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The role of transport sector in CO_2 reduction in Poland

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Abstract. The need for greenhouse gases (GHG) reduction from the atmosphere, resulting from the International Treaties signed by Poland is a serious challenge that requires a complex action in all economy sectors. The UE action plan towards low carbon economy is in line with conclusions of the 21st UN Climate Change Conference (COP21), held in Paris in 2015. The current EU climate and energy objective is to reduce its GHG emissions by 40% below 1990 levels by 2030. The transportation must play a vital role in achieving the target. The transport sector in Poland now is responsible for 15% of the total domestic CO_2 emissions and this share is expected to grow as a consequence of economic development. The potential for CO_2 reduction in this sector is significant. Unlocking this potential can be beneficial for the Polish economy and rational in terms of cost. For example, it would help to stem dependence on oil import, contribute to air quality improvement and accelerate the process of transport infrastructure modernization. Defining the pathways of the future development of the transport sector in Poland under given environmental restrictions requires extensive analysis and appropriate tools to evaluate the effectiveness of various policy instruments, which affect the level of demand and consequently the GHG emissions. In the article, a new "bottom-up" energy model has been proposed to make such assessments. The model, named STEAM-PL (Set of Tools for Energy Demand Analysis and Modeling), has been elaborated to predict future energy demand and emissions of pollutants based on long-term economy and policy scenarios in all economy sectors in Poland. The paper presents the methodological basis for the construction of the model and shows the results obtained for different scenarios concerning the future development of the transport sector.

1 Introduction

Mobility is a fundamental need in modern society. Unfortunately, dynamic growth of transport leads to higher GHG emissions (including carbon dioxide being the main component of the GHG) as a result of increase in energy demand. The rise in fuel consumption also reflects negatively on trade balances and energy security of the oil

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importing countries. It exposes these countries to the risk of oil prices fluctuations, what represents a real menace to their economic growth prospects.

Poland is nearly fully dependent on oil supplies from abroad. Limiting energy consumption as a consequence of CO_2 abatement, coming from the commited obligations, can bring a lot of advantages for the economy and the environment, providing that the development strategy is implemented resolutely. In the EU action plan towards low carbon economy, it is indicated that countries being EU members need to reduce its GHG emissions by 40% to 2030 in comparison with 1990 [1]. The transport sector has to play a vital role in the process. Reduction target to 2030 for non-ETS sectors is a subject of ongoing work. Current proposals suggest necessity of 7% reduction level in reference to 2005 for Poland in the following sectors: transport, construction, waste management and agriculture [2]. Adoption of proposed solutions would mean a very serious challenge for the country, which economy is constantly growing and aspire to reach EU's average level of development on the horizon for 2030.

In 2014, the transport sector emitted 43.6 Mt of CO_2, what was about 15% of the total country emissions. In the future this share is expected to grow as it is observed in other European developed countries. In view of the structure and specific features of the transport sector in Poland, achieving any reduction in comparison with 2005 seems to be impossible. Since the 2005 up until now, considered emissions have already grown up by 26%.

In order to meet the CO_2 reduction goals in a secure and sustainable manner, governments must set in motion legislative initiatives which will provide citizens with incentives for following more sustainable patterns of consumption. Any policies to reduce emissions should be preceded by an impact study. In Poland there have not been almost any research on the development of the transport sector (in the context of the demand for fuels and energy carriers and emissions) with the application of advanced mathematical models that take into account current specific national conditions [3].

The main aim of the article is to present a methodology and a new "bottom-up" model STEAM-PL designed for energy demand and emission of pollutants evaluation in the medium and long term in Poland. Dedicated for the transport sector module STEAM_T, which is a part of the package STEAM-PL, allows to analyze the quantitative effects of implemented policies and measures, considering specific conditions of the Polish transport sector.

2 Energy consumption and CO_2 emissions in the transport sector in Poland

The transport sector is an area of activity, where the most significant energy demand growth took place among all other sectors, after political transformation in Poland.

Table 1. Final energy consumption in transport sector in Poland in years 1995-2014 [ktoe]

	1995	**2005**	**2014**
Gasoline	4 610	4 230	3 535
Diesel	2 796	5 657	9 154
LPG	193	1 702	1 744
CNG	5	15	24
Electricity	402	343	259
Jet fuels	269	319	584
Natural gas	0	236	362
Biofuels	0	49	705
TOTAL	**8 275**	**12 551**	**16 367**

Source: Energy Market Agency – ARE S.A.

