Centre for Climate and Energy Analyses

The Transport European Emission Economic Model TR³E

Technical Documentation for the Model Version 2.0

Authors:

Wojciech Rabiega, Przemysław Sikora, Jan Gąska, Artur Gorzałczyński

Warsaw, February 2022

KOBiZE

VIIEW 2050

AUTHORS AND COPYRIGHT

Wojciech Rabiega, Przemysław Sikora, Jan Gąska, Artur Gorzałczyński

All authors are experts of the Institute of Environmental Protection - National Research Institute (IOS-PIB)/The National Centre for Emissions Management (KOBiZE).

The authors would like to thank Robert Jeszke, Maciej Pyrka, Igor Tatarewicz, Michał Lewarski, Marta Rosłaniec for valuable contributions and the insightful feedback.

The TR³E model documentation (version 1.0) was peer reviewed by dr Olga Ivanova from PBL Netherlands Environmental Assessment Agency.

Upon quoting, please refer to the source, as follows:

Rabiega, W., Sikora, P., Gąska, J., Gorzałczyński A. (2022) The TR³E Model, ver.2.0, Institute of Environmental Protection - National Research Institute / National Centre for Emissions Management (KOBiZE), Warsaw.

This document was prepared in the Centre for Climate and Energy Analyses (CAKE) set up in the National Centre for Emissions Management (KOBiZE), whereas KOBiZE is a part of the Institute of Environmental Protection - National Research institute (IOŚ-PIB).

This document was prepared within the scope of the projects: “*The system of providing and exchanging information in order to strategically support implementation of the climate and energy policy (LIFE Climate CAKE PL)*" - LIFE16 GIC/PL/000031 – LIFE Climate CAKE PL & “*The impact assessment of the EU Emission Trading System with the long-term vision for a climate neutral economy by 2050 (LIFE VIIEW 2050)*” - LIFE19 GIC/PL/00120 - LIFE VIIEW 2050.

If you have any comments or questions regarding this document, please contact: cake@kobize.pl

The document was completed in February 2022.

CONTACT:

Adres: Chmielna 132/134, 00-805 Warszawa
WWW: www.climatecake.pl
E-mail: cake@kobize.pl
Tel.: +48 22 56 96 570
Twitter: @climate_cake

NFOŚiGW

Project "The system of providing and exchanging information in order to strategically support implementation of the climate and energy policy (LIFE Climate CAKE PL)" & “The impact assessment of the EU Emission Trading System with the long-term vision for a climate neutral economy by 2050” (LIFE VIIEW 2050 – LIFE19 GIC/PL/00120) are co-financed from the EU LIFE program and co-financed from the funds of the National Fund for Environmental Protection and Water Management.

Table of content

List of tables

List of figures

List of abbreviations

CAK	Centre for Climate Analyses
CAKE	Centre for Climate and Energy Analyses
CES	Constant elasticity of substitution
CGE model	Computable general equilibrium model
CNG	Compressed Natural Gas
CPM	Cost per mile in euro/vkm
d-PLACE model	Dynamic version of PLACE model (CGE model created in **P**olish **L**aboratory for the **A**nalysis of **C**limate and **E**nergy)
EC	European Commission
EU	European Union
EU ETS	European Union Emissions Trading Scheme
EU28	European Union of 28 Member States
GDP	Gross Domestic Product
GHG	Greenhouse Gases
HDV	High duty vehicles
ICE	Internal combustion engine (vehicles)
IDEES	Integrated Database of the European Energy Sector
IPCC	Intergovernmental Panel on Climate Change
KOBiZE	The National Centre for Emissions Management
LDV	Light duty vehicles
LPG	Liquefied Petroleum Gas
MEESA model	Model for European Energy System Analysis
Non-ETS	Sectors not covered by the European Union Emissions Trading Scheme
pkm	Passenger kilometers
tkm	Tonne kilometers
toe	Tonne of oil equivalent
TR³E model	Transport European Emission Economic Model
vkm	Vehicle kilometers
WEO	World Energy Outlook
ZLEV	Zero- and low-emission vehicle

Keywords: partial equilibrium, transportation, road transport, electric vehicles, aviation, emissions, fuels, JRC-IDEES, TRACCS, baseline scenario, climate policy, EU ETS, non-ETS, low-carbon transition, POTEnCIA

1. Introduction

1. Full of challenges and highly dynamic international and European negotiations in the field of the climate and energy policy, require well in-depth analysis of policy papers and draft legal acts. In order to be able to reliably evaluate this proposals and to actively participate in its creation, it is necessary to have appropriate analytical tools. Such tools enable both the analysis of international proposals and the development of national solutions in the area of climate & energy.

2. The background of modelling exercise

2.1. CAK project

2. To fulfil the analytical needs of the public administration in Poland on the 8th of May 2013 an agreement was concluded between the Minister of Finance, the Minister of Economy and the Minister of the Environment on the construction and use of a workshop for analyses regarding the impact of climate and energy policy on the Polish economy. On the 28th of September 2015, a new agreement was concluded in this regard, incorporating - in addition to the existing signatories - the Chancellery of the Prime Minister to work on the creation of a workshop to analyse the energy and climate policy. According to the Agreement, the analytical workshop was located in the Center for Climate Analysis (Centrum Analiz Klimatycznych - CAK), which was located within the organizational structure of KOBiZE (The National Centre of Emissions Management)[1]. As part of the work of the CAK, a global Computable General Equilibrium (CGE) model PLACE was created along with full documentation. The construction of this model was based on the ROCA model provided free of charge by the World Bank.
3. Modelling team of the CAK comprised delegated employees from the Ministry of Finance, Ministry of Economy and Ministry of Environment/KOBiZE (modelling team).The work of the modellers group mainly concerned the creation and development of the PLACE model, the preparation of analyses / reports and their presentation at the meetings.
4. In addition to the work of the group of modellers, under the Agreement, meetings of the Steering Committee were organized (the Steering Committee consists of appointed heads of departments from ministries of signatories of the Agreement and invited ad hoc guests). At the meetings of the Committee decisions were made on the subject and scope of the analyses carried out, and problems with the construction of the PLACE model were solved. The members of the Steering Committee were kept informed about the progress of work under the CAK.

[1] KOBiZE is a part of the Institute of Environmental Protection – National Research Institute (IOŚ-PIB)

2.2. LIFE Climate CAKE project

5. The Institute of Environmental Protection - National Research Institute (IOŚ-PIB), located in Warsaw, Poland, has been developing a project focused on building a system of providing and disseminating information in order to support the implementation of the EU's climate and energy policy. This overall objective is to be achieved through providing to public administration and society a better information on possible impacts as well as improving the efficiency of climate policy actions. Key elements of the project include creation of sustainable team of experts and building an integrated set of advanced analytical models, able to generate and provide an adequate high quality information and data.
6. The Project goals are defined to support implementation of the EU's climate policy, with an emphasize on climate and energy package 2020 as well as climate policy framework up to 2030 and long-term objectives for 2050. Activities assumed in the project are designed to improve the general management and decision making through a better recognition of impacts associated with policy options considered. The project outcomes will significantly increase a decision makers capacity in terms of its knowledge, skills and responsiveness in both public and private sector. Accordingly, the project will improve an efficiency of greenhouse gases emission reduction, but also will contribute to achieving other environmental policy objectives, e.g. atmospheric air quality and resource efficiency.
7. Main project activities include developing a set of analytical tools to provide a suitable and comprehensive information to decision makers and the public. A dynamic computable general equilibrium model (CGE) will be the central element of this tool-box, while sector models for energy, transport and agriculture will be integrated with feedback and mutual work capability. Project concept assumes involvement of target group representatives to meet their expectation to a maximum possible extent. Therefore, they will participate in both development of the tool-box and – what is extremely important – in defining analytical goals for an expert team. Public administration responsible for climate and energy policy, frequently suffers from an unsatisfactory availability of the comprehensive analytical toolkit, suitable for both deeply analysis and assessment of impacts associated with different options of policy measures discussed and this project answers to these needs. In the approach proposed under this Project, an important, new element is a high degree of interconnection between the models – consisting not only in the fact that data for analyses using sectoral optimisation models will be based on the results of the CGE model, but also the procedure of iterative calculations in which the results of sectoral models will be used in a subsequent cycle of calculations using the macroeconomic model. In consequence, the results obtained using the CGE model and sectoral models will be consistent with each another. At the same time, the results of the CGE model will take into account detailed aspects of processes unfolding in the sectors of energy, transport and

agriculture which ensue from sectoral modelling, while the results obtained using sectoral models will take into consideration general economic effects.

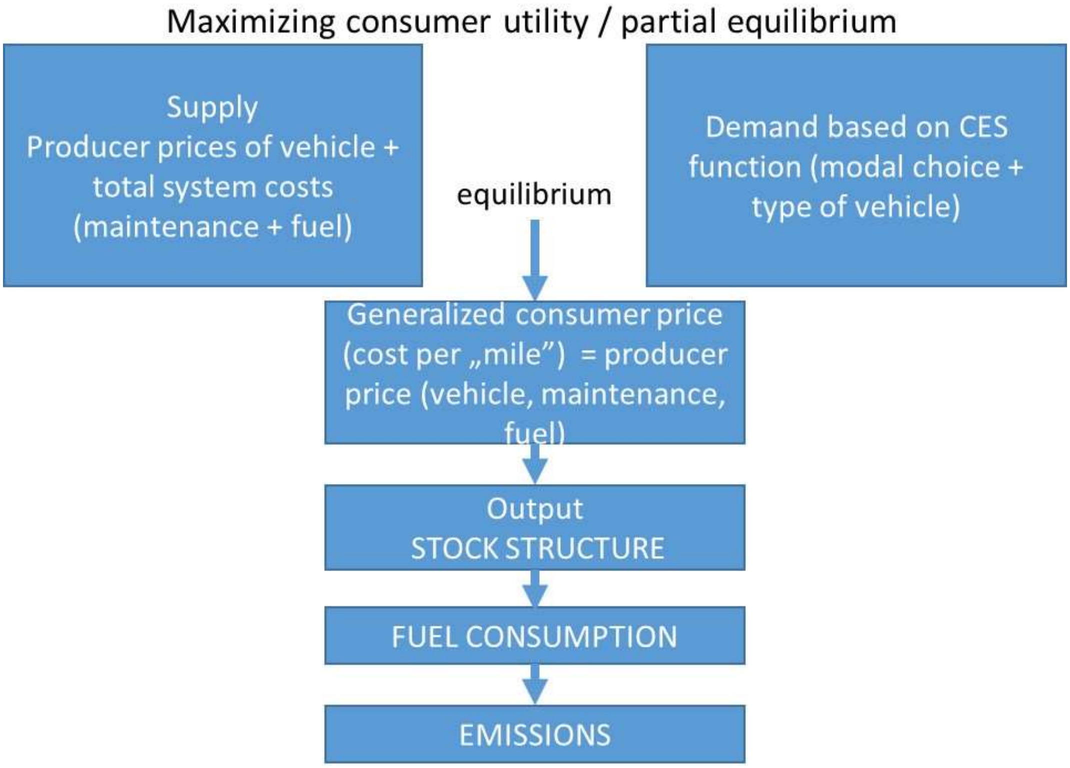
8. A number of analytical reports will be delivered to the target group as well as to the stakeholders and general public. What should be clearly emphasized all those works are to be developed with target group involvement and designed in a way allowing their practical application in both preparing strategic documents and decision making process. The most important project outputs include potential of GHG emission reduction in sectors, adequate strategies for Poland, considering the rules and objectives of the EU climate policy. The report will combine sectoral model results and will provide an additional evaluation of impact assessment across the economy. Besides, a demonstration of practical applicability of the modelling results at the local level is assumed. Specifically addressed guidebook covering analysis results at sectoral level and practical actions and instruments for local administration will be prepared to translate the EU and domestic climate and energy policies into local actions.

3. Model logic and data

3.1. Non-technical model description

9. TR³E transport sector model is based on the concept of partial equilibrium. Partial equilibrium is a condition of economic equilibrium which covers only a part of the market to attain equilibrium. In the other words, partial equilibrium is a balance between supply and demand in just one part (market) of an economy. In the model, based on the partial equilibrium concept, the clearing on the market of some specific goods is obtained independently from prices and quantities in other markets. Therefore, the prices of all substitutes and complements that are not included into the model, as well as income levels of consumers, are taken as given. This makes analysis much simpler than in a general equilibrium model which includes the entire economy, what allow us for much more extensions, e.g. modelling of fleet in the transport sector. Prices adjust in the dynamic process until supply equals demand. It is a quite simple technique that allows one to study efficiency and comparative statics. The stringency of the simplifying assumptions inherent in this approach makes the model considerably more tractable, but may produce results which do not effectively model real-world economic phenomena. Partial equilibrium analysis examines the effects of policy action in creating equilibrium only in that particular market which is directly affected. Partial equilibrium approach ignores effects in any other market or industry and assume that they will have little impact if any. So this approach seems to be useful mainly in constricted markets.

Figure 1. TR³E model logics



Source: CAKE/KOBiZE own study

10. TR³E model is based on the bottom-up approach. The immanent characteristic of bottom-up models is the fragmented view of representative model agent. In other words, each agent understands only a small part of the whole economy. As the market is also a bottom-up system, one of the best description made of bottom-up approach is the one made by Hayek[2]. Following De Grauwe, Hayek argued that "no individual exists who is capable of understanding the full complexity of a market system. Instead individuals only understand small bits of the total information. The main function of markets consists in aggregating this diverse information. If there were individuals capable of understanding the whole picture, we would not need markets". Nonetheless, scope and structure of technical bottom-up models is sometimes criticized for excluding many economic costs and behavioural effects.

[2] De Grauwe, P. "The academic view up front: towards a new macroeconomics" in. "The Euro and economic stability" Edward Elgar Publishing Limited, 2010 and Hayek, F., "The Use of Knowledge in Society", American Economic Review, 1945, XXXV, no. 4, 519-530.

3.2. Data sources

3.2.1 IDEES database

Means of transport

11. TR³E model is filled by several data sources. The main data comes from JRC IDEES database. Integrated Database of the European Energy Sector (IDEES) brings together all statistical data that are relevant to the energy system, combining the energy balances with macro-economic, demographic, activity (e.g. industrial output; mobility) and climatic data. It draws on the Eurostat energy balances, power generation statistics, transport statistics, pocketbooks, macroeconomic and demographic data, as well as, information from UN databases (UNFCC National GHG Inventory Submissions, FAOSTAT etc.), the U.S. Geological Survey and the British Geological Survey. In doing so, it provides information on the factors that influence a sector's energy demand at the aggregate level. On the other side, JRC-IDEES offers processed data that aim at deepening the understanding of the energy system's historic evolution and their underlying drivers, and thereby also creates a robust basis for the assessment of energy policy futures. To this end, the database makes available a two detailed decomposition of historical time series of energy consumption and production that at the aggregate level match the official statistics.

