**Increasing transport modeling detail in energy planning models: vehicle age distributions; car classes and fuel blending**

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## Overview

The transport sector is the second-biggest greenhouse gas emitting sector in the European Union, with around a quarter of overall emissions. In the European Green Deal, EU Commission has a set goal to reduce greenhouse gas emissions in the transport sector by 90% by 2050. Such an ambitious goal will require radical changes in the transportation sector. It is most likely that transport decarbonization will rely on substituting ICE vehicles with electric and hydrogen fuel cell vehicles. However, a rapid expansion of electric vehicle stock and green hydrogen production will inevitably affect the overall electricity demand and the hourly demand curve's shape. On the other hand, flexible electric vehicle charging and hydrogen production timing can be utilized to partially balance electricity generation from renewable sources, allowing higher penetration of renewables in the power system. For this reason, there is a need to include the transportation sector in energy planning models. This paper describes a developed transport modeling approach within MESSAGE software based on commonly used and novel practices in the modeling community. Those approaches were supplemented by adding additional detail, like vehicle age distributions, car classes, fuel blending, to better represent the transport sector transition to sustainable fuels.

## Methods

In the developed transport modeling approach, demands are set for travel (in person-kilometers) and cargo transportation (in ton-kilometers). Travel demand was further split into short-distance and long-distance travel. Vehicles were modeled as technologies, which consume fuel to produce travel or cargo transportation. Some vehicle technologies can generate only short-distance travel (city busses, trolleybuses[[1]](#footnote-1)) and some only long-distance travel (intercity buses, trains), while personal cars can be used for both. Either cargo trains or trucks can be used to deliver goods.

MESSAGE is an optimization model, so it will always prefer the least-cost option to supply the demands. Since public transportation is the most cost-efficient way of travel, the model will try to satisfy the travel demands by it as much as possible. However, in reality, the majority use personal cars because of greater versatility, reach, and shorter travel time (in most cases). As a solution, Hannah E. Daly et al. proposed to use a fixed travel time budget (TTB) and travel time investment (TTI). This travel time budget is based on Schäfer's and Victor's claim that there is a fixed travel time budget of 1.1h per person per day and on a developed methodology on how to derive travel time budget for different travel modes, including motorized modes of travel.

We tried to improve Daly et al. proposed modeling approach by differentiating cars not only by fuel type but also by year of production and class (in the case of cars). On average newer vehicles have a better fuel economy due to ever-increasing environmental regulations. However, if all petrol vehicles are modeled only as a single technology, entered efficiency is the same for new and old vehicles. If efficiency is set to increase throughout the modeling years, it increases for vehicles already in stock as well. We addressed this problem by having separate technologies representing different car age groups and constraining vehicle age distribution in the model to match the one in reality. Car differentiation by class into A-B (mini and small cars), C-D (medium and large), E-F (executive and luxury), and J-M (SUV and multi-purpose cars) helps to represent fuel consumption and transition better. Cars of these classes have different fuel efficiencies and prices. The price ratio of electric and petrol cars is not the same for small and luxury cars. Furthermore, changing how vehicle stock changes by class make it possible to evaluate complementary behavioral aspects.

Modeling the transport sector for smaller countries, which has access to a large foreign market of used cars, requires an extra step. The vehicle distribution curve for the largest countries has a declining shape, i.e., share size in car stock drops with car age. Of course, there are fluctuations due to various effects. However, a general trend is as explained. In these countries, cars taken out of stock are replaced by new ones. In small countries with access to the foreign used car market, the vehicle age distribution is almost bell-shaped. For example, in Lithuania, in 2018, 14-year-old cars had the most significant share of car stock – 7.2%, while new cars only 1.2%. When modeling the transport sector for such countries, vehicle depreciation has to be taken into account because cars taken out of stock are replaced mostly by used foreign cars. Car depreciation was modeled by decreasing investment costs throughout the modeling years.

Conventional fuel blending with biofuels is already applied in various countries as an intermediate measure in decreasing emissions. It can be modeled by adding technologies, which produce different fuel blends, which are later consumed by vehicles. Older vehicles might not be compatible with higher biofuel blends. Thus, modeling fuel blending synergizes well with differentiating vehicles by age as it enables modeling compatibility issues.

