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Scenarios for greenhouse gas emissions and energy consumption of road transport in Finland

Exploring the impact of existing policies

Johanna Markkanen | Arttu Lauhkonen | Anni Niemi

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Preface

The WEM2022 scenario of this work is an updated version of an earlier unpublished version WEM2022 scenario which was created for Finnish Transport and Communications Agency Traficom. It was an outcome of the United Nation (UN) Reporting project in which transport greenhouse gas (GHG) emission scenarios and impacts of policies on GHG emissions were calculated for Finland's eighth National Communication report (NC8).

The first WEM2022 scenario was reported to Traficom on 8.8.2022. It was updated on 7.2.2023 using updated input data for the vehicle fleet composition, amounts of new registrations and vehicle imports, and the shares of different motive powers of new registrations and vehicle imports.

The first version of WEM2022 was not published, and we saw it important to bring out the latest developments regarding the GHG emissions of road transport for the public discussion. By the time we were writing this publication, new statistics had been published which we wanted to take into account in the scenario assessments. We also had developed the model further by adding new features that had a minor impact on the output. Therefore, the scenarios produced earlier in August 2022 were re-run using the updated input data but keeping everything else as in the earlier WEM2022-version.

We succeeded in creating a more comprehensive tool for scenario assessments, although targets for improvement were discovered. In addition to modelling of the baseline scenario, we created some alternative scenarios to study the impact of new registrations on the GHG emission pathways, which could be considered important in the creation of future policies of the transport sector. The results of scenarios should be never taken as forecasts or facts, but to see them as possible outcomes with the specified inputs for the scenarios. Scenarios are always stories of the possible futures.

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Abbreviations

BEV	Battery electric vehicle
CH_4	Methane
CNG	Compressed natural gas
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
E5	Petrol blend with maximum 5 vol-% ethanol
E10	Petrol blend with maximum 10 vol-% ethanol
E85	Petrol blend with maximum 85 vol-% ethanol
ED95	Ethanol-diesel vehicle
EU	European Union
EV	Electric vehicle
FFV	Flexible-fuel vehicle
GHG	Greenhouse gas
GWP100	Global warming potential over 100-year time period
HVO	Hydrotreated vegetable oil
LULUCF	Land Use, Land Use Change and Forestry
N_2O	Nitrous oxide
non-ETS	Non-emission trading sector
PHEV	Plug-in hybrid vehicle
UN	United Nation
WAM	With additional measures
WEM	With existing measures

1 Introduction

Domestic transport remains a large source of greenhouse gas (GHG) emissions in Finland accounting for 20% of the country's national GHG emissions in 2021 (Official Statistics of Finland, 2022a). Pressure increases to further reduce GHG emissions from domestic transport as Finland has set a goal to become carbon neutral by 2035, and rapid phasing out of fossil fuels is required for all the energy sectors. In addition, the transport sector aims currently for 50% reductions of GHG emissions by 2030 compared to 2005 level to comply with European Commission's (EC) non-emission trading sector (non-ETS, i.e., burden sharing sector) emission reduction target for Finland (Jääskeläinen, 2021).

The Ministry of Transport and Communications of Finland published *Roadmap to fossil-free transport* describing the policies and other measures required to reach the target of 50% reduction (Jääskeläinen, 2021). As a part of the *Roadmap to fossil-free transport*, long-term emission scenarios were created to estimate the impact of existing policies and measures (WEM scenario) and additional policies and measures (WAM scenario) until 2050. Since then, global pandemic and European energy crisis caused by the Russia's invasion of Ukraine have impacted fossil fuel prices which in turn increased efforts towards energy independence in Finland. Electric vehicles (EV) are under a high demand in passenger transport as their cost of driving differs significantly from that of combustion engine vehicles (Traficom, 2021), but supply remains short and manufacturing times are long.

New transport policies formulated during the Governmental period of Prime Minister Sanna Marin are already in force and the implementation of the *Roadmap to fossil-free transport* continues, which implies that the WEM and WAM scenarios as defined in the roadmap are already outdated. To provide relevant recommendations for policy makers, updated scenarios for energy consumption and GHG emissions are necessary. Also, considering that the availability of EVs was the key variable in achieving GHG emissions reductions assessed in Jääskeläinen (2021), the underlying assumptions regarding the number of new registrations ought to be revised.