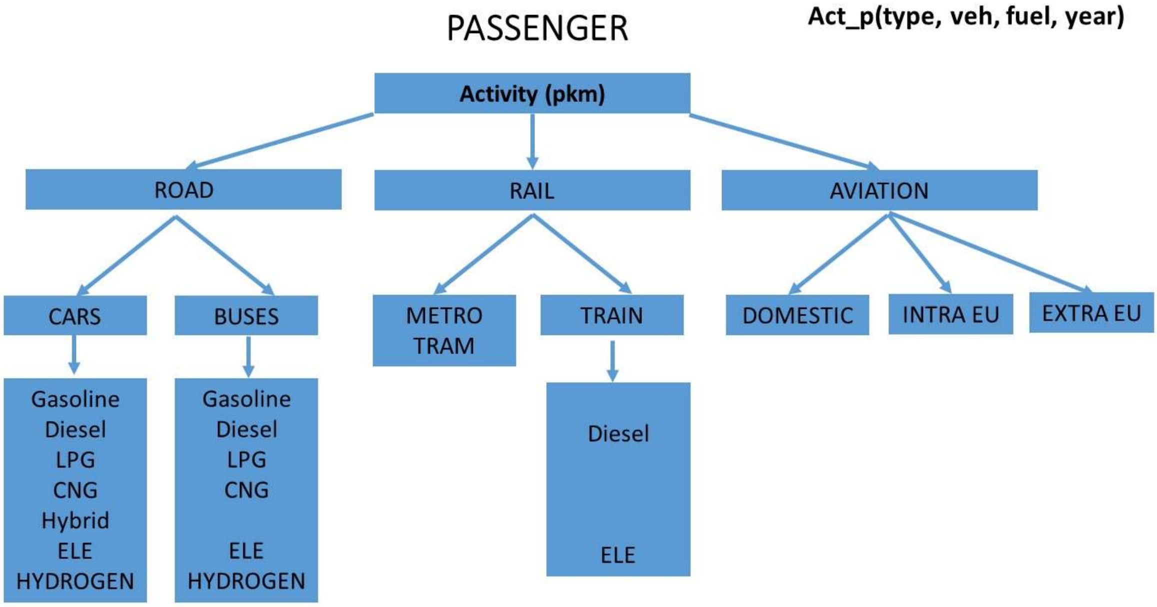
12. JRC-IDEES contains historical statistical data concerning 4 mains block: demographics, economy, activity levels and energy use. This data is complemented by sectoral details as well as technology data and the operating characteristics. In JRC-IDEES detailed information about CO_2 emissions and stock energy equipment can be find.

    JRC-IDEES database provides a very detailed decomposition of energy use and activity in transport sector for all EU Member States. The structure of database was designed by representative "vehicle" configuration:

    - Explicit techno-economic characteristics;
    - Activity expressed in km driven;
    - Occupancy rate, vehicle's load factor.

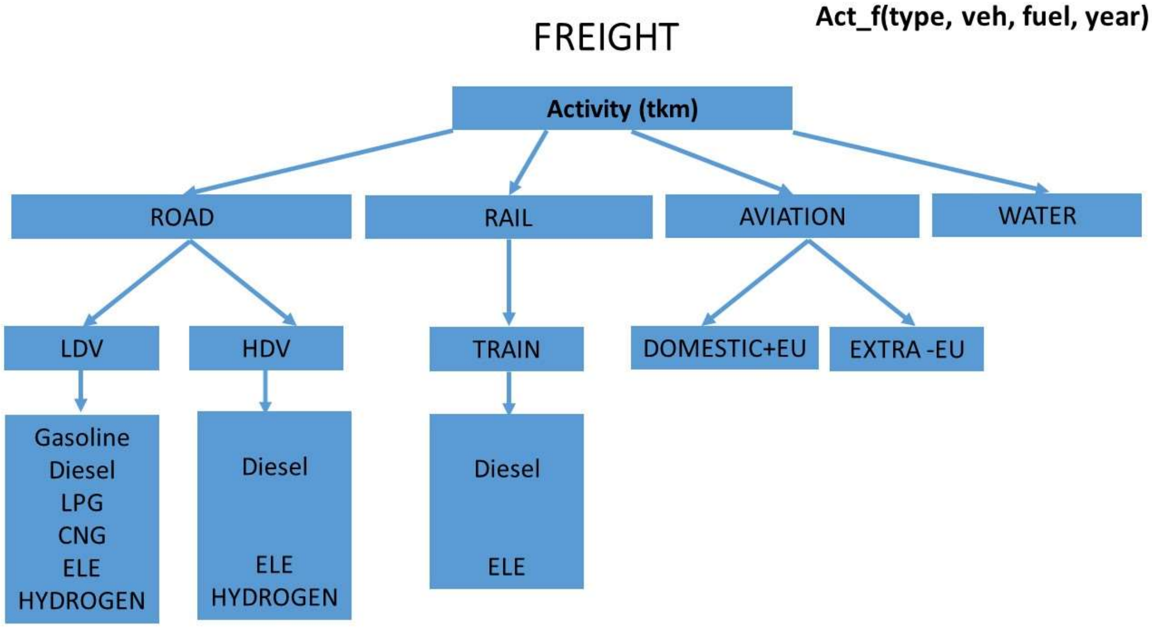
13. Database covers 4 main transport modes (road, rail, aviation and water transport), up to 11 means of transport (vehicle category), as well as the characteristics on engine types per mean (37). "TR³E" model is based on the IDEES database version 1.0 which comprises observed data up to 2015. Passenger transport data in IDEES is summarized on the figure 2.

Figure 2. Passenger transport activity in the JRC-IDEES



Source: CAKE/KOBiZE own study

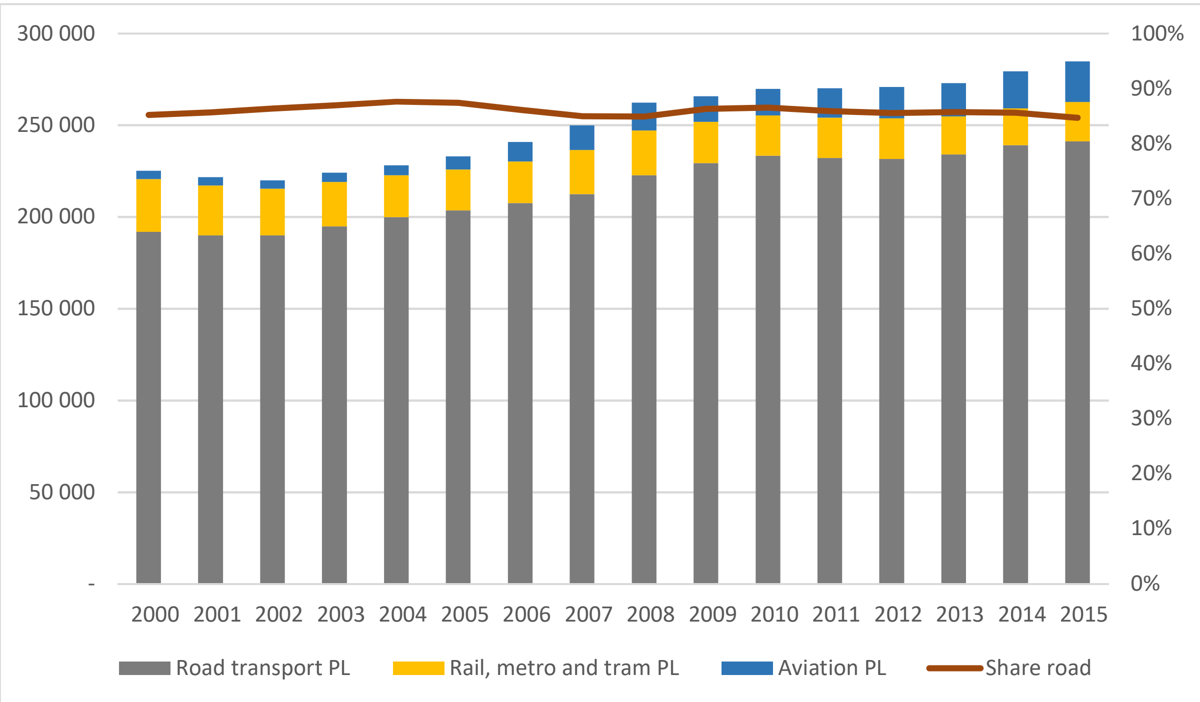
Figure 3. Freight transport activity in the JRC-IDEES



Source: CAKE/KOBiZE own study

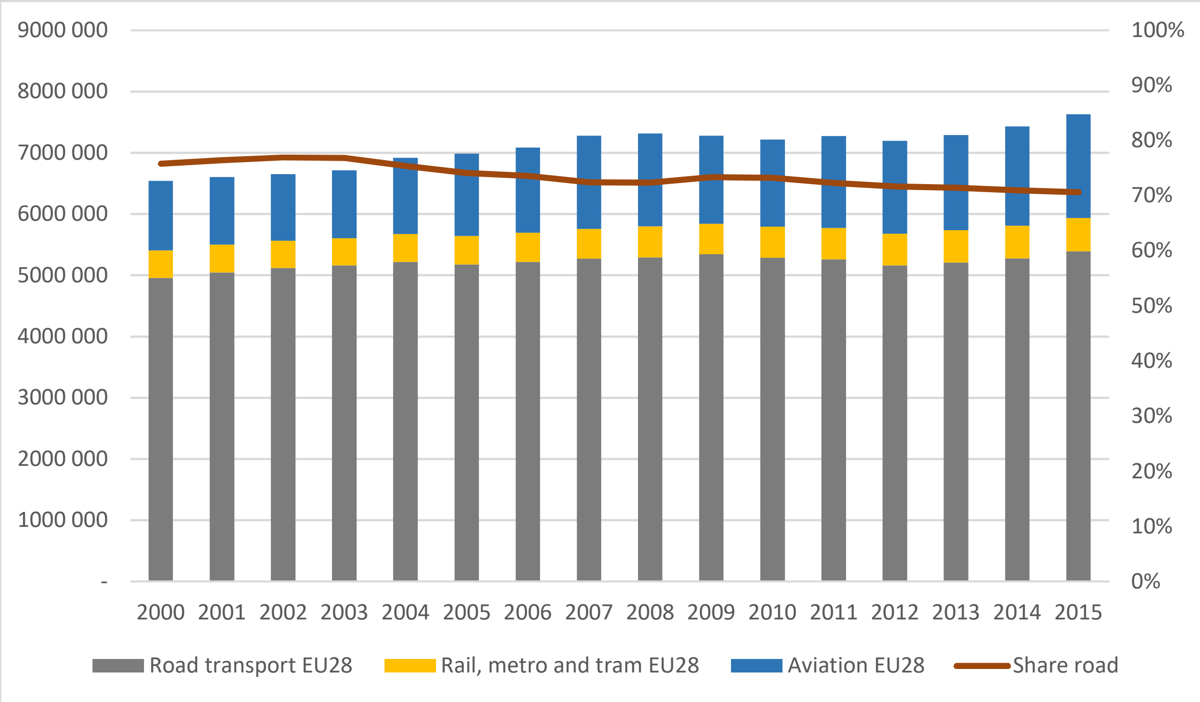
14. The decision tree for passenger transport will be the core of the model and very detailed. It is due to the fact that the road transport constitutes 86% of activity in passenger transport.
15. Data from IDEES is supplemented by data from other databases, such as TRACCS database (costs of transport) or POTEnCIA model to define the baseline. If we look at the data on the transport activity at the level of the European Union, we see dominant share of road transport (figure 5). Another but less important mean of transport is aviation. The less represented mean is a rail activity. The similar situation occurs in Poland (figure 4). But it is important to underline that the dominant share of road transport in Poland is bigger than the one in the EU28. In Poland share of road transport varies a little bit but seems stable around 85%. In the EU28 we observe little but constant decrease of share of road transport in the total transport activity. Amount of passenger activity in rail and aviation sectors are more less at the same level, which differs Poland to EU28.

Figure 4. Transport activity in Poland 2000-2015 (mln pkm) and share of road transport (in % - red line)



Source: CAKE/KOBiZE own study

Figure 5. Transport activity in the EU28 2000-2015 (mln pkm) and share of road transport (in % - red line)