Energy consumption in this sector nearly doubled since 1995 and reached the level of 16.4 Mtoe in 2014 [Fig. 1]. Growing share of energy consumption in transport is associated with the increasing role of the road transport, both passenger and freight.

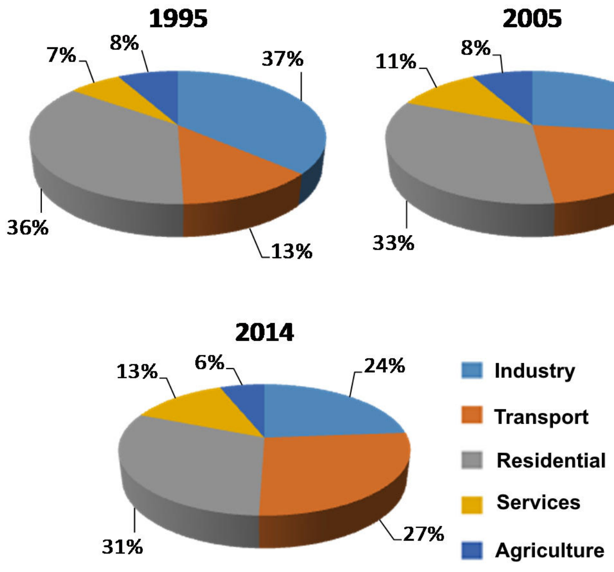

Fig. 1. Final energy consumption shares in particular economy sectors in Poland

In the non-ETS sectors the criteria of the measurement of CO_2 emissions are not defined. That is why they are estimated according to the amount of energy carriers consumption basing on CO_2 emission factors. Calculated by The National Centre for Emissions Management (KOBiZE) CO_2 emission volumes in transport in 2014 were at 43.6 Mt [4], what constituted 15% of the total country emission of the given component [Fig. 2].

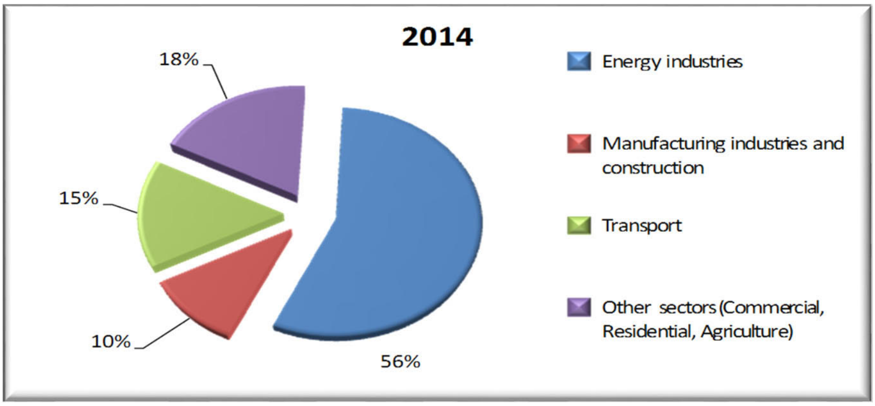

Fig. 2. CO_2 emission shares by economic sectors in 2014

Energy efficiency in transport clearly had an influence on the decrease in the rate of emissions growth. But this effect was not strong enough to balance the implications of the growing demand for the transport activity. One of the main reasons of this was a rebound effect (more fuel efficient car = higher its weight and more intensive usage). Among different modes of transport, road transport is a key one in terms of CO_2 reductions [Fig. 3].
In 2014 this type of mode accounted for 97% of the total CO_2 country emissions.