1.1 Goal and scope

This study aimed to provide up-to-date scenarios for road transport sector in Finland including the last known policies in force. Also, the study explores impacts of the number of new registrations on the GHG emission projection. The focus was on revising and reconstructing Finland's WEM scenario by developing a bottom-up-model to forecast energy consumption and GHG emissions of road transport.

The research questions (RQ) were:

- RQ1: How do GHG emissions and energy consumption of road transport in Finland develop until 2050 in the new WEM scenario?
- RQ2: If the amount of new passenger vehicle registrations is constrained, how will it change the GHG emissions in the new WEM scenario?

The study aims at defining the sets of climate policies aimed at reducing GHG emissions of road transport and defining the impacts of those policies on the vehicle fleet development, kilometrage development and biofuel shares for the WEM scenario. Also, the study aims to consider the recent developments in the vehicle market and revise the assumptions regarding new registrations in the last WEM scenario. Based on the modelled results, vehicle fleet development and GHG emissions will be analyzed and compared with the national targets. Lastly, the study aims to provide relevant recommendations for policy makers based on the results of this study.

The paper presents the work in the following order: Chapter 2 sheds light on the policies assessed and model development in previous studies within the geographical area in question while critically reviewing literature and establishing gaps in existing literature. Chapter 3 describes methods and data used in the study. The calculation principles of the model and input data are explained in Section 2.1. Construction of the studied scenarios are described in Section 2.2. Chapter 3 presents the key results of the study are presented in the following order: First, the development of vehicle fleet, kilometrage, energy consumption and GHG-emissions in the new WEM2022 scenario. Then, alternative scenarios are presented by comparing their results to WEM2022 scenario and pointing out relevant differences and potential causes. Numerical results are presented as rounded values mainly to two milestone years: short-term impact to 2030 and long-term to 2050. Non-rounded values for key results are listed in Appendices. A holistic analysis of the results and their implications are presented in detail in Chapter 4. Finally, the conclusions are summarized in the Chapter 5.

2 Literature review

The baseline, or WEM, scenario for future GHG emissions of transport is under a constant change as policies are implemented and external factors, such as fuel prices, affect everything from the composition of vehicle fleet to the distances driven. There are a limited number of studies which focus solely on the GHG emission scenarios of the road transport sector in Finland, but none of the studies focus on the entire transport sector including road, water, rail and air transport.

Individual impact assessments of some transport policies have been published related to impacts of increasing the distribution obligation of liquid biofuels and later also of gaseous biofuels to 30% by 2030 (Sipilä et al., 2018) and to 34% (Sipilä et al., 2021) by 2030. Also, impact of speed limits on road transport GHG emissions were studied by Malin et al. (2023) and Kiviranta (2021). Individual policy impact assessments give insights on the impact mechanism of the policy in question, but they do not capture possible interactions between policies which may occur if the mechanisms of the policies are downright supportive or conflicting (Nissinen et al., 2015). The results from policy impact assessments can be used as input data to produce sector-level scenarios such as the road transport scenarios discussed in this paper.

Lehtilä et al. (2021) constructed WEM- and WAM scenarios for all energy sectors in Finland to support the preparation of the updated Climate and Energy Strategy and the Medium term Climate Change Policy Plan. Nationwide scenarios included also domestic transport sector, but the assessment was performed using energy system model TIMES-VTT, which uses vehicle fleet and kilometrage projections as an input data instead of generating detailed projections for the transport sector (Lehtilä et al., 2021). The input data for transport sector was produced using sector-model ALIISA, which calculates the vehicle fleet, kilometrages and consumption of vehicles in Finland (Lehtilä et al., 2021). ALIISA model was also used to produce the latest WEM and WAM scenarios in Jääskeläinen (2021). However, although ALIISA depicts the road transport sector in Finland, the model is incomplete: it does not include motorcycles, mopeds and quadricycles, which form the L-class vehicle category, nor account for other greenhouse gases than carbon dioxide (CO_2) and for the emissions from use of urea in diesel vehicles to comply with emission regulations (Valtioneuvoston Hankeikkuna, 2021b). All the GHG emissions reported in the UN Kyoto Protocol are, anyway, considered in the TIMES-VTT assessments, including also transport sector.