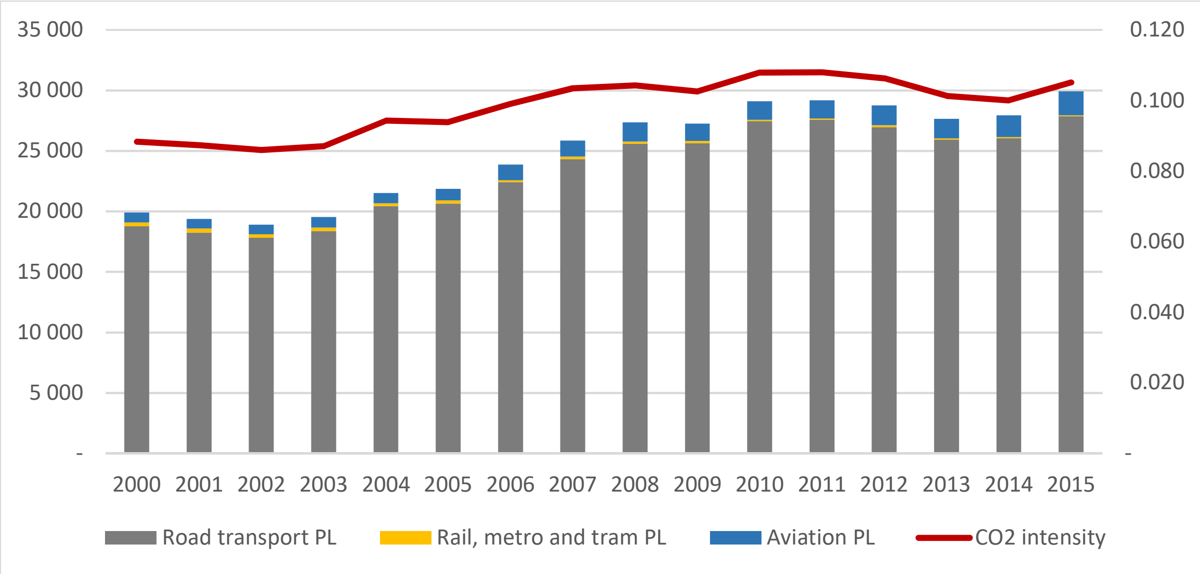


Source: CAKE/KOBiZE own study

Energy use and CO_2 emissions

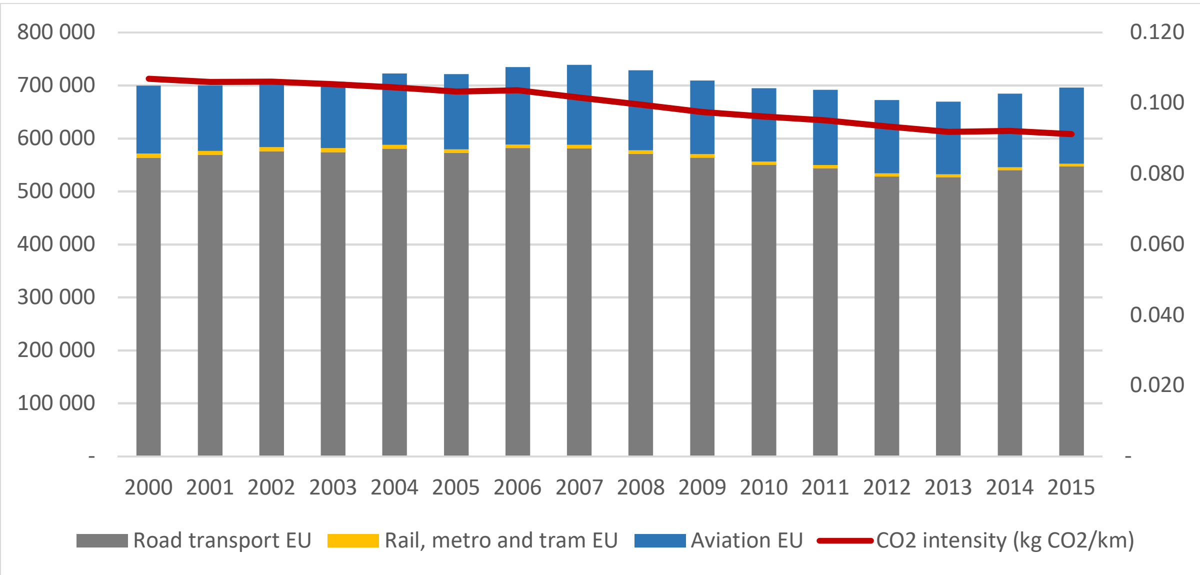
16. JRC-IDEES covers so far only CO_2 emissions. Although there is a need to include non-CO_2 emissions from external resources, which is going to be done by the JRC in the near future. CO_2 emissions data for Poland show an increase between 2000 and 2015. Main source of emissions is the road transport which is connected to the share of road activity. Emissions from the rail sector are negligible. We can observe a raising share of aviation emissions. Situation in the EU28 is slightly different. Dominant role plays road transport but the share is smaller than in Poland. This is due mainly of bigger share in aviation CO_2 emissions. Emissions in the rail sector in Poland seems negligible. Another interesting observation from JRC-IDEES it is a CO_2 emissions intensity. In Poland between 2000-2015 intensity seems stable around 0,1 kgCO_2/pkm. Contrary, in the EU28 CO_2 intensity between 2000-2015 drops from 0,105 to 0,090 kgCO_2/pkm.

Figure 6. CO_2 emissions in Poland from transport sector ($ktCO_2$) and CO_2 intensity (in $kgCO_2/pkm$ - red line)



Source: CAKE/KOBiZE own study

Figure 7. CO_2 emissions in the EU28 from transport sector ($ktCO_2$) and CO_2 intensity (in $kgCO_2/pkm$ - red line)

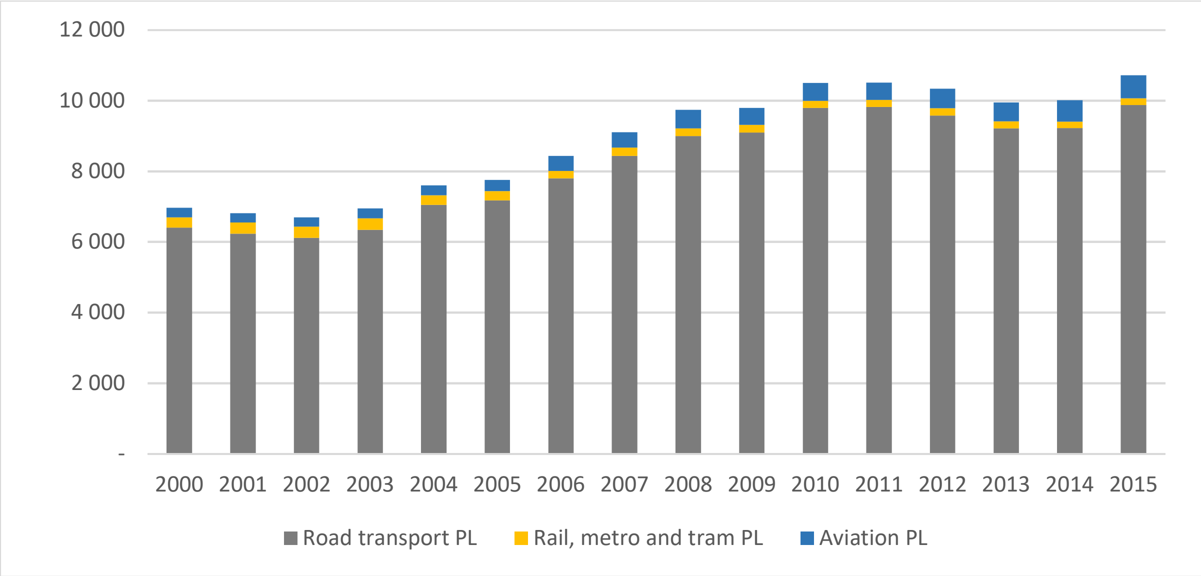


Source: CAKE/KOBiZE own study

17. Analysing data on energy consumptions correlation with CO_2 emissions could be seen. Between 2000 and 2015 there is a slight increase of energy consumption in Poland mainly due to the increase of road transport activity. The same indicator at the EU28 level seems to be rather stable or even decrease in previous years. At the EU28 level share of energy

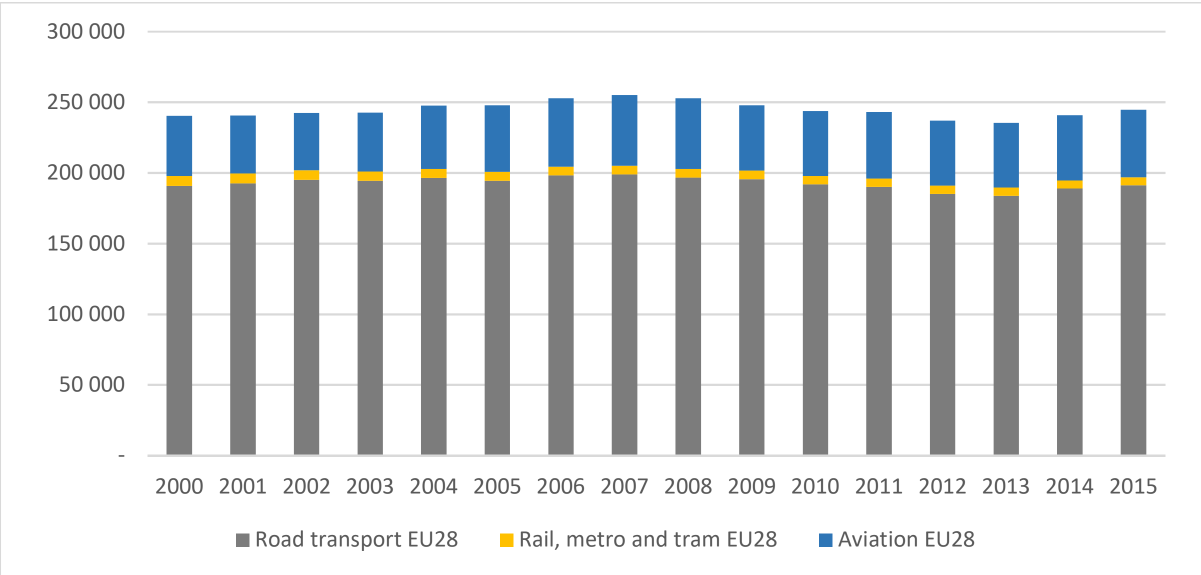
consumption by aviation sector in total energy consumption is more relevant that in Poland.

Figure 8. Energy consumption in Poland 2000-2015 (ktoe)



Source: CAKE/KOBiZE own study

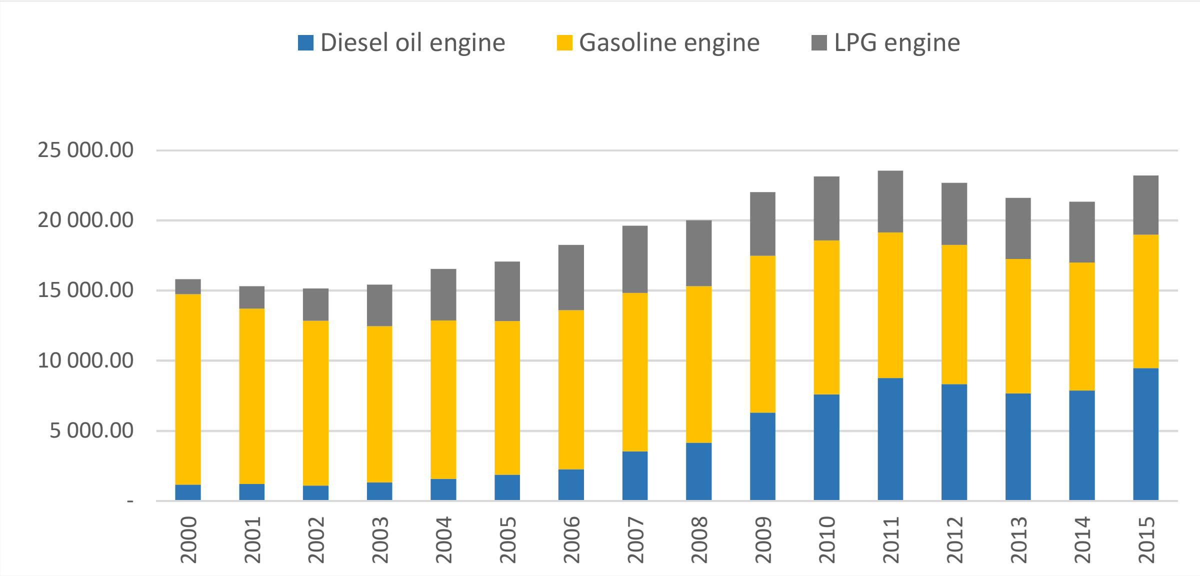
Figure 9. Energy consumption in EU28 2000-2015 (ktoe)



Source: CAKE/KOBiZE own study

18. Despite of growing activity of passenger transport, emissions stabilize at the same level from 2010. Growing share of diesel cars, which carbon intensity of energy is decreasing substantially, can be observed.
19. Data on the detailed fuel split between transport modes in passenger transport shows the constant increase of diesel and LPG cars share between 2000-2015. In the same time share of gasoline cars remains stable (or decrease slightly) – figure 10.

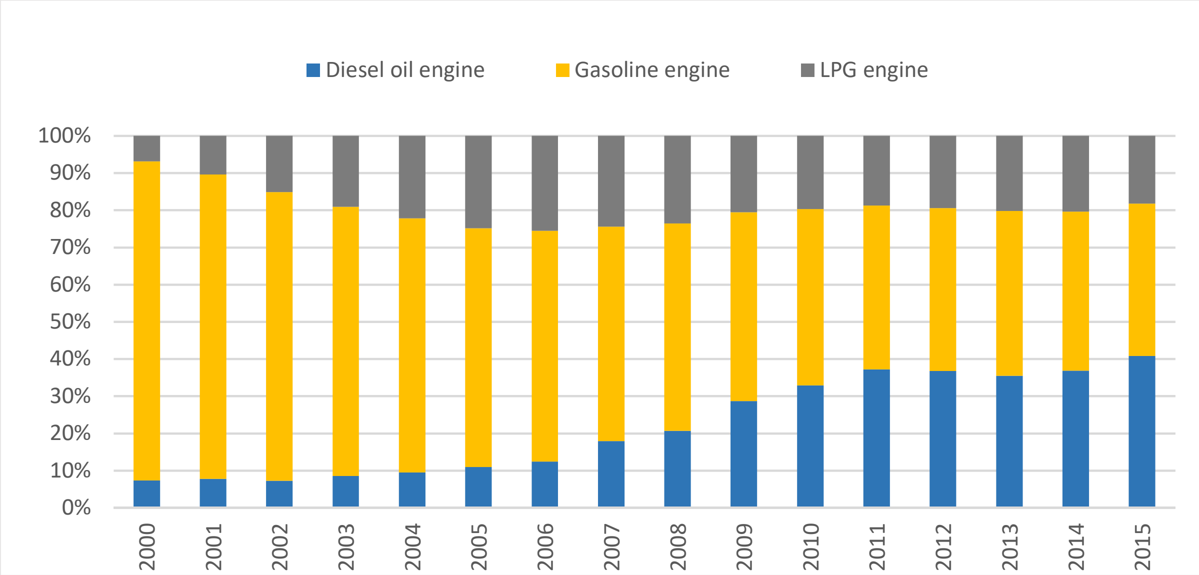
Figure 10. Split of CO_2 emissions in passenger transport in the EU28 (kt CO_2)



Source: CAKE/KOBiZE own study

20. If it comes to the CO_2 emissions from passenger cars, as it was shown already, emissions in passenger cars sector are constant, but there are quite significant changes in fuel types shares between 2000 and 2015 (figure 11). Change in diesel and LPG cars' shares have an impact on CO_2 emissions but not influenced the total CO_2 emissions as efficiency of diesel and gasoline cars is comparable.

Figure 11. Structure of CO_2 emissions in passenger transport in the EU28 (%)



Source: CAKE/KOBiZE own study

3.2.2 TRACCS database

21. TRACCS was a project funded by European Commission (DG CLIMA) and its aim was the collection of transport data to support the quantitative analysis of measures relating to transport and climate change. The main achievements of the project are the following:

- Collection of country-specific data (stock, activity, economic) for the various transport modes in each of the EU28 Member States, plus Iceland, Norway, Switzerland, Republic of North Macedonia and Turkey.
- Data collected on an annual basis for the period 2005-2010.
- Validation and interpretation of the data.
- Creation of a final processed detailed dataset that can be easily digested and incorporated by other models.
- Documentation of inconsistencies between data series and adjustment of data, where necessary, to ensure the delivery of a complete and consistent dataset.
- Development of indicators on the economic, environmental and usage aspects of transport.

22. The main TRACCS project deliverable is the coherent transport dataset for every Member State of the EU and some other countries. In TR³E model TRACCS database was used as a source of costs data in transport sector. We derived from this database specific information on the costs of new vehicles, costs of maintenance and fuel costs. We used 2010 data as the most recent one of that dataset.

3.2.3. PRIMES Reference Scenario 2020

23. Another important source of needed data is the 2020 reference scenario of the PRIMES model. The PRIMES Reference scenario is one of the European Commission's key tools in the areas of energy, transport and climate action. It allows policy-makers to analyse the long-term economic, energy, climate and transport outlook based on the current policy framework. We have derived from this data source the information on the activity growth in the transport sector up to 2050. Data on the activity is used in the baseline scenario as well as in the analytical scenarios. For Poland average GDP growth between 2015 and 2050 is set to 2.0% (y/y), while the average growth in activity is set to 1.5% y/y for passenger and 2.0% y/y for freight transport. For the EU average growth in activity between 2015 and 2050 has been set to 0.8% for passenger and 1.3% for freight respectively (y/y). Based on the above Primes data, the elasticities are calculated which are used to determine new activity levels using the GDP increases from the d-Place model.

