ei = Eu/Tp$, where
Ei is the energy intensity,
Eu is the energy used in MJ and
Tp is the transport performance in passenger km.

(2) $Eco_2 = Ey/Tp$, where
Eco_2 is the CO_2 emission,
Ey is the yearly CO_2 emission in g and
Tp is the transport performance in passenger km.

3. RESULTS OF CALCULATIONS FOR THE WARSAW TRANSPORT SYSTEM

The results are presented in graphs as described.

3.1. Energy intensity of various modes of transport in Warsaw

The first graph relates to the energy intensity of the modes of transport in the Warsaw transport system. As fig. 2 shows, the least energy-intensive mode of transport in Warsaw in 2015 was the metro. Only a bit more energy-intensive were trams. The modes of public transport in the Warsaw transport system were usually a few times more energy intensive than modes of individual transport: motors and mopeds or cars. Motors and mopeds were over 2 times more energy intensive in Warsaw, than suburban buses, the least energy-intensive mode of public transport. However, suburban buses are an aging fleet, as they are predominantly 20-year-old diesel buses imported from Western Europe. Cars, the most energy-intensive mode of transport, were over 12 times more energy intensive than the metro.

Table 3

Passenger transport performance indicators in Warsaw in 2015, Sources: as indicated in the table, otherwise (*in italics*) own study

Modes of transport	Number of passengers (thou. passengers)	Average distance traveled with one trip (km) [6]	Passenger transport performance (thou. passenger*km)
City buses	574401 [31]	10,8	*6203531*
Suburban Buses	*24981*	38,5	*961781*
Trams	272101 [31]	10,8	*2938691*
Metro	224292 [31]	11,4	*2556929*
Suburban trains	25311 [31]	11,4	*288545*
Cars	*299525*	23,1	*6919034*
Motors and mopeds	*5592*	11,8	*65985*

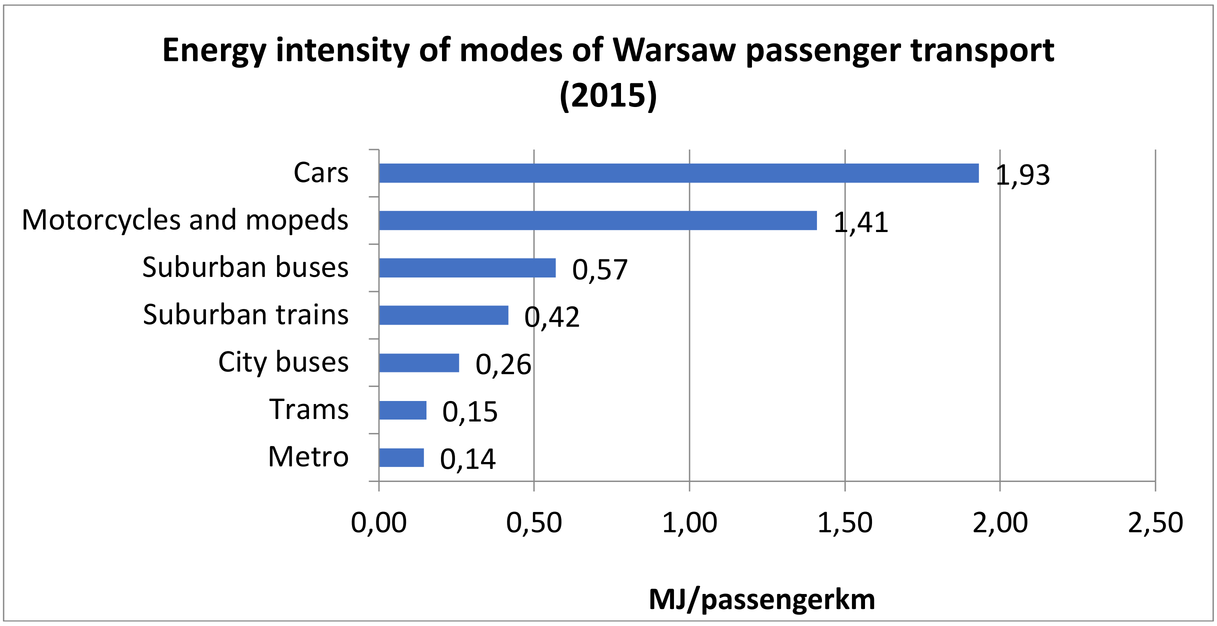

Fig. 2. Energy intensity of modes of passenger transport in Warsaw (2015), Source: Own study

3.2. CO_2 emission intensity of modes of transport in Warsaw

Fig. 3 shows the CO_2 emissions of modes of transport in the Warsaw transport system. The least CO_2 emission-intensive modes of transport in Warsaw in 2015 were public transport buses under the management of the Warsaw Public Transport Authority. It is worth noting here that the buses were usually of a higher ecological standard (EURO4 and better); however, most of them are still diesel buses and only about 100 buses in 2015 were using alternative fuels: electricity or gas [31]. Such a high result of this indicator may be due to the high passenger occupancy of the Warsaw bus system. In any case, this result for city buses in Warsaw is surprising because buses are performing better than trams or the metro in terms of CO_2 emissions. The most emission-intensive modes of public transport were suburban trains, which performed not much better than motorcycles and mopeds. The highest CO_2 emissions were caused by passenger cars, which is not surprising. The least emission intensive means of transport, that are city buses, are only about 6 times less intensive than passenger cars.