A spin-off of ALIISA model was constructed by Westerholm (2017) and Giacosa (2017): MATERO is a similar bottom-up model, and it was developed to compute energy demand and GHG emissions of road transport in Finland, Sweden and Norway. Their work focused on assessing scenarios related to various powertrains, transport needs, energy efficiency of vehicles and the shares of biofuels. Although MATERO considered various climate- and health-related emissions from vehicles, their model also excluded L-class vehicles.

The assumptions regarding the development of vehicle fleet and the mix of policies considered in the WEM and WAM scenarios in both Lehtilä et al. (2021) and Jääskeläinen (2021) are already outdated due to the implementation of EU FitFor55-policy package; sales projections of passenger vehicles and vans are heavily impacted by the new directives, and sales projections have a strong impact on the vehicle fleet development. In addition, all the WEM and WAM scenario assessments were finalised before the war in Ukraine and energy crises.

Aro et al. (2022) studied the use of scenarios in climate policy planning in Finland, focusing on the work of Lehtilä et al. (2021), by interviewing relevant actors behind the scenarios. They suggested to revisit more frequently previously created scenarios, and to provide a more extensive array of policy scenarios instead of providing a single alternative pathway. The WEM scenario produced by Lehtilä et al. (2021) are being updated in a research project (PEIKKO) funded by the Prime Minister's Office[1]. Additionally, uncertainties related to the most relevant factors affecting WEM scenario will be assessed providing some alternative pathways for the WEM scenario.

The inevitable problem in producing transport GHG emission scenarios currently is that the scenarios become outdated in a fast pace: transport sector in EU is undergoing a rapid change as more and more electric and hydrogen vehicles are pushed to the market by ever-tightening EU Legislation while at the same time purchase incentives for electric vehicles are not granted more funding (Ministry of Transport and Communications, 2022). Also, EU-states are urgently trying to meet their GHG emissions reduction targets by setting new national policies. Hence, there is a clear need for revised WEM- and WAM scenarios for road transport sector to assess the impacts of recent changes in the transport policy mix on the projections of vehicle fleet development, energy consumption and GHG emissions. Also, a comprehensive scenario model is needed which considers the entire road transport sector and all relevant GHG emissions.

[1] More information regarding the project PEIKKO (Perusskenaariot energia- ja ilmastotoimien kokonaisuudelle kohti päästöttömyyttä) is available at: https://tietokayttoon.fi/-/perusskenaariot-energia-ja-ilmastotoimien-kokonaisuudelle-kohti-paastottomyytta-peikko-

3 Methods and data

3.1 Model development

A new model (ELIISA) was developed for scenario modelling. VTT's ALIISA model (e.g., VTT, 2023; Nylund et al., 2015) was used as the basis for the development of the new ELIISA model. ALIISA has a unique and tailored method to compute Finland's vehicle fleet. ALIISA is a deterministic model, which simulates the development of CO_2-emissions of passenger vehicles, light- and heavy-duty vehicles until 2050 based on assumptions regarding fuel consumption and kilometrage driven by vehicles. It is a bottom-up model, which describes the parts, i.e., vehicles, of the road transport system in detail. ALIISA also considers the distribution obligation, however, without automatic optimization of the amounts of biofuels. The current construction of ALIISA as an extensive excel-model was seen difficult to use in producing scenarios and was prone to human errors. Also, data sources were partially unpublished and untraceable, which would not support the principles of open science. Overall, ALIISA's method was considered as a good foundation for the new ELIISA model and any modifications to the original methods and source data were done with caution. The new ELIISA model was built in Python-environment using open-source data.

ELIISA model

ELIISA is a deterministic model that combines simulation and optimisation in Python-environment. It is a national-level model depicting Finland's vehicle fleet and its emissions. In principle, the model can take any vehicle fleet, e.g., regional, as an input. The model computes timeseries starting earliest from 2021 and ending latest in 2050, including an option to extend the timeseries. ELIISA is a bottom-up model: it computes first vehicle fleet, after which annual kilometrage and energy consumption are calculated. The results are calculated for each combination of vehicle type, motive power and year of manufacture separately and summed up in the end.

Bio and fossil fuel consumption are calculated by setting a constraint for the maximum amount of biofuels used. Minimum amount of biofuel consumption is defined in Finland's legislation for distribution obligation of biofuels until 2030, and we assume that the proportion of biofuels set in the legislation will not be exceeded. GHG emissions are computed based on fuel consumption and fuel type. The methods are described in detail in the following sections.