3.2.4. Relationship between the TR3E model and the d-Place and MEESA models

24. Achieving climate neutrality will be associated with the costs of transformation. This translate to marginal abatement reduction cost (MAC) of CO_2. The cost of reduction is expressed as the non-ETS price in EUR/tCO_2. This price is provided from the d-PLACE model and then converted in the TR^{3}E model into the emission cost based on the emission intensity of a given vehicle technology according to the formula:

$$\mathbf{emiss\_cost = nets\_pem \cdot emiss\_int},$$

where:

- emiss_cost - emission cost per 1 km,
- emiss_pem - non-ETS price (marginal abatement cost) from the d-Place model, [in EUR/tCO_2],
- emiss_int - emission intensity of activity [in tCO_2/km].

Then, the emiss_cost parameter is added to the fuel price, which increases the operating costs of vehicles using fossil fuels. In the case of Poland, the costs in the non-ETS sector obtained in the NEU scenario reach the level of approx. 120 EUR/tCO_2 in 2030, while in 2050 they increase to approx. 1300 EUR/tCO_2 [51]. The applied marginal cost of reduction should not be directly equated with the price of emission allowances (EUAs) in the EU ETS. Since no market model for the EU ETS was used to determine the marginal reduction cost. Therefore, it did not take into account, inter alia, surplus of EUA/EUAA allowances on the market, the functioning of the MSR (Market Stability Reserve) reserve and the possibility of banking allowances between subsequent years and EU ETS settlement periods. The possibility of buying allowances by enterprises to meet future needs was not taken into account, as well as the role of financial institutions, whose activity on the EU ETS market is now starting to grow.

25. The last aspects that play a role are the prices of electricity, hydrogen and petroleum-derived fuels. Projections of these prices are generated in the MEESA energy model and fed to the TR³E model via the d-PLACE model. The electricity and hydrogen prices depends on energy generation mix structure, which is generating in MEESA model. Based on the data provided, the price growth paths for the years 2020–2050 were calculated [in the case of energy prices—separately for each EU country, while for petroleum-derived fuels - the average growth for the EU]. The TR³E model, on the other hand, provides the MEESA model with information about the transport demand for electricity, hydrogen and petroleum-derived fuels. The feedback between the TR³E and MEESA models to some extent reflects the possible directions of development both on the side of transport and the energy mix in the process of achieving the goal of climate neutrality.

4. Technical description of TR³E

26. TR³E model is a simulation model, what is its one of the main feature. TR³E is also the deterministic model, where its characteristics are assumed by the form of equations. The model simulates the changes in transport activity, vehicle choice as well as modal choice and respective CO_2 emissions in relation to given baseline scenario. Such exercises are performed both for passenger and freight scenario. So TR³E can be used for analysis of different transport policy developments scenarios. Model consist of two modules: demand module (where flows of transport activity are calculated) and supply module (where more detailed characteristics of vehicle categories and technologies are developed).

4.1. Model coverage

4.1.1 Geographical coverage

27. In TR³E model every European Union Member State has its own representation. Model is ready for expansion of its scope to neighbouring countries such as Turkey or Balkan countries subject to data availability as the model structure is very versatile. Table 1 lists all regions included in TR³E as well as the codes included in the model.

Table 1. Regions in TR³E model and respective codes

	Country	Code
1.	Republic of Austria	AUT
2.	Kingdom of Belgium	BEL
3.	Republic of Bulgaria	BGR
4.	Republic of Cyprus	CYP
5.	Czech Republic	CZE
6.	Federal Republic of Germany	DEU
7.	Kingdom of Denmark	DNK
8.	Kingdom of Spain	ESP
9.	Republic of Estonia	EST
10.	Republic of Finland	FIN
11.	French Republic	FRA
12.	The Kingdom of Great Britain	GBR
13.	Hellenic Republic	GRC
14.	Republic of Croatia	HRV
15.	Hungary	HUN
16.	Republic of Ireland	IRL
17.	Italian Republic	ITA
18.	Republic of Lithuania	LTU
19.	Grand Duchy of Luxembourg	LUX
20.	Republic of Latvia	LVA
21.	Republic of Malta	MLT
22.	Kingdom of Netherlands	NLD
23.	Republic of Poland	POL
24.	Portuguese Republic	PRT
25.	Romania	ROM
26.	Slovak Republic	SVK
27.	Republic of Slovenia	SVN
28.	Kingdom of Sweden	SWE

Source: CAKE/KOBiZE own study

4.1.2 Sectoral and modal coverage

Passenger module

28. TR³E model takes into the account the demand of households and private firms for passenger transport activity. We distinguish both work and non-work transport purposes. Moreover, we use geographic division to the area where the transport activity takes place.

Agent can maximise the utility on the urban and non-urban roads, depending on the type of activity.

Table 2. Overview of vehicles categories and vehicle types in TR^{3}E

Vehicle category	*Vehicle types*	*Details*
Road transport:		
• **car**	7 vehicle types	petrol, diesel, LPG, gas, hybrid, electric, hydrogen
• **motorbikes & mopeds**	1 vehicle type	petrol
• **bus**	6 vehicle type	petrol, diesel, LPG, gas, electric, hydrogen
• **LDV (freight)**	6 vehicle type	petrol, diesel, LPG, gas, electric, hydrogen
• **HDV (freight)**	6 vehicle type	domestic (diesel, electric, hydrogen) & international (diesel, electric, hydrogen)
Rail transport:		
• **tram/metro**	1 vehicle type	electric
• **train passenger**	2 vehicle type	diesel, electric
• **train freight**	2 vehicle type	diesel, electric
Air transport:		
• **plane passenger**	2 vessel types	intra EU, extra EU
• **plane freight**	2 vessel types	intra EU, extra EU
Water transport:		
• **freight ship**	1 vessel type	inland and coastal

Source: CAKE/KOBiZE own study

Freight module

29. In the freight module in TR^{3}E tool road, rail, aviation and water activity is modelled. The vehicle fleet module for road attribute total tonne-kilometres to two road freight vehicle
types:

- LDV: light duty vehicles (<3.5 ton)
- HDV: heavy duty vehicles (>3.5 ton)

In the other areas of transportation we assume one vehicle per category, respectively: train, plane and ship (vessel).

Table 3. Overview of vehicles categories and vehicle types in TR³E – freight transport

Vehicle category	Vehicle types	Details
Road transport:		
• **LDV**	6 vehicle type	petrol, diesel, LPG, CNG, electric, hydrogen
• **HDV**	6 vehicle type	domestic (diesel, electric, hydrogen) & international (diesel, electric, hydrogen)
Rail transport:		diesel, electric
Air transport:		
• **plane**	2 vehicle types	intra EU, extra EU
Water transport		
• **ship**	1 vessel type	inland and coastal

Source: CAKE/KOBiZE own study

30. These vehicles has its own internal structure – light duty vehicles are divided into six types – petrol, diesel, LPG, CNG, electric and hydrogen. For heavy duty vehicles, three technologies were distinguished – diesel, electric and hydrogen (separately for domestic and international transport). Currently (2015 – 2020) only diesel HDV are in operation and there is no other type of vehicle in use but due to the reduction goals of the EU, the use and development of zero-emission technologies was assumed. In contrary, the types of air and water transport are not distinguished due to the lack of data and technologies. Therefore, the new technologies in the these transport sectors are modelled implicitly as the fall in emission intensity of air and water transport per tonne-kilometre. Rail transport is divided into two technologies – diesel and electric, but as they constitute only a small chunk of EU emissions, we decided not to model fleet here.

4.2. Model structure – algebra

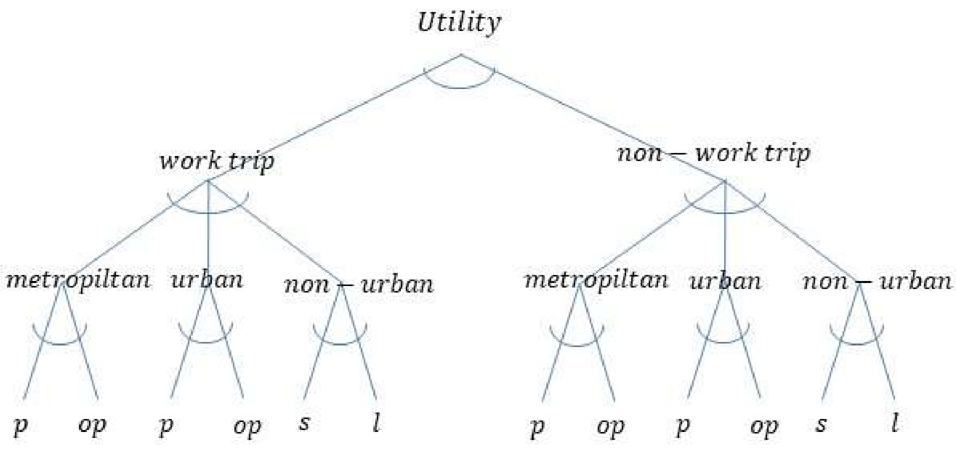
31. TR³E transport model consists of two basic parts – demand side and supply (cost) side. The transport activities, expressed in passenger kilometres (pkm) are traded on competitive markets. The cost is determined by the costs of fuel, maintenance and the costs of new vehicles, which must be bought to replace the scrapped vehicles. The sections below present the demand and supply side of the simplest transport model. The total demand for transport activity ultimately will be taken from the d-PLACE model and put into the TR³E. In contrary TR³E model will allow for providing emissions in the transport sector as well as the demand for electricity that can be fed in the energy sector model.

4.2.1 Demand side

32. Demand part of model consist of flows of transport activity and the modal choice of transport clients as a decision making process. These flows are represented by the levels of demand for the transport activity. In other words, demand module shows the relation between user choices on different transport types under the constraints derived from the implementation of given policies in that area. The main assumption is that the users of transport are selecting the volume of transport and preferred mode based on the price for each mode. In other words, the consumer maximize his utility under the given budget constraint. The result of consumer choice is the demand for various types of transport modes. This price is a sum of given costs which are set in the model. The demand module produce projections of passenger kilometres (pkm) and tonne kilometres (tkm) that are demanded to fulfil needs of a given policy.

33. In TR³E the nested CES utility function represents this decision making process, and captures the preferences of households and firms. In TR³E the choice of transport type is modelled in a nested way. The choices made by households and private entities are based on the prices of the transport types. The outcome of the demand module is the detailed numbers of passenger km (pkm) and tonne km (tkm). On the other side the vehicle km numbers are a derived, assuming steady occupancy rates and load factors. We do not use separate nested functions for households and for private firms (see figure 12), but rather for passenger and freight transport.

Figure 12. Passenger primary decision tree

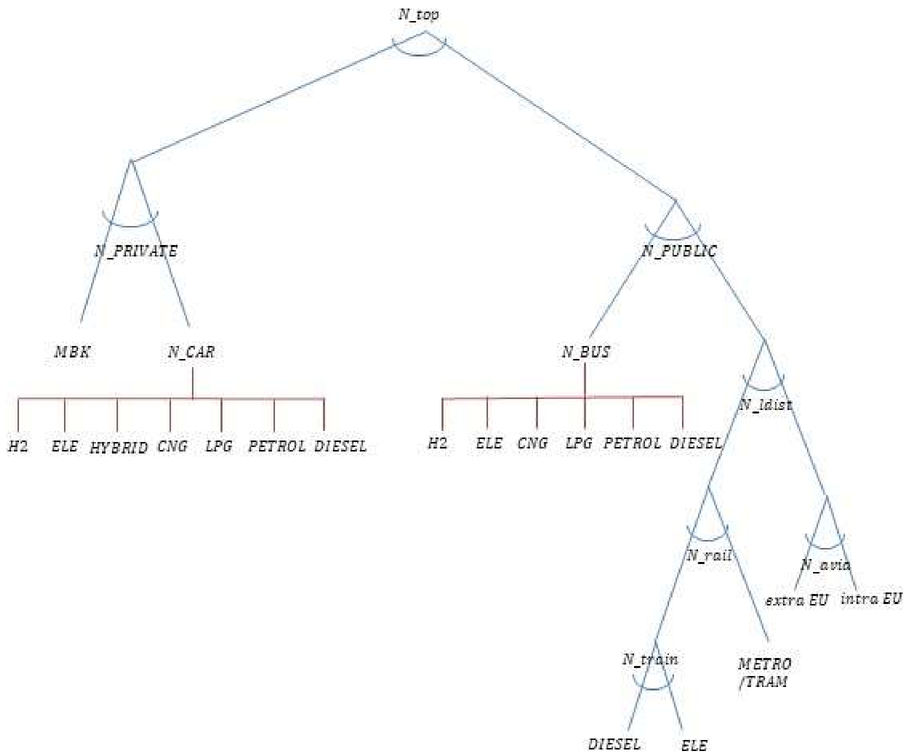


Source: CAKE/KOBiZE own study

34. Type of choice is modelled through nested constant elasticity of substitution (CES) function. Constant elasticities of substitution captures the constant percentage change in

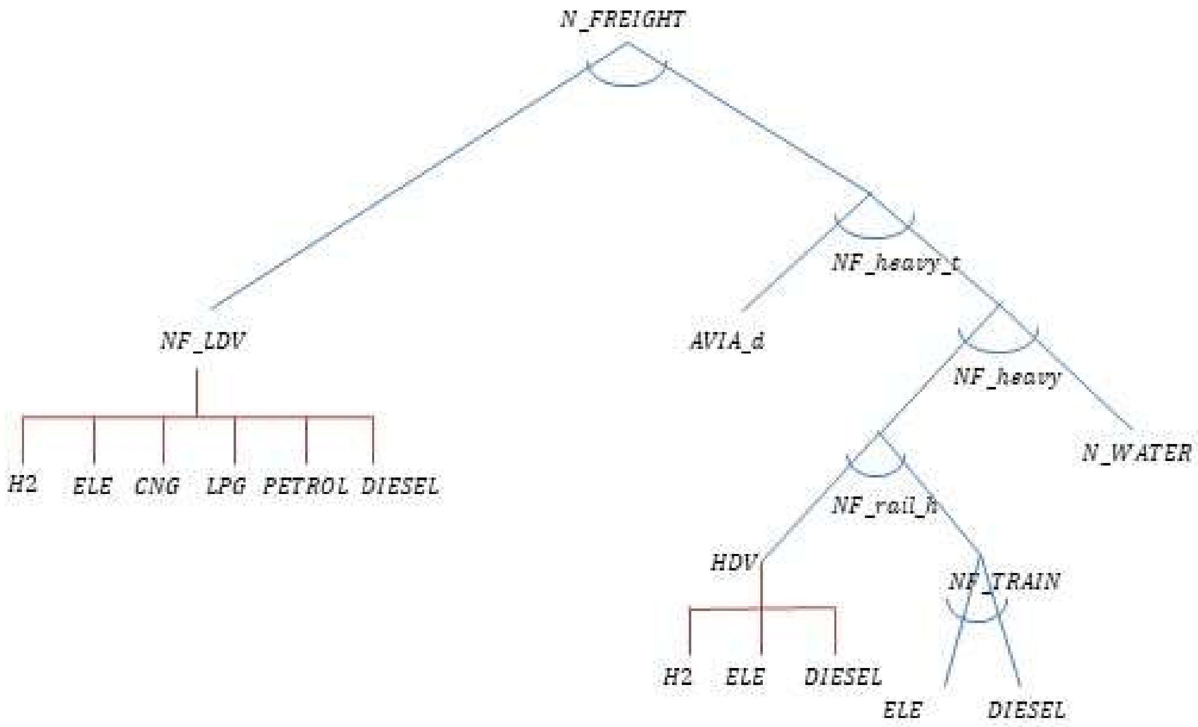
the ratio of two inputs (e.g. labour, capital) used in response to a percentage change in their prices. The decision tree for private transport (cars) is as it is shown on the figure 13.