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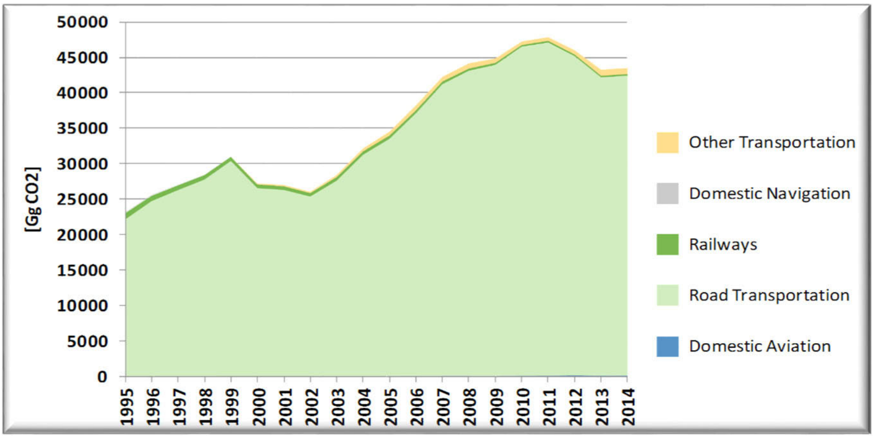

Fig. 3. CO_2 emission by transport branches in years 1995-2014

3 CO_2 reduction measures in transport

Technology improvements alone will not be sufficient to stop the growth in greenhouse gas emissions from transport, other policy measures will be necessary.
Paragraphs below provide a list of examples of CO_2 reduction measures that can be taken into account in the transport sector in Poland. Measures in this list can be divided into technical and other measures, that physically reduce the CO_2 emissions of transport.

1. The improvement of fuel efficiency of vehicles and reduction of emissions in road transport
    a. Improved combustion engines
    b. Improved aerodynamics
    c. Weight reduction
    d. Engine downsizing + turbo
    e. Low rolling resistance tyres
    f. Fuel efficient driving, lower driving speed
2. Alternative fuels (market-orientated measures to influence users choice towards more fuel-efficient cars):
    a. LPG, CNG, Liquid biofuels and biogas, Electricity, Hydrogen
    b. Hybrid vehicles
3. Modal shift in passenger transport
    a. Prioritization public transport and non motorized modes
    b. High speed rail system development
4. Modal shift in freight transport
    a. Promoting intermodal transport
    b. Development of inland transport
5. Transport infrastructure modernization
    a. Modernizing infrastructure and the service of conventional rail transport
    b. Inteligent Transportation Systems
6. Improved logistics and goods distribution process [5].

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4 Methodological approach

Proposed in the article model, named STEAM (**S**et of **T**ools for **E**nergy Demand **A**nalysis and **M**odelling) consists of five independent modules, dedicated for analysis of particular economy sectors (Fig. 4).