3.1.1 Vehicle fleet

The starting point of vehicle fleet computation is the latest data on existing fleet including only vehicles in active traffic use (Traficom, 2022a,b). The model considers all the main vehicle types and motive powers in Finland as depicted in Table 1.

Table 1. Vehicle attributes in ELIISA.

Vehicle types	**Motive powers**	**Years of manufacture**
M1: Passenger vehicle	Petrol	1980[2] …
M2, M3: Bus	Diesel	end of timeseries
N1: Van	Methane-petrol (CNG-bifuel)	
N2, N3: Rigid truck	Ethanol-petrol (FFV)	
N2, N3: Articulated truck	Ethanol-diesel (ED95)	
L1, L2: Moped	Plug-in hybrid, petrol (PHEV-petrol)	
L3, L4: Motorcycle	Plug-in hybrid, diesel (PHEV-diesel)	
L5, L6, L7: Quadricycle	Battery electric (BEV)	
	Fuel cell	

Annual vehicle fleet is calculated by adding new registrations and imported vehicles to the fleet of previous year and subtracting removals from the fleet. Removal rate of vehicles is inherited from ALIISA model: removal factor is a function of end-of-life-age of a vehicle type in an inventory year.

The total amounts of new registrations and imported vehicles, as well as their motive power distributions are expert estimates based on recent trends and expected changes in the future e.g., increase in electrification of vehicle fleet. Imported vehicles can account for nearly a third of Finland's annual registrations, and that is why imported vehicles are added to the fleet of specific years of manufacture according to a distribution extracted from register data (Traficom, 2022a). The age distribution is calculated for each vehicle type and motive power, and it is assumed to stay constant over the time series.

2 Year model 1980 includes all vehicles manufactured in 1980 or earlier.

3.1.2 Kilometrage

Annual kilometrage is assumed to depend on the age of vehicle. The base variable for kilometrage calculation is average annual kilometrage per vehicle, which is defined for all vehicle types. In case of passenger vehicles, average annual kilometrage is also defined for four groups of motive powers which have a similar typical usage (1: petrol, FFV and CNG-bifuel; 2: BEV; 3: PHEV-petrol; 4: diesel and PHEV-diesel).

Assigning average annual kilometrage for different motive powers enables the consideration of the effect of energy prices on driving behaviour. ELIISA model does not contain any price-related variables, but the information can be embedded in the input variables using modelled time series of kilometrages from economic models.

The timeseries of average annual kilometrages are calibrated in a way that meets the national kilometrage prediction for a specific vehicle fleet as defined by the Traficom (2021). The kilometrage at the start of the timeseries is calibrated to match to the official statistics of vehicle fleet in the same year, i.e., the computed kilometrage of vehicle fleet in 2021 will match to the official kilometrage statistics of Finland. All L-class vehicles create an exception, since their kilometrage is not accounted for in neither official predictions nor statistics (Official Statistics of Finland, 2022b). Their average annual kilometrages are assumed constant throughout the time series.

Kilometrage is divided by street type for methane (CH_4) and nitrous oxide (N_2O) emissions calculations, but the output kilometrage of the model is on an aggregated level including all street types.

Distance driven by vehicles is also split for fuel types in cases where the vehicle can utilise more than one type of fuel in the engine(s) e.g., distance driven using electric engine and combustion engine for plug-in hybrid vehicles. We assume that 50% and 75% of kilometrage of light and heavy-duty plug-in hybrid vehicles are driven using electric engine, respectively. CNG-bifuel vehicles are assumed to be driven 75% (passenger vehicles), 80% (vans) and 99% (heavy-duty vehicles) using methane (i.e., biogas and/or natural gas) as fuel. For heavy-duty vehicles, the share of kilometres driven using methane is assumed to decrease from 99% to 94% by 2050.

3.1.3 Energy consumption

Energy consumption by vehicles is defined in the model as the direct energy consumed by the specific vehicle in terms of fuel or electricity. The calculation method was improved for ELIISA model, since in ALIISA mode, energy consumption was calculated from the fuel consumption. As the energy content of certain fossil and biofuels differ, it was seen more accurate to first compute the energy consumption of the vehicle and the fuel consumption from the energy consumption.

Energy consumption is calculated based on driven kilometrage. Energy consumption is assumed to depend on the year of manufacture of the vehicle so that energy efficiency of the engines improves over time.