Figure 13. Passenger secondary decision tree



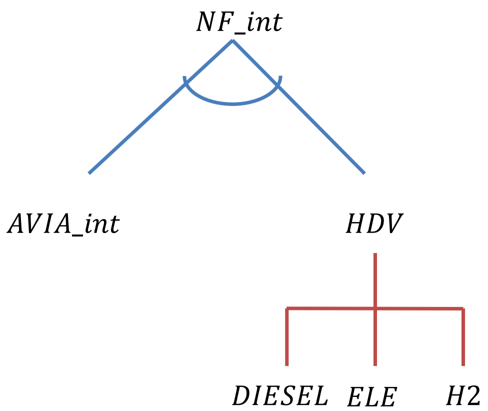
Source: CAKE/KOBiZE own study

Figure 14. Freight decision tree on domestic and intra EU transport activity



Source: CAKE/KOBiZE own study

Figure 15. Freight decision tree on international freight transport activity



Source: CAKE/KOBiZE own study

35. Therefore, the demand function for given vehicle type i (car, motorbike, rail, bus) is equal to (according to Rutherford[3]):

$$Y_{m,i,t} = \bar{Y}_{m,i,t} \cdot \frac{Y_{m,t}}{\bar{Y}_{m.t}} \cdot \left(\frac{P_{m,i,t}}{P_{m,t}}\right)^{-\sigma}$$

Where:

$Y_{m,t}$ is the demand for the aggregate mix in mode m,

$P_{m,t}$ denotes price for the aggregate mix in mode m,

$Y_{m,i,t}$ is the demand for technology i in mode m,

$P_{m,i,t}$ denotes price for technology i in mode m,

$\bar{Y}_{m,i,t}$ and $\bar{Y}_{m.t}$ – corresponding benchmark values,

σ - denotes elasticity of substitution between the vehicle technologies.

36. Unit costs function – they provide information about prices used in demand functions at each level in CES tree. We know prices (exogenously given) of the detailed alternatives at the bottom of nested CES tree and derive the prices of the upper alternatives using the CES composite prices formulas:

$$P_{m,t} = \bar{P}_{m,t}\left(\sum_{i} \theta_{m,i,t} \left(\frac{P_{m,i,t}}{\bar{P}_{m.i,t}}\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$$

$\theta_{m,i,t}$ – denotes share of the technology i and mode m in the aggregate mix, reflecting the "maturity" of given technology and consumer preferences.

4.2.2 Supply module

37. The supply module allows to see to split of vehicle categories into the detailed types and technologies. Supply module is based on the changes in the vehicle fleet. On the basis of historical vehicle fleet and its evolution (via scrappage rate) and on the future growth of transport volumes (from the demand module), it is possible to determine the future vehicle stock. Total stock of vehicles is characterised by the vehicle lifetime, costs, fuel type and mileage. Table 2 summarises the vehicles categories and types which are represented in TR³E model, both for passenger and freight means of transport.

[3] T. F. Rutherford, Lecture Notes on Constant Elasticity Functions, 2002

38. The substitution possibilities between corresponding means of transport are defined by CES functions (see Rutherford[4]). This logic is used at each level of the transport decision tree. At the bottom level, we have the cost of passenger-km travelled by each type of the car, therefore, for each technology, we have the following equation:

$$P_{m,i,t} = (CPM_{m,i,t}/\overline{cpm}_{i,t})/(OC_{m,i,t}/\overline{oc}_{i,t})$$

Where: $CPM_{m,i,t}$ is the cost of kilometre travelled by vehicle in given technology in mode m, $OC_{m,i,t}$ is the average occupancy rate and $\overline{cpm}_{i,t}$ and $\overline{oc}_{i,t}$ are benchmark levels consecutively. As can be seen from the equation above, prices are normalized to 1, to simplify the notation.

39. In the current version of the model, there are three components of the cost per mile – cost of fuel (constant), cost of maintenance per each vehicle and costs of new cars[5]. Therefore:

$$CPM_{m,i,t} = P\_FUEL_{m,i,t} + P\_MAINT_{i,t} \cdot \frac{VEH_{i,t}}{TOT_{DEM\,i,t}} + P\_NV_{i,t} \cdot \frac{N\_VEH_{i,t}}{TOT\_DEM_{i,t}}$$

In this case:

$P\_FUEL_{m,i,t}$ is the price of fuel for technology i and mode m,

$P\_MAINT_{i,t}$ is the annual cost of maintenance of vehicle in technology i, and

$P\_NV_{i,t}$ is the price of new vehicle.

$TOT\_DEM_{i,t}$ is the total demand for kilometres travelled (by car) in given technology. It is defined by the following equation:

$$TOT\_DEM_{i,t} = \sum_{m} Y_{m,i,t} / OC_{m,i,t}$$

40. Therefore, it defined as sum of demand for given technology over all modes divided by average occupancy rate ($OC_{m,i,t}$). $VEH_{i,t}$ is the number of vehicles in technology i. The demand for vehicles is just the total demand for mileage travelled in given mode divided by the average mileage of the vehicle. It is therefore set as:

$$VEH_t = \frac{TOT\_DEM_t}{AVG\_MILEAGE_t}$$

[4] T. F. Rutherford , Lecture Notes on Constant Elasticity Functions, 2002

[5] G. Barnes, P. Langworthy, Per Mile Costs of Operating Automobiles and Trucks, Journal of the Transportation Research, January 2004

On the other hand, the supply of the vehicles is equal to the sum of non-scrapped vehicles from the previous period and new vehicles:

$$VEH_{i,t} = (1 - sc_{i,t})VEH_{i,t-1} + N\_VEH_{i,t}$$

41. The choice of technology within given type, when fleet (passenger cars, motorbikes, buses, trains, LDVs, HDVs and freight trains) is not modelled through the CES function. Instead, we assume, that these vehicles are perfect substitutes, when they are used, but when new vehicle is bought, the decision on the type of vehicle is based on the standard multinomial discrete choice model (e.g. Ben-Akiva and Lerman, 1985), so the share of given type in the sales of new vehicles is calculated as:

$$SHNV_{i,t} = \frac{\exp\left(\theta_{i,t}\left(\frac{CPM_{i,t}}{\overline{\overline{cpm}}_{i,t}}\right)^{-\sigma}\right)}{\sum_{j\in J}\exp\left(\theta_{j,t}\left(\frac{CPM_{j,t}}{\overline{\overline{cpm}}_{j,t}}\right)^{-\sigma}\right)}$$

It is worth to mention, that discrete choice and nested CES are quite similar and using them together in one model does not result in inconsistencies. In the current version of the model, occupancy rates, average mileage and prices of fuel, maintenance and new vehicles are given exogenously:

$$OC_{m,i,t} = \overline{oc}_{i,t}$$

$$AVG\_MILEAGE_{i,t} = \overline{avg\_mileage}_{i,t}$$

$$P\_F_{m,i,t} = \overline{p\_f}_{m,i,t}$$

$$P\_MAINT_{i,t} = \overline{p\_maint}_{i,t}$$

$$P\_NVEH_{i,t} = \overline{p\_nveh}_{i,t}$$

In TR³E model the fleet of the vehicles was modelled using survival rate based on probability density. For this purpose, cumulative distribution function (CDF) of the Gompertz distribution was used:

$$F(x;\eta,b) = 1 - exp(-\eta(e^{bx} - 1))$$

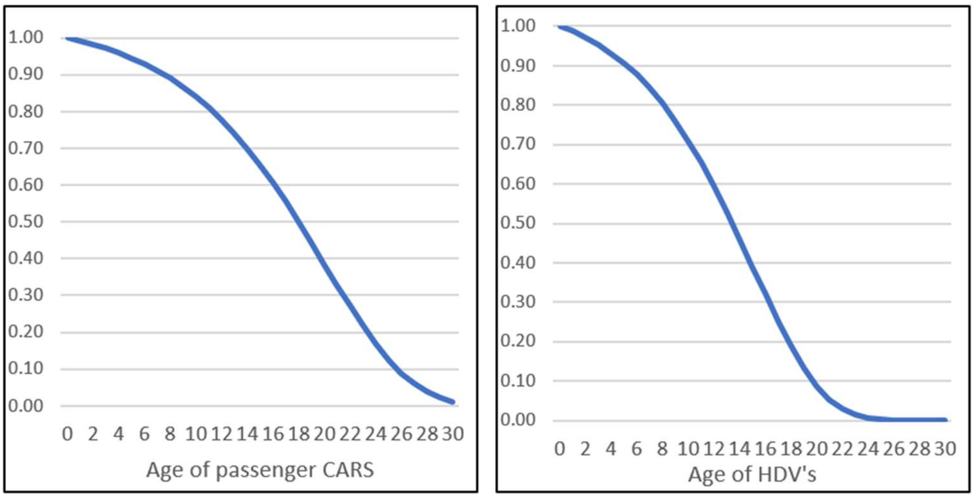
This function is a type of mathematical model—generalised logistic function. The Gompertz survival function corresponds to exponential mortality rate increases with time. The parameters in this distribution are:

b—denotes the scale parameter;

η—indicates the shape parameter (corresponding to scrappage rate).

All the parameters of the CDF (Gompertz's) function were selected such that they properly reflect the vehicle structure by age of fleet[6,7]. For passenger cars, age of fleet was designed up to 30 years and for freight vehicle to 25 years old. The survival rates that were used in the fleet module of TR^{3}E model are presented on Figure 16. The average age of the vehicles was calculated using IDEES dataset and corresponds to the average age of the vehicle from the theoretical distribution. In the fleet module, new cars replace the scrapped ones and come into use to meet the demand for additional transport services (activities).

Figure 16. Survival rates for passenger and freight transport (depending on the age of vehicles).



Source: own calculations based on TR3E model results.

4.2.3 CO_2 emissions module

42. Data on CO_2 emissions was taken from the JRC-IDEES database. JRC-IDEES contains CO_2 emissions data for all vehicles categories, including different fuel types (i.e. petrol, diesel, CNG, LPG, hybrids, plug-in hybrids). As well the emission coefficients in kt CO_2/ktoe can be find in this database. Apart from the emissions factors, JRC-IDEES shows data on the emission intensity in g of CO_2/km per every vehicle category, both in passenger and freight transport. In TR^{3}E model, emissions intensity is calculated endogenously according to changes in fleet (depending to deployment of electric and hydrogen vehicles) within the years and vehicle category. CO_2 emissions are then calculated as the activity level of given

[6] El-Gohary A., Alshamrani A., Al-Otaibi A. N., The generalized Gompertz distribution, Applied Mathematical Modelling, Volume 37, Issues 1–2, 2013, Pages 13-24

[7] Wilson, D. L. (1994). The analysis of survival (mortality) data: fitting Gompertz, Weibull, and logistic functions. Mechanisms of ageing and development, 74(1-2), 15-33.

transport mode time its emission coefficient. In each year the average emissions intensity is recursively calculated on the basis of the emission factors of previous years and the new emission factors. Thus the average emission is a weighted average calculated from the formula:

$$\left|\binom{current}{fleet}\cdot\begin{bmatrix}average\\emissions\end{bmatrix}+\binom{new}{fleet}\cdot\begin{bmatrix}emissions\\new\ fleet\end{bmatrix}\right|:\begin{bmatrix}number\\of\\vehicles\end{bmatrix}$$

4.2.4 Costs module

43. In TR³E model the choice between the transport modes is derived on the basis of demand functions that take into the account the specific prices for users and the differences between those prices. In the transport demand module, concept of cost per mile was used. There are three components of the cost per mile:

- cost of fuel (constant),
- cost of maintenance per each vehicle,
- cost of new vehicle.

Formula shows this disaggregation of cost per mile:

$$CPM_{m,i,t} = P\_FUEL_{m,i,t} + P\_MAINT_{i,t}\cdot\frac{VEH_{i,t}}{TOT_{DEM\,i,t}} + P_{NV\,i,t}\cdot\frac{N\_VEH_{i,t}}{TOT\_DEM_{i,t}}$$

44. We can easily disaggregate cost per mile according to policy scenario (i.e. reduced cost of purchase a new vehicle due to government subsidies). The cost per mile could depend on the given transport policy.

4.3. Model solving

4.3.1. Elasticity parameters

45. In TR³E model we use CES functions. It requires the input values of substitution elasticities. These substitution elasticities are assumed to be equal for all countries and all years (we have no specific knowledge about elasticities across countries and in first step of building scenarios ease of substitution is on the same level). In most cases, we assume nested constant elasticity of substitution (CES) function as their „production" technologies, meaning that we allow substitution between means of transport. In other cases means of transport are perfectly substitutable (see nests N_BUS, N_CAR, NF_LDV on Fig. 13 and Fig. 14).

46. Some of parameters of substitution between technologies were estimated based on demand functions (ex. between petrol and diesel fuels). For this purpose, the following estimated model was used:

$$\ln\left(\frac{X_{fuel\ 1}}{X_{fuel\ 2}}\right) = \beta + \sigma \cdot \ln\left(\frac{P_{fuel\ 2}}{P_{fuel\ 1}}\right) + e$$

47. This model is based on Okagawa, Ban approach, which assumes that the agent is behaving in a way to minimize the costs[8]. In TR[3]E model the role of producers is fulfilled by a supply module. Consumers decisions are being taken in the demand module. Okagawa, Ban argue that "consumers have utility functions and they purchase goods and services to maximize their welfare. Producers have production functions and produce goods and services using labor and capital to minimize their production costs. In most cases, we assume nested constant elasticity of substitution (CES) functions as their production technologies, meaning that we allow substitution between production factors and intermediate inputs".

48. Values of elasticities of substitution for passenger transport are presented in the table 4.

Table 4. Substitution elasticities for passenger transport in TR[3]E model

	Nest	*Elasticity value*
1.	N_top	0.6
2.	N_private	0.6
3.	N_public	0.7
4.	N_Ldist	4.2
5.	N_avia	0.6
6.	N_avia_d	0.75
7.	N_rail	2.5
8.	N_train	3.0

Source: CAKE/KOBiZE own study

[8] A. Okagawa, K. Ban: Estimation of substitution elasticities for CGE models, Discussion Paper 08-16, Osaka University, April 2008

49. Values of elasticities of substitution for freight transport (domestic and international) are shown in the table 5.

Table 5. Substitution elasticities for freight transport in TR³E model

	Nest	*Elasticity value*
1.	NF_domest	0.5
2.	NF_heavy_t	2.0
3.	NF_heavy	2.25
4.	NF_rail_h	2.5
5.	NF_train	5.0
6.	NF_int	1.5

Source: CAKE/KOBiZE own study

4.3.2. Solving the model (analytical scenarios).

50. In reality, costs of purchase of cars (technology prices) will change over time. To construct first trial analytical scenarios, solving process reflects shocks concerning changes in vehicle prices up to 2050 and changes of costs per mile for aviation and rail.