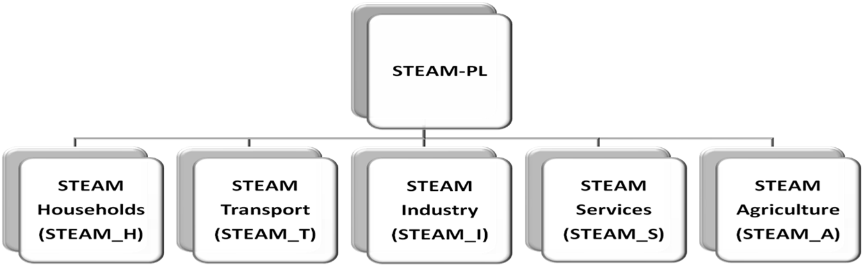

Fig. 4. STEAM-PL modular structure

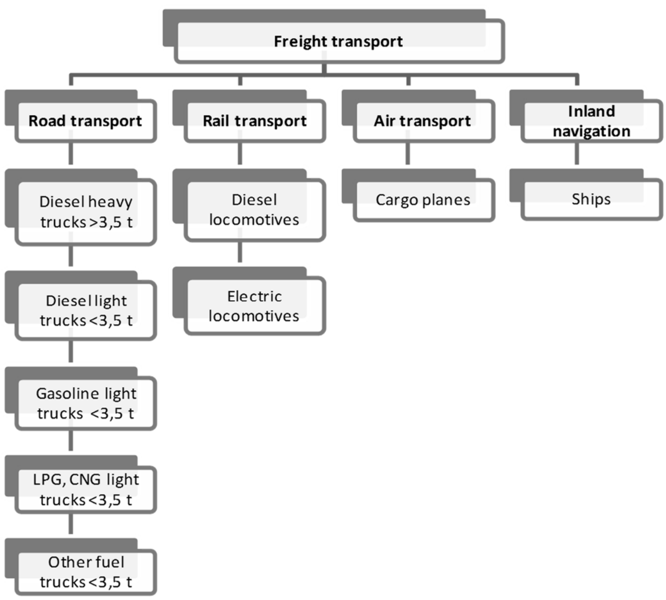

Fig. 5. Model STEAM_T structure – Freight transport

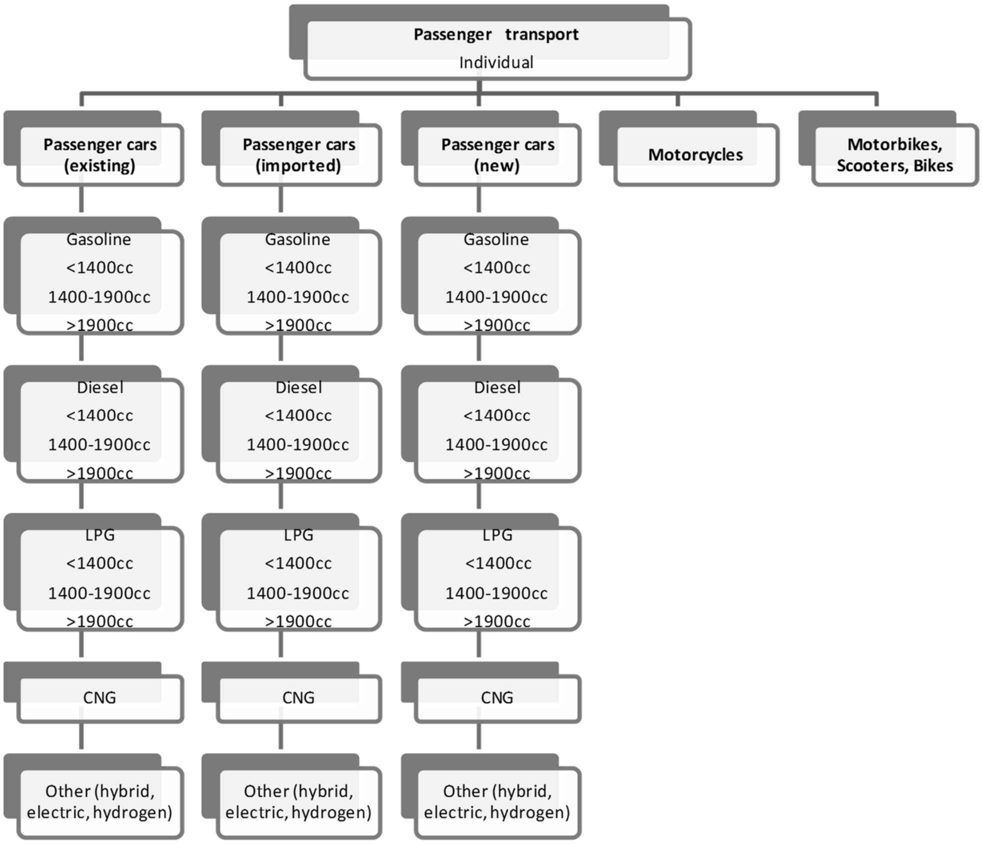

Fig. 6. Model STEAM_T structure – Individual passenger transport

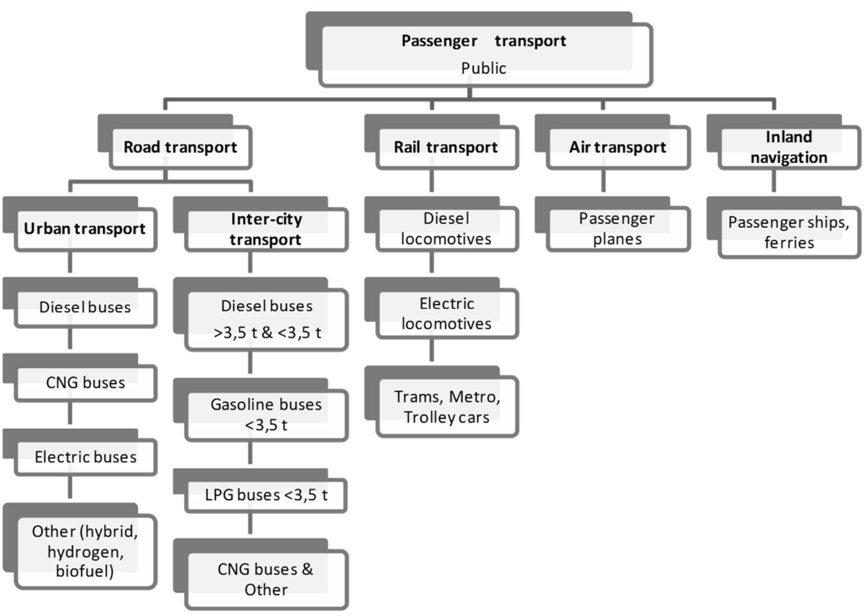

Fig. 7. Model STEAM_T structure – Public passenger transport

STEAM-PL is an integrated „bottom-up" and "top-down" model, which reflects all important technical aspects of energy utilization, including technological development. An engineering approach, has been supplemented with econometric modeling of market shares, employed to estimate the penetration of supply alternatives. A market share algorithm is used in the model to determine the response of various energy demand segments to changes in energy prices and costs of particular technologies. A market share algorithm has been adopted from the ENPEP/BALANCE methodology [6]. This solution makes possible to analyze the effects of various economic instruments e.g. fuel tax, cars subsidizing. STEAM-T is a module dedicated for analysis of the transport sector in Poland. Very detailed structure basing on the most accurate statistical data verified by different sources allows to include various specific conditions of functioning of the transport sector in Poland, like: average age of vehicles and their technical condition, number of vehicles really in use, which is totally different from the number of vehicles registered and high share of imported cars. STEAM-T module generates energy demand and emissions of pollutants projections