## Results

The proposed methodology was tested by modeling Lithuania's passenger transport sector in 5-year periods from 2020 to 2060. The exception is the last period, which is for 2050-2060. From the results, we see that diesel cars in Lithuania remain the primary mode of travel up to 2035-2039 in both short and long-distance travel. Afterward, it is superseded by electric vehicles. In general, throughout the modeling periods, the share of pkm traveled in diesel cars decreases. There is only a 4% increase in short distance travel in 2025-2029, compared to the 2020-2024 level (55%). The share of petrol cars remains relatively the same in short-distance travel between 2020 and 2034 – 29-34%. However, it increases in long-distance travel from 16% to 28% in 2030-2034. The share of travel by electric vehicles gradually increases from 2020 till 2060. In 2025-2029 it reaches 1% in short-distance travel. 10% in 2025-2030, 24% in 2030-2034, 43% in 2035-2039, 61% in 2040-2049 and 75% in 2050-2060. In long-distance travel, it reaches 0.3%, 6%, 18%, 35%, 57% and 79% respectively. As a result, electric vehicles' electricity demand increases from 12.4 GWh to 3 TWh (the final electricity demand in Lithuania in 2020 was 11 TWh). The share of hybrid cars in travel slowly increases from 2% to 7% in short-distance travel and from 1% to 3% in long-distance travel. FCEVs are not used before 2045. In 2050-2060, only 1% of short-distance and 0% of long-distance travel is by FCEVs. Similar trends are observed in public transport, where diesel vehicles are gradually replaced by electric vehicles.

Results by vehicle class show that C-D and J-M class cars are electrified the fastest. Results by vehicle production year show that generally older cars tend to be diesel cars, while newer cars petrol or electric. The reason for these results is that diesel cars are more expensive to buy but have lower fuel costs. As vehicles depreciate nominal price gap between diesel and petrol cars shrinks, and it becomes more attractive to buy used diesel cars instead of used petrol cars. The same does not happen for electric vehicles because of implemented additional inconvenience costs. The idea behind these costs is to evaluate inconvenience caused by longer charging times compared to refueling, limited car range, and limited public charging. Newer electric vehicles have shorter charging times and longer ranges, thus have lower inconvenience costs.

Calculated CO2 emissions fall throughout the modeling periods from 5510 kt to 200 kt due to several factors. The first one is decreasing overall travel demand caused by the shrinking population. The second is increasing vehicle efficiency. The third one, the use of higher biofuel content blends. The last and the most significant in the long run is transport electrification. However, it should be noted that emissions due to additional electricity production, required to satisfy growing demands in transport, were not considered.

Figure. Distance travelled in MPKT by different transportation modes and CO2 emissions from fuel combustion.[[2]](#footnote-2)

## Conclusions

Possible high penetration of electric vehicles in the future would significantly affect electricity demand curve, additionally flexible electric vehicles charging could be used to balance variable electricity generation from wind and solar power plants. For these reasons, there is a need to include transport sector into energy planning models, especially if the aim of the model is to determine decarbonization pathways.

In the scientific literature, there were attempts made to include transportation sector into energy planning models. However, they often have a lack of detail. In this presentation, we propose a new approach on how to improve transport sector modelling in energy planning models by differentiating vehicles not only by mode and fuel but also by age, class and by modelling conventional fuel blending with biofuels. This helps to better represent fuel consumption and emissions in the model.

In transport models vehicle fleet age distribution constraints have to be set for smaller countries, which has access to a large foreign market of used cars, because vehicles taken out of stock are replaced by newer used vehicles instead by new ones.

Proposed modelling approach was tested by creating Lithuanian transport model. The results showed gradual transport electrification, decreasing CO2 emissions by 96% by 2050-2060, without placing any constraints on emissions. However, electricity demand in transport increased by more than 5 TWh (3 TWh in personal transport). Electricity supply in the model was unlimited. If the same model would be incorporated into power model, most likely, the results would be somewhat different for the both models.

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1. The modeling approach was developed by creating a model for Lithuanian case. For this reason, trams and metro are not mentioned. However, these transport modes can be modelled using the same principles. [↑](#footnote-ref-1)
2. [↑](#footnote-ref-2)