51. For passenger transport we set between 1% and 1.5% price fall year to year for new electric and hybrid cars (to get the price of electric and hybrid cars at the level of ICE in 2050). Prices of light duty vehicles for technologies based on fossil fuels consumption are 0.5% higher year to year than in the baseline assumptions. It reflects additional fees for LDVs based on fossil fuels (LDVs are mainly used by firms and companies which generate the profits so in the future environmental fees could be introduced – similar to companies covered by EU ETS). In case of electric light duty vehicle we assumed 0.5% new vehicle prices fall. Prices of electric buses are supposed to decrease by 2% year by year. These assumptions are valid both for the EU and for Poland. Decrease in electric vehicle prices caused shift in activity. Scenarios results show more than a triple higher growth of electric cars number in the EU comparing to the baseline.

52. Second area of changes in analytical scenario (concerning technological progress) comparing to the baseline scenario is the aviation sector. As aviation represents important CO_2 emissions rise due to activity growth, we have assumed 1% yearly growth of costs per mile in that sector, what will have an impact on consumer decision. In a given period of time 2015-2050, it will cause over 40% price rise for customers, and it will have an important impact on the activity. On the other hand, the promotion of rail transport is assumed as well as the gradual decline of cost per mile in case of railway transport (0.25% y/y for trains). One of the main conclusions is that the increase of prices in aviation sector will decrease the demand and the activity in aviation will fall in 2050 by more than a half in comparison to the baseline. The level of activity within whole transport sector will be maintained. This important change will be done mostly by consumers switching from planes to trains mainly and to cars and buses in the second order.

5. Baseline scenario

53. A baseline scenario is the most likely scenario for the future developments in the transport sector, taking into the account policies and measures being adopted up to 2015. Baseline scenario is used as a reference for comparison against an alternative scenario, e.g. a fleet electrification scenario. The development of the TR³E baseline involved the construction of a coherent reference case for transport demand, vehicle stocks and emissions levels. This reference has been developed for all regions modelled. It covers years from the base year 2015 until 2050. The baseline volumes for activity levels have been taken mainly from the PRIMES central scenario results[9].

5.1. General assumptions on the development of the transport sector - Overall changes in activity

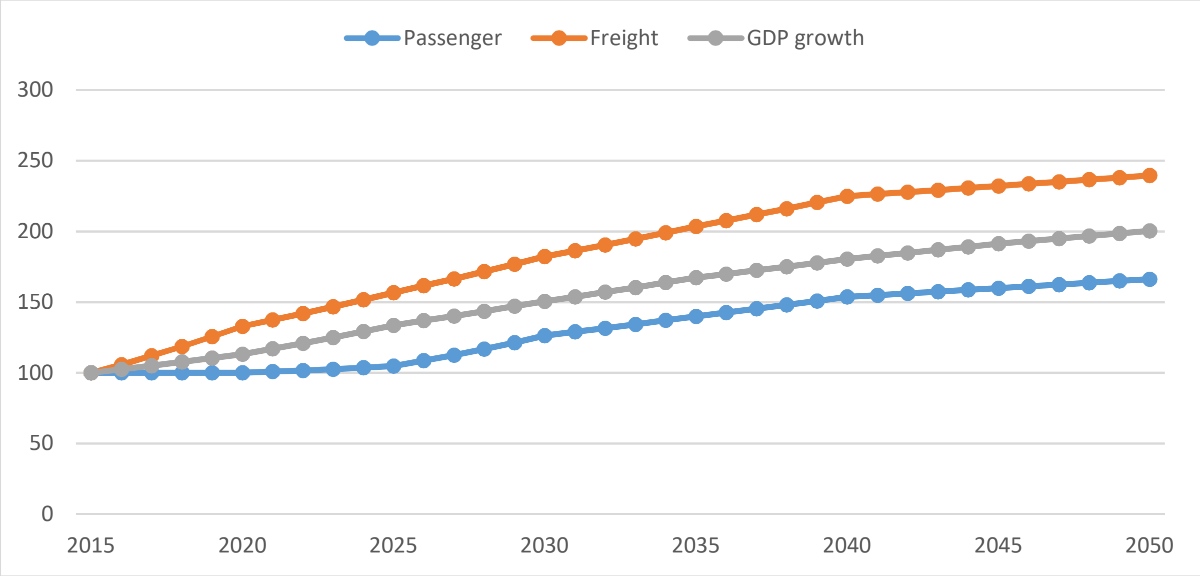
54. In TR³E model the baseline scenario is prepared to better understand the impact of the implementation of current policies and measures on the sector activity as well as on the CO_2 emissions levels. As it was previously mentioned baseline scenario serves as a reference point to which comparison of analytical (policy) scenarios is made.

55. In the baseline scenario, we set different assumptions on the development of the economy and specific indicators as CO_2 emissions intensity, the prices of different types of vehicles and costs of fuels. We adopt the same activity growth projections both for baseline scenario and for analytical (policy) scenarios. Activity growth assumed in the model is consistent with the Reference scenario of PRIMES model[10]. Therefore, in the case of Poland average GDP growth between the years 2015 and 2050 is set to 2.0% (y/y), while the average growth in activity is set to 1.5% y/y for passenger and 2.0% y/y for freight transport. For the EU average growth in activity between the years 2015 and 2050 has been set to 0.8% for passenger and 1.3% for freight respectively (y/y). Emission intensities in the baseline scenario are set at the same level as in the PRIMES Reference scenario 2020.

[9] https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

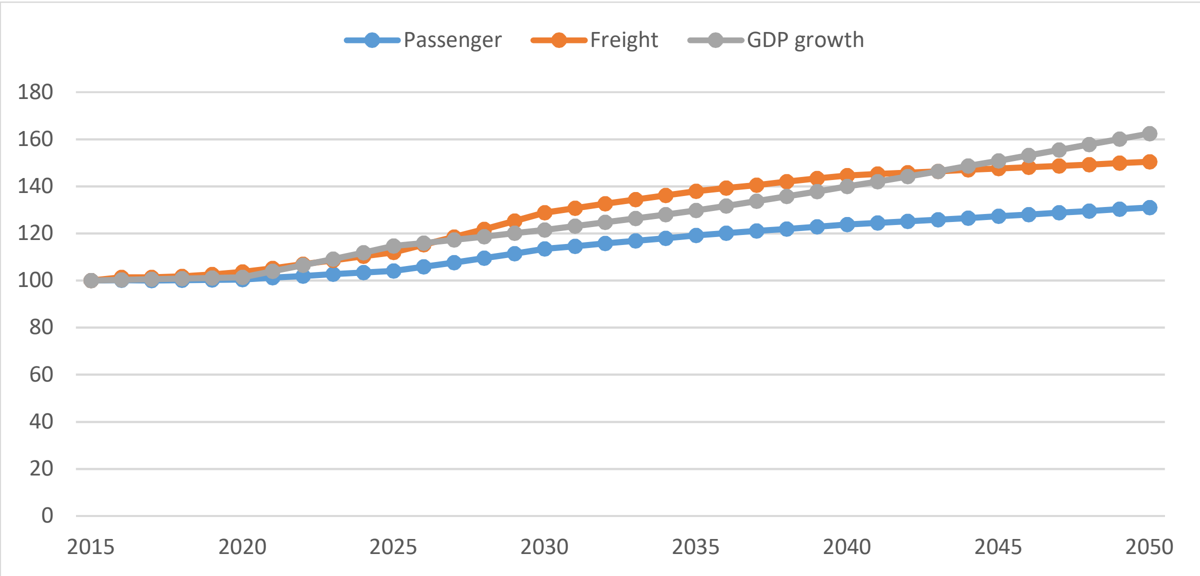
[10] Idem

Figure 17. Growth in passenger and freight activity in Poland (%)



Source: TR³E model

Figure 18. Growth in passenger and freight activity in EU (%)



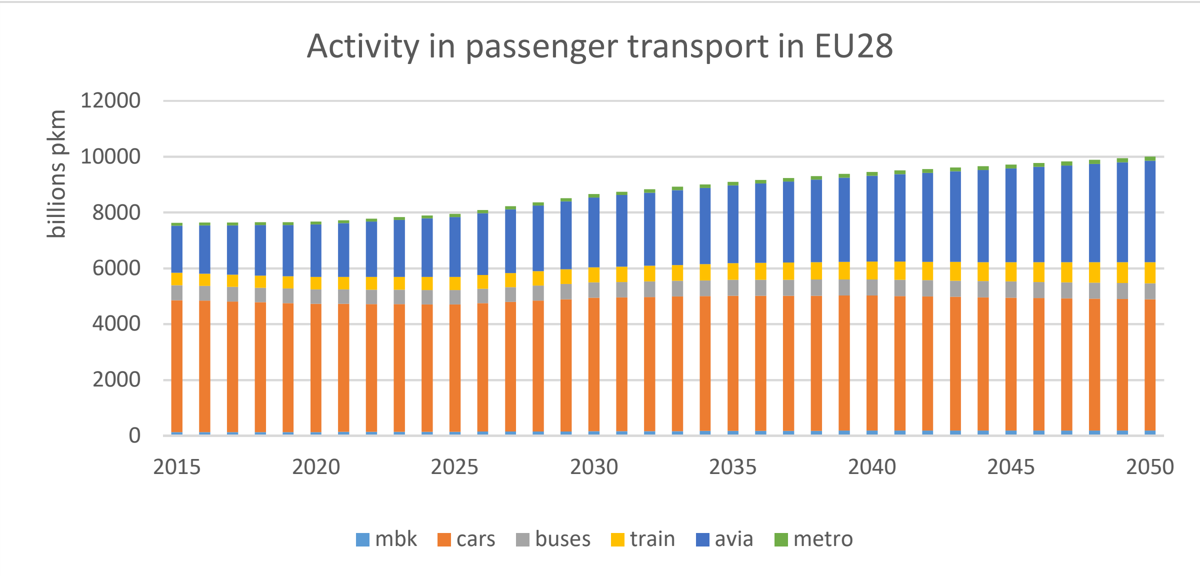
Source: TR³E model

5.2. Assumptions on the development of activity

56. Private cars represent more than a half of total passenger transport activity in the EU (however, this share will fall from 62% in 2015 to 47% in 2050). Second largest mode of passenger transport is aviation with a growth in share from 22% in 2015 to 36% in 2050. Such change is fuelled by the GDP and welfare growth – wealthier passenger choose to

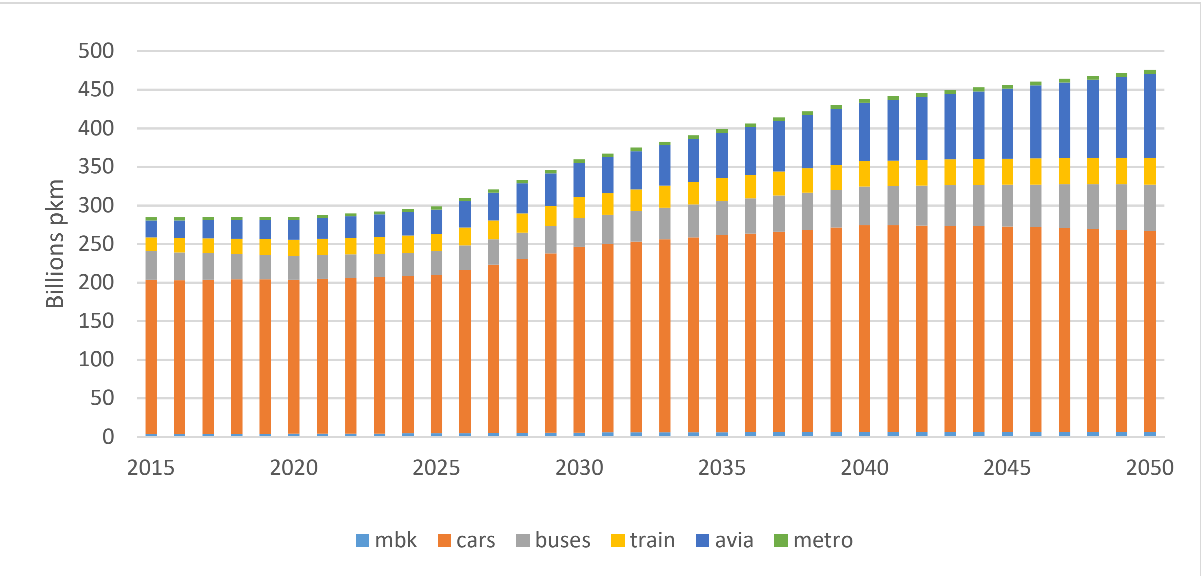
commute using more convenient and faster air transport over other modes. In case of Poland, share of private cars activity in passenger transport is higher than in the EU, but it falls from 70% (in 2015) to 55% (in 2050). The growth in the share of aviation in passenger transport in Poland will be substantial – from 8% in 2015 to 23% for 2050. Such change is motivated by the convergence of the Polish transport patterns to that observed in other EU Member States as well as by the economic development and increase in wealth.

Figure 19. Passenger transport activity in EU (billions pkm)



Source: TR³E model

Figure 20. Passenger transport activity in Poland (billions pkm)

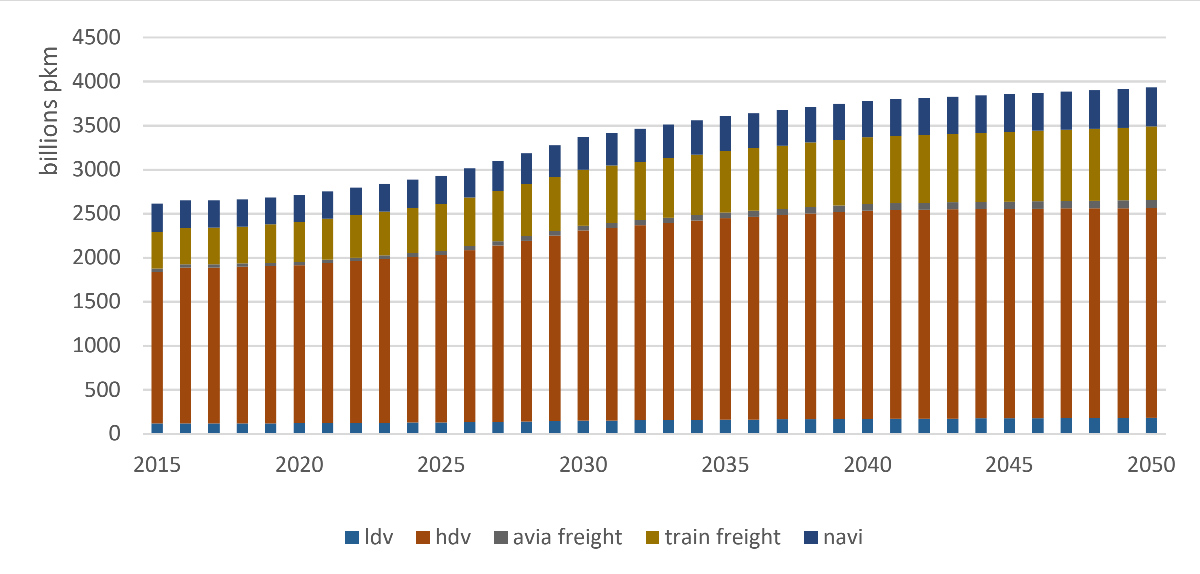


Source: TR³E model

57. Aviation is the most growing part of transport sector in Poland and projected activity in 2050 is five times higher than in 2015. In the EU, the growth is slightly slower and activity in 2050 is almost two times higher than in 2015. In case of buses the EU activity in 2050 will grow about 10%, while in Poland, we expect 60% growth between 2015 and 2050. In the baseline scenario, we expect 10-20% growth (depending on the country) in the number of passenger-kilometers travelled by cars between 2015 and 2050.