broken into passenger (individual, public) and freight transport modes as well as different types of vehicles specified within each group. The demand for a transport fuel is equal to the product of vehicle utilization rate and total stock of vehicles:

$$D_t = S_t * R_t * U_t \tag{1}$$

Where D_t – the demand for fuel at time t
S_t – the vehicle stock
R_t – the utilization rate (kilometers per year)
U_t – the unit energy consumption (litre per kilometer)

The level of vehicle stock is linked with the economic, social and technological growth. The pace of a new car additions is limited by vehicles per 1000 population ratio, estimated by using comparisons with other European countries. The model employs a market share algorithm using a logit function to estimate the share of different fuel and vehicle types (2):

$$MS_i = \frac{\left(1/(P_i \times Pm_i)\right)^r}{\sum_i^n \left(1/(P_i \times Pm_i)\right)^r} \tag{2}$$

where MS – market share of a given type of vehicle
i – given type of vehicle
P – cost of operation
PM – premium multiplier
γ – price sensitivity coefficient

STEAM_T module has a very detailed structure, reflecting all key elements and aspects of the functioning of the transport sector in Poland (Fig. 5, 6 & 7).

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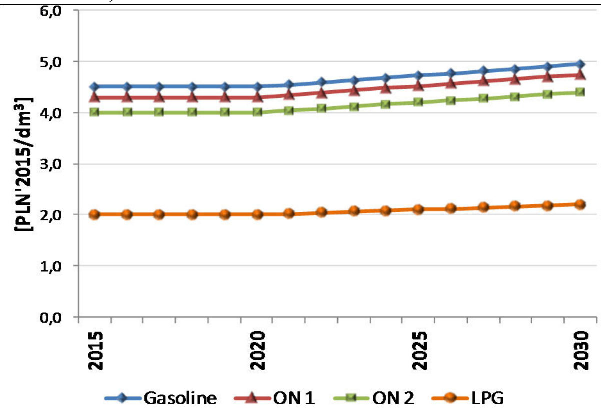
Table 2. Main assumptions

<table>
<tr><td>Time horizon</td><td>2030</td></tr>
<tr><td>GDP growth</td><td>2016-2020 3.9% AAGR, 2021-2030 3.3% AAGR Source: [7]</td></tr>
<tr><td>Population</td><td>2020 – 38.2 mln, 2030 – 37.2 mln Source: [8]</td></tr>
<tr><td>Fuel prices