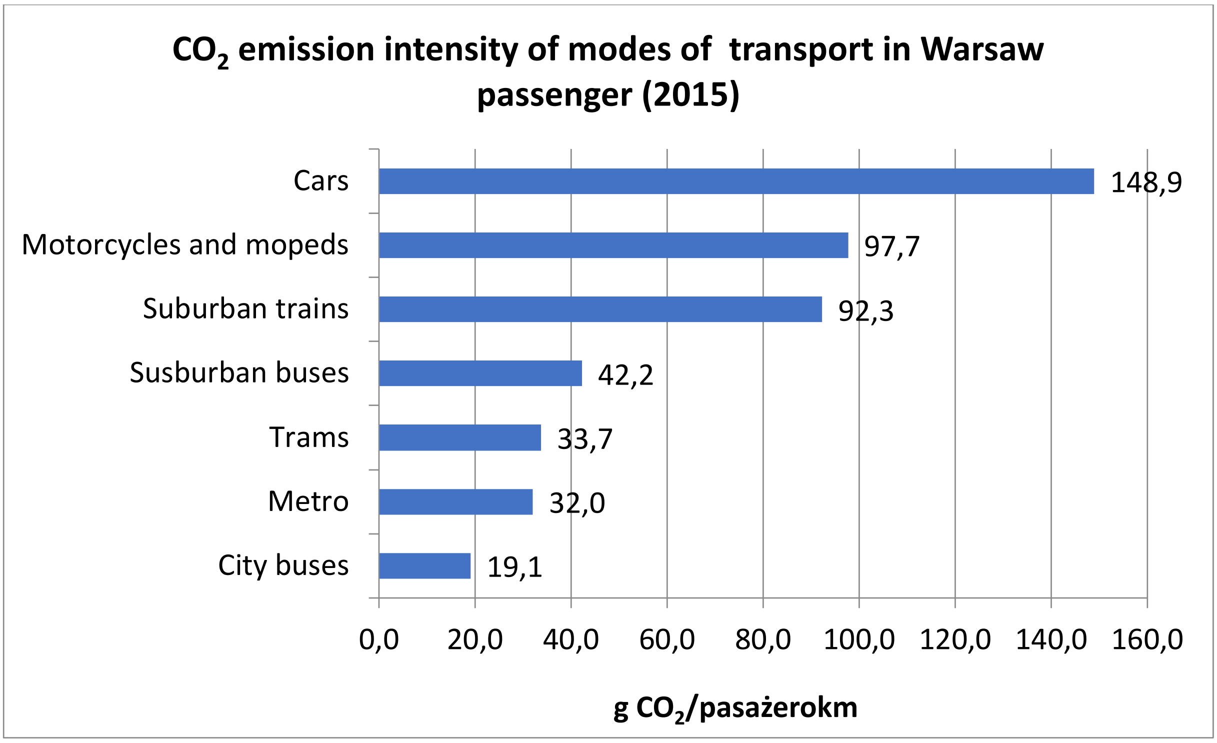

Fig. 3. CO_2 emission intensities of different modes of passenger transport in Warsaw (2015), Source: Own study

4. DISCUSSION OF RESULTS

The results of energy intensity for Warsaw correspond to the usual picture presented for other countries and regions in international comparisons described in the first part of this article. Electric modes of transport that use rails are the least energy intensive, while motors and passenger cars are the most energy intensive. The somewhat specific characteristic of Warsaw transport is that city buses are found to be less energy intensive and are placed in this respect between suburban trains and trams.

The results for CO_2 emission intensity correspond to the usual picture presented in international comparisons, but with some specific characteristics. City buses have been found to have the lowest CO_2 emission intensity, which has already been noted in some other countries like Germany, Spain and Switzerland. Interestingly enough, suburban trains have not been found to be among the least-emitting modes of transport and show emissions similar to motors and mopeds, much worse than trams, metro and suburban buses. Suburban railways in Warsaw in fact have a much worse emission factor than in Great Britain or Italy, where railways also have quite high CO_2 emission intensity.

5. CONCLUSION

Energy intensity and CO_2 emission intensity of various modes of transport seem to be well-established indicators for transport. It is calculated in many countries and used as a factor for comparison between states and regions. Only occasionally can calculations of this kind of indicator be found for smaller areas like cities. Calculation of energy intensity and CO_2 intensity for modes of transport in Warsaw seems to be a separate exercise. It is probably the first calculation of these kinds of indicators for Warsaw in Poland.

The results of energy and CO_2 emission intensities for Warsaw show a general picture that is similar to other regions and countries, especially European countries, such as Germany or Switzerland. A specific characteristic of Warsaw City is that city buses have relatively good energy intensity and CO_2 emission intensity results, whereas suburban rail seems to be relatively worse compared to other regions.

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Received 22.11.2019; accepted in revised form 12.05.2021