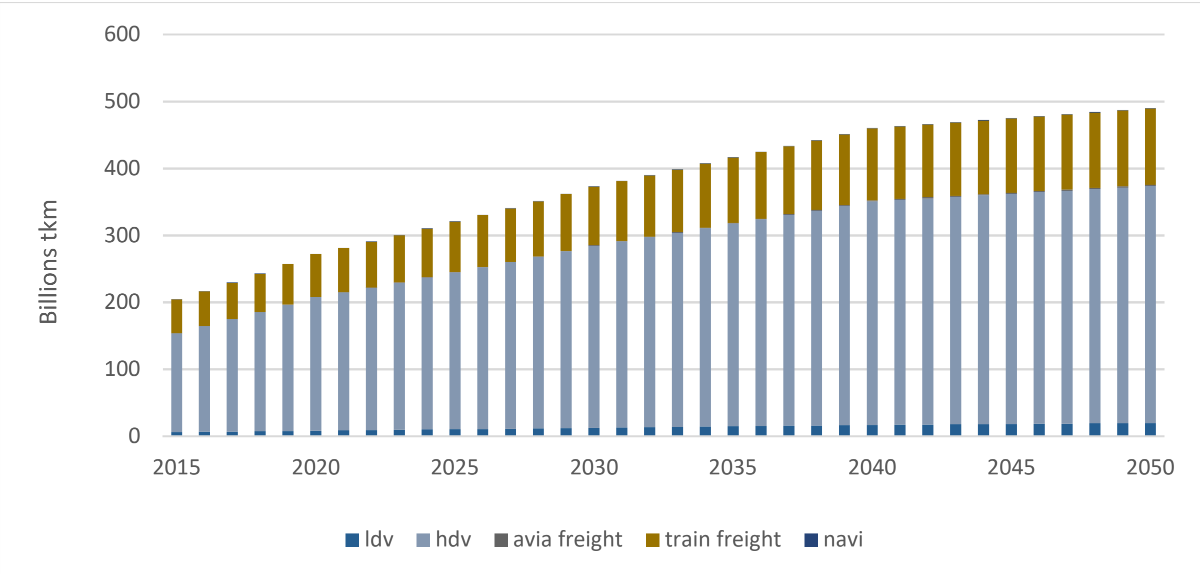
58. It is worth to mention that freight transport relies mainly on heavy duty vehicles. Share of that activity in total freight transport remains constant between 2015 and 2050 - 62% in the EU and 72% in Poland.

Figure 21. Freight transport activity in EU (billions tkm)



Source: TR³E model

Figure 22. Freight transport activity in Poland (billions tkm)



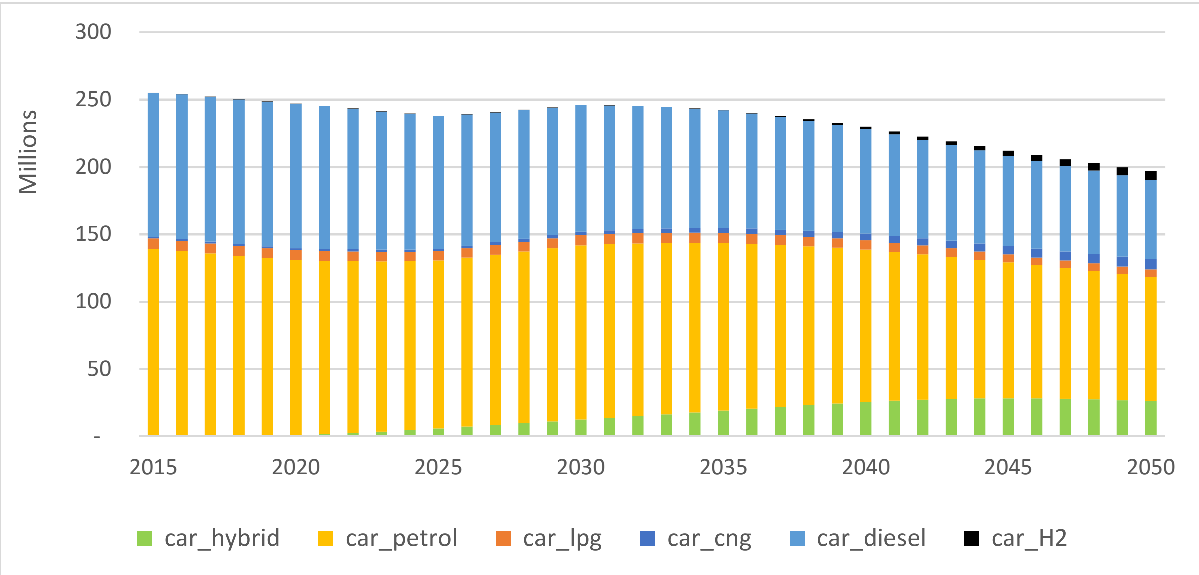
Source: TR³E model

5.3. Assumptions on the development of fleet structure

59. Fleet of private cars in the EU-28 in 2015 is consisted mostly of petrol (55%) and diesel cars (42%). After 2020 growth in electric cars activity is assumed exogenously. In the baseline scenario, in 2050 the share of EVs in total passenger cars fleet will constitute 26% of total, while share of petrol and diesel cars will decrease to 35% and 23% respectively.

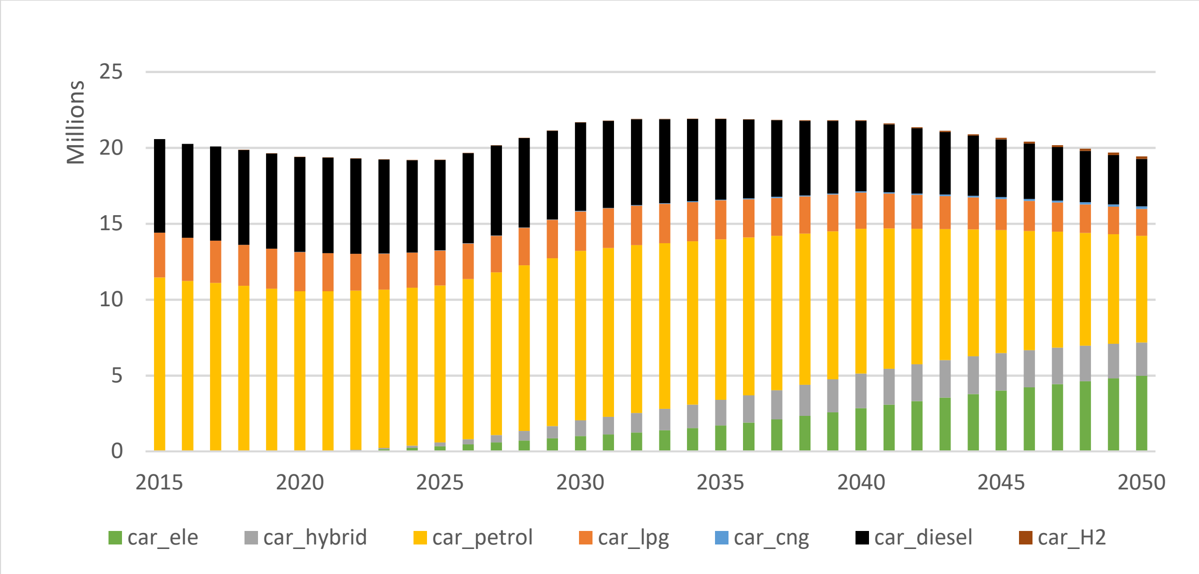
60. Similar trends are observed in Poland. In 2015, the share of petrol cars is 56% and diesel cars is at 30% (% of total cars). In baseline scenario the share for electric cars is assumed in 2050 at the level of 26%.. The share of hybrid vehicles is assumed to grow to 11%. As a consequence of transport electrification, in 2050 the share of petrol cars will decrease to 36% and of diesel cars to 16%.

Figure 23. Number of passenger cars in EU (millions)



Source: TR³E model

Figure 24. Number of passenger cars in Poland (millions)

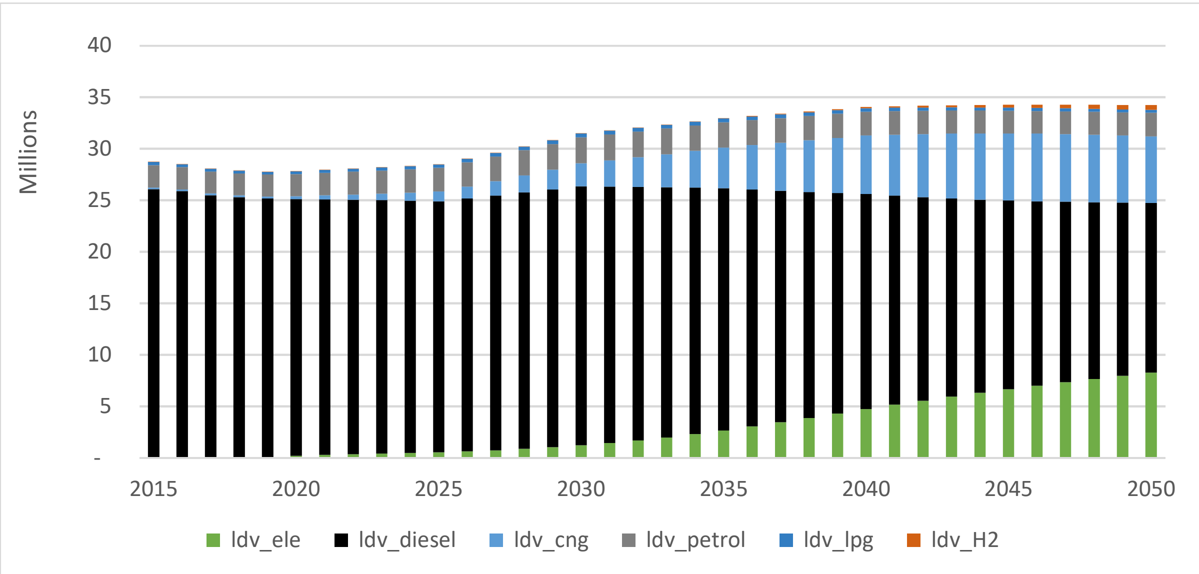


Source: TR³E model

61. As it comes to freight fleet, baseline scenario results show the increase in the EU of total number of vehicles in freight transport between 2015–2050. Average growth rate is at 0,6% (y/y). In baseline scenario it is assumed that in 2050 share of electric light duty vehicles in EU will reach 24% (it is due exogenous assumption about activity).

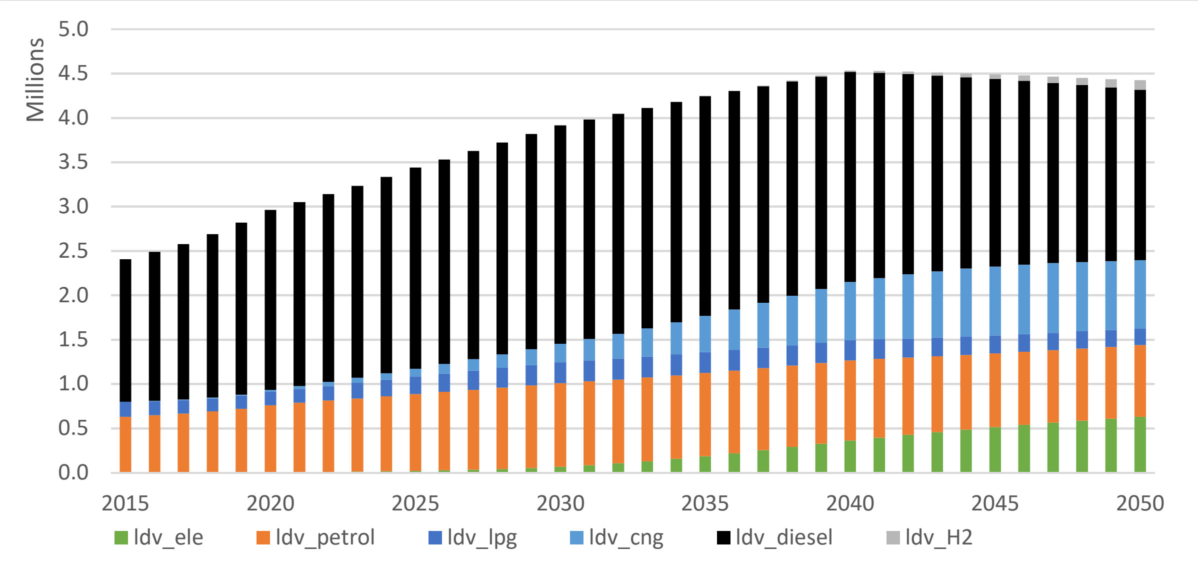
62. Baseline scenario results shows that in Poland numbers of LDV and HDV will growth in the rate 1,5% y/y (0,9p.p. higher than in EU). The share of electricity LDV in 2050 will be on level about 14%.