ON1 – diesel for non-commercial use

ON2 – diesel for commercial use</td><td>

Source: [9], own assumptions</td></tr>
<tr><td>Number of passenger cars (in use)</td><td>2020 – 16.0 mln
2030 – 17.5 mln Source: Econometric model</td></tr>
<tr><td>Passenger transport activity</td><td>2020 – 410 [Gpkm]
2030 – 461 [Gpkm] Source: Econometric model</td></tr>
<tr><td>Passenger cars average mileage (annual) [km]</td><td><table>
<tr><th></th><th>2020</th><th>2030</th></tr>
<tr><td>Gasoline cars</td><td>7 000-8 500</td><td>7 500-9 000</td></tr>
<tr><td>Diesel cars</td><td>10 560-11 000</td><td>11 000-11 320</td></tr>
<tr><td>LPG cars</td><td>10 200-10 670</td><td>10 500-11 440</td></tr>
<tr><td>CNG cars</td><td>12 000-12 400</td><td>13 000-13 900</td></tr>
<tr><td>Electric cars</td><td>7 900-8 760</td><td>8 300-9 710</td></tr>
</table>Source: [10], own assumptions</td></tr>
<tr><td>Passenger cars fuel consumption [dm³/100km]</td><td><table>
<tr><th></th><th>2020</th><th>2030</th></tr>
<tr><td>Gasoline cars <1400cc</td><td>5.3-6.6</td><td>5.1-6.3</td></tr>
<tr><td>Gasoline cars 1400-1900cc</td><td>6.3-7.8</td><td>6.1-7.6</td></tr>
<tr><td>Gasoline cars >1900cc</td><td>7.9-9.8</td><td>7.7-9.6</td></tr>
<tr><td>Diesel cars <1400cc</td><td>4.6-5.7</td><td>4.4-5.5</td></tr>
<tr><td>Diesel cars 1400-1900cc</td><td>5.9-7.3</td><td>5.7-7.1</td></tr>
<tr><td>Diesel cars >1900</td><td>6.8-8.5</td><td>6.6-8.3</td></tr>
<tr><td>LPG cars <1400cc</td><td>6.0-7.6</td><td>5.8-7.3</td></tr>
<tr><td>LPG cars 1400-1900cc</td><td>10.9-13.7</td><td>10.6-13.2</td></tr>
<tr><td>LPG cars >1900cc</td><td>12.6-15.7</td><td>12.2-15.3</td></tr>
<tr><td>Hybrid cars</td><td>4.0-5.0</td><td>3.5-4.5</td></tr>
<tr><td>CNG cars [Nm3/100 km]</td><td>9.0-11.3</td><td>8.8-11.0</td></tr>
<tr><td>Electric cars [kWh/100km]</td><td>12.8-13.5</td><td>11.0-12.5</td></tr>
</table>Source: [10], car manufacturers data, own assumptions</td></tr>
<tr><td>Transport of goods</td><td>2020 – 2 096 519 [1000 t]
2030 – 2 301 670 [1000 t] Source: Econometric model</td></tr>
<tr><td>Freight transport activity</td><td>2020 – 410 [Gtkm]
2030 – 473 [Gtkm] Source: Econometric model</td></tr>
<tr><td>Number of trucks (in use)</td><td>Heavy trucks >3,5 t 2020 – 0,7 mln, 2030 – 0,72 mln
Light trucks <3,5 t 2020 – 2,1 mln, 2030 – 2,1 mln
Source: Econometric model</td></tr>
<tr><td>Trucks average mileage (annual) [km]</td><td><table>
<tr><th></th><th>2020</th><th>2030</th></tr>
<tr><td>Diesel heavy trucks >3.5t</td><td>28 700</td><td>31 900</td></tr>
<tr><td>Diesel light trucks <3.5t</td><td>7 600</td><td>7 700</td></tr>
<tr><td>Gasoline light trucks <3.5t</td><td>15 300</td><td>17 000</td></tr>
<tr><td>LPG light trucks <3.5t</td><td>19 500</td><td>19 000</td></tr>
</table></td></tr>
</table>

	CNG light trucks <3.5t	17 000	19 000
	Source: [10], car manufacturers data, own assumptions		
Trucks fuel consumption [dm^3/100km and Nm3/100km for CNG]]		**2020**	**2030**
	Diesel heavy trucks >3.5t	38.0	35.0
	Diesel light trucks <3.5t	9.2	8.5
	Gasoline light trucks <3.5t	8.8	7.0
	LPG light trucks <3.5t	11.6	10.6
	CNG light trucks <3.5t	10.9	8.7
	Source: [9], own assumptions		
CO_2 emission factors	LPG – 63.1 kg/GJ Gasoline – 69.3 kg/GJ Jet fuel – 70.0 kg/GJ Diesel – 74.1 kg/GJ *Source: [4]*		

5 Main assumptions

Two scenarios have been prepared to analyze the future energy demand and possibility of CO_2 reduction in the transport sector. The first one (Business as usual scenario – **BAU**) assumes no active government policy in this field. Energy efficiency progress is made mainly basing on market rules. No additional solutions are taken into account, except those that have already been accepted.

The second one (Modernization scenario – **MOD**) assumes implementation of a sets of policy instruments, which require active role of government and public funds involvement, including:

1. Support the use of electric cars (approx. 1.4 million cars in use in 2030).
2. Support the use of hybrid cars (approx. 1.6 million cars in use in 2030).
3. Support the development of rail passenger and freight transport, including intermodal (increase the number of passengers transported by rail from 260 mln in 2014 to 460 mln in 2030, increase the weight of goods transported by rail in the total transported weight from approx. 12% to 20 % in 2030).
4. Support the process of introducing in the bus fleet of public transport the electric, CNG, hybrid and bio fuel combustion vehicles (the share of electric and hybrid buses in the total number of buses increases to 15% in 2030, while the CNG to 7%).
5. Support the development of the CNG technology in cars and trucks.
6. Support the development of water transport (increase the weight of cargo transported by inland waterways in the total weight of 0.7% to 1.3% in 2030)
7. Implementation of higher biofuels share in fuels sold (up to 10%).

Main assumptions taken into the calculations common for the prepared scenarios have been presented in the table 2:

6 Results

Results of elaborated scenarios in reference to energy demand and CO_2 emissions in the domestic transport sector have been presented below.

In the BAU scenario fuel consumption increases from 16.9 Mtoe to 19.7 Mtoe in years 2014-2030 [Fig. 8], while CO_2 emissions rises from 43.6 Mt to 50.4 Mt at the given time [Fig. 10]. In comparison with the year 2005, which constitutes the reference year set by ETS and non-ETS system, emissions increase by 46%. Implementation of the policy instruments listed in the section 5, allows to reduce the growth to 35% only. Energy demand in the MOD scenario increases to 18.6 Mtoe in 2030 (1.1 Mtoe less than in the BAU scenario) [Fig. 9]. CO_2 emissions reach the level of 46.6 Mt. This result is far from the expectations coming from

EU proposals and shows that CO_2 reduction in the Polish transport sector will be very challenging. More actions are needed exceeding those assumed in the MOD scenario in order to achieve deeper reductions.

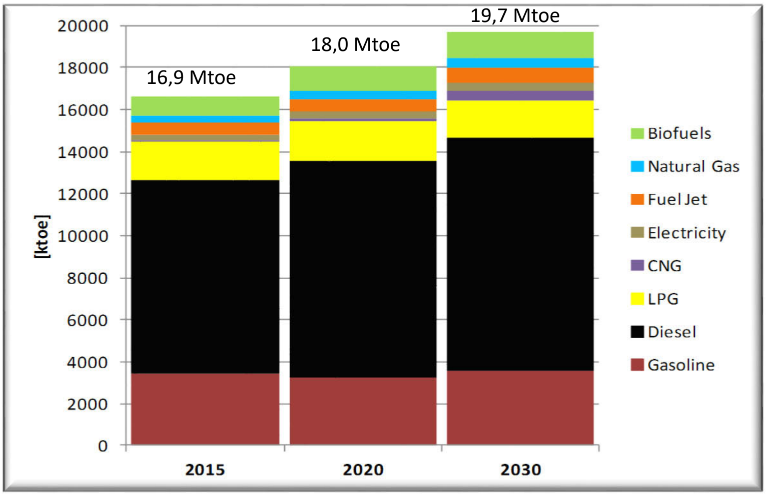


Fig. 8. Energy demand projection in the transport sector in Poland – BAU scenario