Figure 25. Freight (LDV) transport fleet in 2015-2050 in EU (millions)



Source: TR³E model

Figure 26. Freight (LDV) transport fleet in 2015-2050 in Poland (millions)



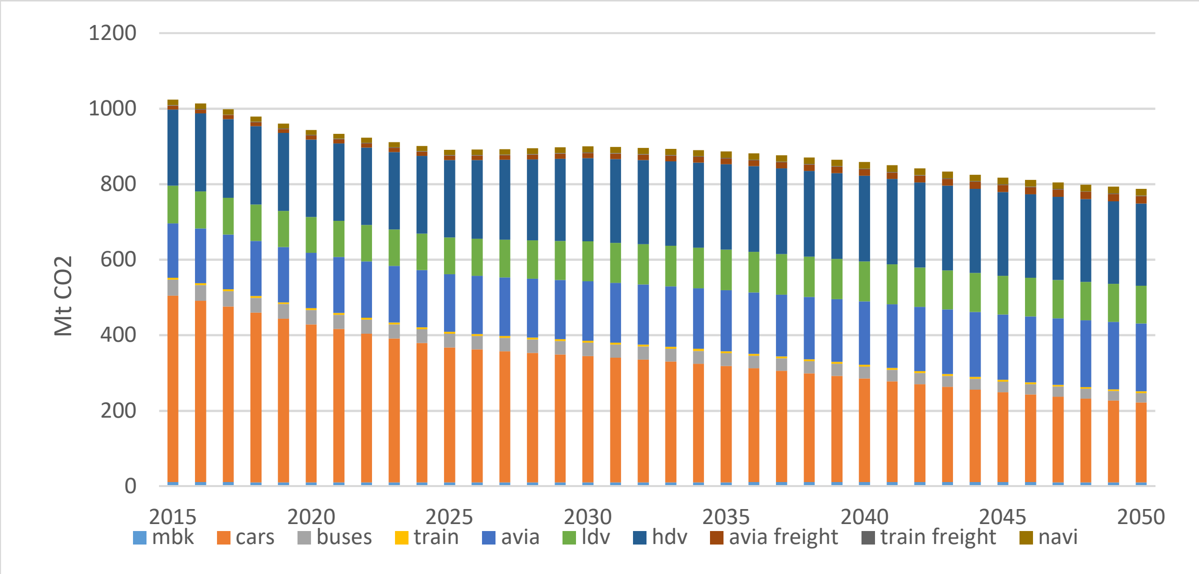
Source: TR³E model

63. It is important to have in mind the dominant share of diesel light duty vehicles in the total number of LDV in the period 2015-2050, both in the EU and in Poland (44% in Poland and 48% in the EU in 2050).

5.4. CO_2 emissions – reduction potential

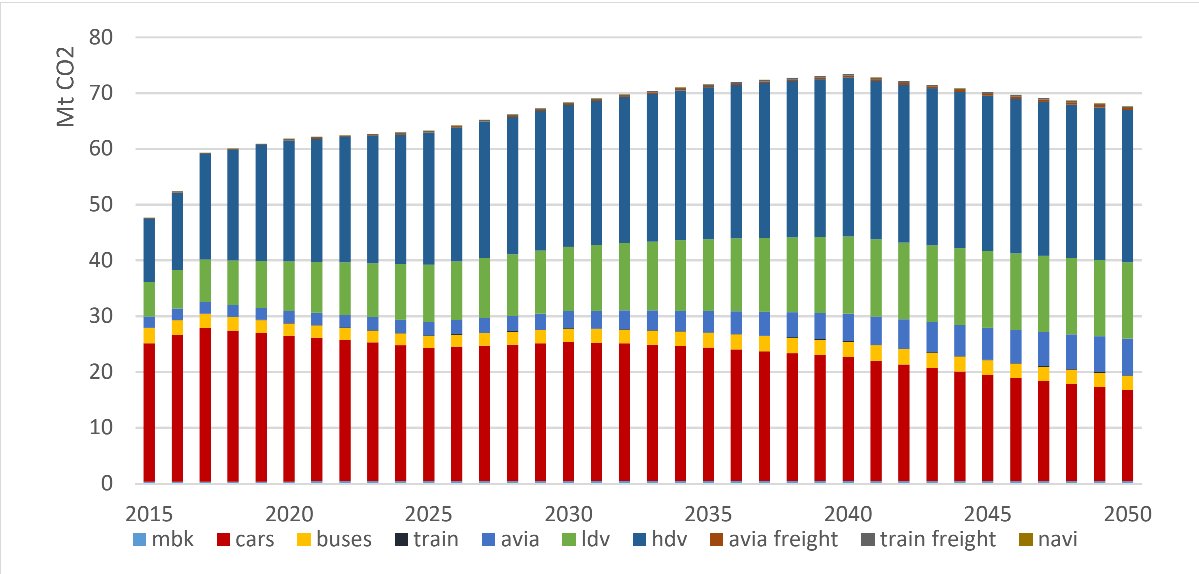
64. In baseline scenario in EU we can observe three main factors explaining the development of the CO_2 emissions: private cars transport (share of 48% in 2015 and 27% in 2050), passenger aviation (share of 14% in 2015 and 23% in 2050) and heavy duty vehicle transport (share of 20% in 2015 and 28% in 2050). In Poland the situation in terms of the emissions from transport sector is similar to the one in the EU but has a slightly different shares. Emissions from cars are at the level of 52% in 2015 and 24% in 2050, emissions of light duty vehicles – 13% in 2015 and 20% in 2050. In case of heavy duty vehicles we observe higher shares for Poland than in the EU average - 24% in 2015 and 40% in 2050. Passenger aviation has lower share than in the EU – about 10% of total emissions in transport sector.

Figure 27. CO_2 emissions by mode in 2015-2050 in EU (Mt CO_2)



Source: TR³E model

Figure 28. CO_2 emissions by mode in 2015-2050 in Poland (Mt CO_2)



Source: TR³E model

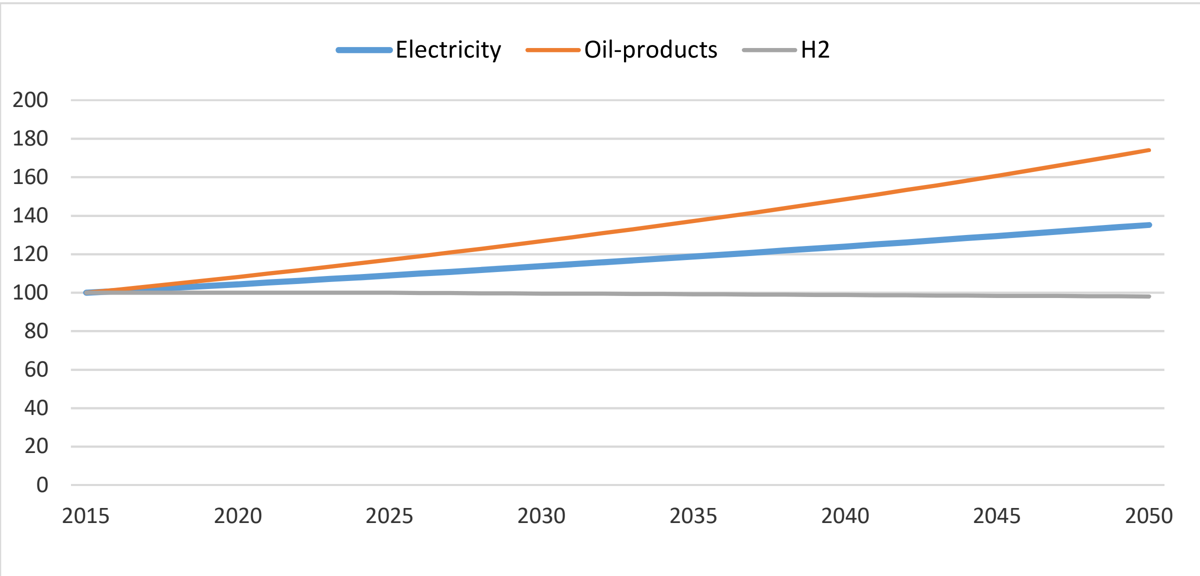
65. Difference between EU and Poland is the distribution of emissions over time. In the EU we observe constant decrease of total emissions from the 2015. In case of Poland starting from the 2015 emissions are rising reaching the maximum level in the 2040 and then we can observe slightly decrease until the end of analysed period of time. The reason of this difference is linked to higher GDP growth in Poland comparing to the EU average as well as the projected development of the transport activity in the future (mainly freight transport activity which is growing in 2% pace y/y). In baseline scenario there is no of significant development of electricity and hydrogen technology for heavy duty tracks.

5.5. Assumptions on the development of costs

66. General costs of transport activity are one of the main elements in TR³E model. Especially, if costs for users are to be determined, additional assumptions need to me made. User cost of transport are the result of model calculation and depends on the assumptions on the prices of vehicles, prices of maintenance and price of fuels. As fleet information is available only for cars, LDVs, buses and HDVs, these vehicles were taken into account while calculating user costs of mobility. This information were taken from the following sources:

- Basic cost of vehicle is taken from the TRACCS database. We used data for the year 2010 as the most recent one of that dataset.
- Cost of fuels are harmonized with MEESA energy model input. Level of prices of fossil fuel are taken from TRACCS database. Prices dynamics up to 2050 are derived from WEO 2017 current policies scenario, and it is assumed that this prices will rise three times up to 2050. Dynamics for electricity prices are taken from MEESA energy model, and it is assumed two times growth up to 2050.
- Costs of maintenance are taken from TRACCS database and are the same in each scenario (year 2010 data, same as in case of cost of vehicles).

Figure 29. Energy carriers cost dynamics in Poland (2015-2050)



Source: MEESA model

6. Model outcome

67. Model results can be grouped into different categories. Table 6 shows aggregated information on the main model outcomes.

Table 6. Model outcome

Disaggregation levels	No.	Description:
Regions (country)	**28**	AUT, BEL, BGR, CYP, CZE, DEU, DNK, ESP, EST, FIN, FRA, GBR, GRC, HRV, HUN, IRL, ITA, LTU, LUX, LVA, MLT, NLD, POL, PRT, ROM, SVK, SVN, SWE
Trip purpose	**2**	Working trips (commuting and business), non-working trips
Trip distance/network	**2**	Urban trips (short distance), non-urban trips (long distance)
Vehicle category	**11**	motorbike, car, bus, light duty vehicle, heavy duty vehicle, passenger train, metro/tram, freight train, freight ship, passenger plane, freight plane
Fuel type	**7**	Diesel, petrol, LPG, CNG, hybrid, electric, hydrogen
Vehicle type	**37**	motorbike: **1** car: **7** bus: **6** light duty vehicle: **6** heavy duty vehicle: **6** metro/tram: **1** passenger train: **2** freight train: **2** freight ship: **1** passenger plane: **1** freight plane: **1**
Vehicle age	**31**	vintages: 1-30
Year	**36**	yearly periods: 2015-2050

Source: CAKE/KOBiZE own study

68. Specific values of TR³E model outcomes are formulated in given units. Table 7 shows units of model data outcomes.

Table 7. Units in TR³E model results

Values	Unit
pkm	Million passenger km/year
tkm	Million ton km/year
vkm	Million vehicle km/year
Vehicles	Number of vehicles
CO_2 emissions	Tons/year
Energy consumption	kWh/year

Source: CAKE/KOBiZE own study

References:

Antoszewski, M., Boratyński, J., Zachłod-Jelec, M., Wojtowicz, K., Cygler, M., Jeszke, R., Gąska J., Rabiega W., Kąsek, L., „CGE model PLACE", MF Working Paper Series, 2015 (22)

Ben-Akiva, M. E., Lerman, S. R., "Discrete choice analysis: theory and application to travel demand", MIT press 1985, Vol. 9

De Ceuster, G. ,"Tremove – Final report", Transport & Mobility Leuven, July 2007

De Grauwe, P. "The academic view up front: towards a new macroeconomics" in. "The Euro and economic stability" Edward Elgar Publishing Limited, 2010

El-Gohary A., Alshamrani A., Al-Otaibi A. N., The generalized Gompertz distribution, Applied Mathematical Modelling, Volume 37, Issues 1–2, 2013, Pages 13-24, https://doi.org/10.1016/j.apm.2011.05.017.

European Commission (2016), "EU Reference Scenario 2016. Energy, transport and GHG emissions Trends to 2050"

European Commission (2018), "A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy"

Mantzos L., et al. "The Potencia Central scenario. An EU energy outlook to 2050", Luxembourg, Publications Office of the European Union, 2019

Okagawa, A., Ban, K. "Estimation of substitution elasticities for CGE models", Discussion Paper 08-16, Osaka University, April 2008

Papadimitriou G., "Transport data collection supporting the quantitative analysis of measures relating to transport and climate change (TRACCS)", Final report, December 2013

Rutherford, T., "Lecture notes on constant elasticity functions", University of Colorado 2002

Wilson, D. L. (1994). The analysis of survival (mortality) data: fitting Gompertz, Weibull, and logistic functions. Mechanisms of ageing and development, 74(1-2), 15-33. https://doi.org/10.1016/0047-6374(94)90095-7

Annex 1: List of input parameters in the TR^{3}E model

	Parameter name	Description
1.	avg_mil_bus	average mileage for buses
2.	avg_mileage	average mileage for cars
3.	cpm_b	baseline cost per 1000 vehicle kilometres in euro
4.	cpm_f_b	cost per mile vkm in euro
5.	cpt	costs per tonne kilometres (tkm) in euro
6.	ene_p	energy use in passenger transport in ktoe
7.	load_factor_b	load factor of vehicle in freight (t per movement)
8.	maint_bus	maintenance costs per year for buses and coaches in euro
9.	maint_f	maintenance costs in road freight transport per vehicle in euro
10.	mileage_all	annual mileage per vehicle in km
11.	oc_rate_data	occupancy rate raw data for passenger transport
12.	occ_rate_b	baseline occupancy rate
13.	oper_bus	operation costs per year for buses and coaches in euro
14.	oper_f	operation costs in road freight transport per km in euro
15.	p_fuel_b	baseline fuel cost per km in euro
16.	p_fuel_data	cost of fuels for cars in euro
17.	p_maint_ b	baseline maintenance cost per vehicle (insurance, repair, etc.) in euro
18.	p_maint_traccs_2010	maintenance costs per year for car maintenance in euro
19.	p_nv_b	baseline price of new vehicles in euro
20.	p_nv_data	cost of purchase of new vehicle in euro
21.	p_nv_f	price of new vehicle in road freight transport in euro
22.	pkm_rail	cost per passenger kilometres (pkm) in euro
23.	sc	baseline scrappage rate
24.	sc_bus	scrappage rate for buses
25.	sc_train	scrappage rate for trains
26.	scrapage	scrappage rate for vehicles
27.	tot_vkmf	vehicle kilometres (vkm) for freight transport in millions of km
28.	totkm_b	baseline distance travelled with given type of car
29.	v_b	baseline number of vehicles
30.	v_old	number of vehicles left from the previous period
31.	vbf	stock of vehicles, aircrafts and trains in freight transport

Source: CAKE/KOBiZE own study

Annex 2: Main changes in the TR^{3}E model between versions

Main changes in the TR^{3}E model between current 2.0 version and previously published 1.0 version:

- Extension of the model with the use of hydrogen technology (passenger and freight transport) and electric technology for Heavy Duty Vehicle (HDV)
- Emissions and energy intensity is calculated endogenously according to changes in fleet (depending to deployment of electric and hydrogen vehicles) within the years and vehicle category
- Linking passenger and freight activity with the GDP level from the d-Place model and elasticity calculated on the basis of the PRIMES Reference Scenario 2020
- The "emiss_cost" parameter is added to the cost per mile, which increases the operating costs of vehicles using fossil fuels. The cost of reduction is expressed as the non-ETS price in EUR/tCO_2. This price is provided from the d-PLACE model and then converted in the TR_3E model into the emission cost based on the emission intensity of a given vehicle technology.
- Linking the projections of electricity, hydrogen and petroleum-derived fuels prices from the MEESA energy model with the TR^{3}E model.