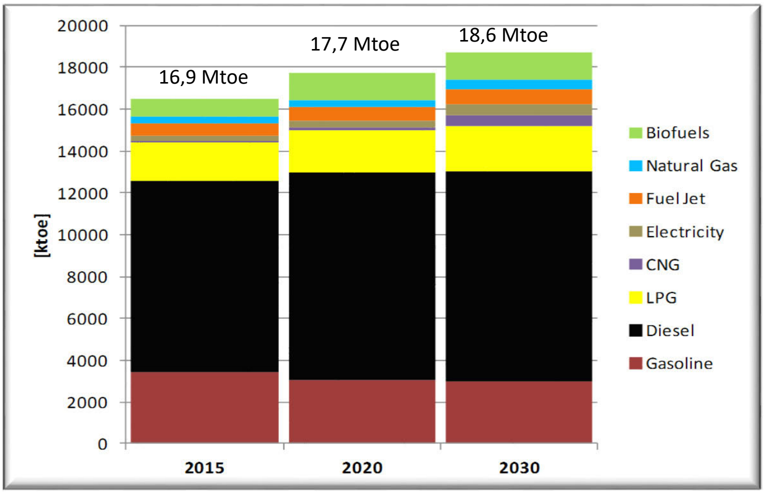


Fig. 9. Energy demand projection in the transport sector in Poland – MOD scenario

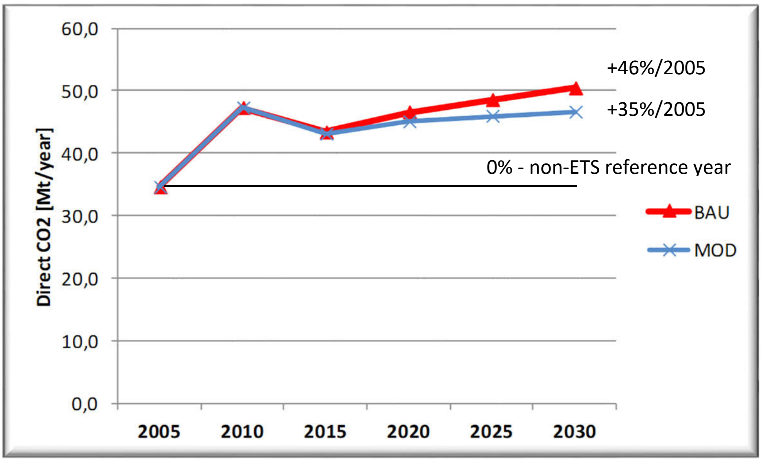


Fig. 10. CO_2 reduction pathways in the transport sector in Poland

7. Summary

Poland as a EU member and signatory to the Paris Agreement must face the challenge of CO_2 reduction up to 2030 and afterwards. The transport sector has to play an important role in this process. This sector accounts for approx. 15% of the total domestic emissions and its share is expecting to grow as a consequence of the economic growth. Actions taken towards low-carbon mobility can be beneficial for the Polish economy, providing that respective solutions are implemented resolutely with preventing excessive costs as one of the objectives. The key issue in the process of the strategy formulation is the correct assessment of the effectiveness of regulatory instruments. In the article a new energy model STEAM-PL and a dedicated to transport sector analysis module STEAM_T have been proposed to capture the effects on energy demand and emisson of pollutants.

The module is based on a "bottom-up" approach, supplemented with econometric modeling of market shares, employed to estimate the penetration of supply alternatives. A market share algorithm is used to determine the response of various energy demand segments to changes in energy and technology prices. Described functionalities and very detailed structure of the module considering specific conditions of the transport sector in Poland makes it a very useful tool to carry out quantitative analysis. Obtained results show that, without active role of the government CO_2 emissions will rise in the transport sector by approx. 46% in comparison with 2005. Implementation of a set of reduction measures listed in the article will allow to constrain the increase up to 35%, but still it is far from lastly proposed on the EU forum obligations. Further reduction requires additional measures of CO_2 abatement.

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