The base values for energy consumption were taken from ALIISA model (Valtioneuvoston Hankeikkuna, 2021b) for passenger vehicles, vans, buses and trucks. For motorcycles, mopeds and quadricycles, energy consumption per kilometre was calculated using energy consumption factors provided by European Environment Agency (2016). Calibration of consumption was done in a similar manner as the calibration of kilometrage: energy consumption factors are adjusted so that in the start of timeseries the energy consumption of the vehicle fleet in 2021 is set to match to the official statistics of Finland regarding energy consumption in road transport (Official Statistics of Finland, 2022c).

3.1.4 Biofuel distribution obligation and fuel consumption

The biofuel distribution obligation is assumed to be realized according to the minimum limits set in legislation 1134/2022 (Finlex, 2022). Biofuel distribution obligation defines the total share of biogenic or other fuels renewable of origin from the total energy content of the fuels sold. The following liquid and gaseous fuels are considered in the current legislation: petrol, diesel and methane. Biofuel distribution obligation obliges only those fuel distributors, whose sales are more than one million litres annually (Finlex, 2021), but for simplicity, we assume that all the sold road transport fuels contain biofuel.

The share of biocomponent of petrol (E5, E10) is constant at around 5 or 10 vol-%, and over 99% of petrol sales is assumed to be E10 blend. The biofuel content in gaseous fuels and diesel fuel can be anything up to 100%, so for simplicity, we assume that biomethane content stays at the level of last inventory year for which fuel sales are reported by Statistics Finland. The amount of biodiesel in diesel blend is therefore computed so that whatever amount of biofuel is not filled in petrol and methane blends, will be filled in diesel blend to account for the total distribution obligation. The fuel blend properties depend on the amounts and properties of biofuels (ethanol and biodiesel as HVO) since their heat values differ from those of fossil fuels (petrol and diesel) with the exception of methane. Fuel properties are calculated after optimising biofuel amounts to meet the obligation. Fuel consumption is then calculated from the energy consumption using heat values of fuel blends.

3.1.5 Greenhouse gas emissions

GHG emissions are calculated based on either fuel consumption or kilometrage depending on the emission compound. ELIISA model calculates CO_2, CH_4 and N_2O emissions. CO_2 is calculated from the fuel consumption since the carbon content of fossil fuels are well known. However, CH_4 and N_2O emissions depend also on the emission control technologies (i.e., EURO-class) and speed of the vehicle. CH_4 and N_2O emission factors are calculated according to the formula in European Environment Agency (2016).

CH_4 and N_2O emissions are calculated per kilometre driven at certain speed. For this calculation, the kilometrage of vehicles of different motive powers and EUROclasses is divided into ten categories. The categories depict the main street types in Finland and correlate the average driving speed of the vehicle type with the street type. The distribution of kilometrage per street type originates from ALIISA model.

Biogenic CO_2 is not included in GHG emissions since it is reported as a part of the LULUCF sector (Land Use, Land Use Change and Forestry) in the national greenhouse gas emission inventories. However, biogenic CH_4 and N_2O emissions are accounted to the total GHG emissions (IPCC 2006).

GHG emissions are expressed in carbon dioxide equivalents (CO_2eq). Values for global warming potential over 100-year time period (GWP100) without climate-carbon feedbacks for CH_4 and N_2O are 28 and 265, respectively (Myhre et al., 2013). Urea is used in later diesel vehicles to comply with tighter emission regulations: CO_2 emissions from the use of urea is included in the total GHG emissions with the assumptions inherited from ALIISA model.

3.2 Construction of studied scenarios

The starting point for construction of new scenarios was the latest published baseline for transport sector in Finland, named WEM2021 (Valtioneuvoston Hankeikkuna, 2021a). WEM2021 was produced using ALIISA model. The scenario includes the impacts of climate and energy policies, which affect the development of GHG emissions of road transport and were put into force or decided before 1.1.2020. Instead of using the results of WEM2021 directly as our baseline, we imported the vehicle fleet development data and implemented the WEM2021 scenario in ELIISA.

First, we analysed the impact of the improved energy consumption calculation method and the impact of using open-source data on the baseline results. Then, we updated the vehicle fleet for the starting year of time series (2021), adjusted the kilometrage and energy consumption to match the official statistics for 2021. The vehicle fleet statistics for 2022 was already available at the time of modelling the scenarios, so the latest data was updated to the model.

3.2.1 New baseline WEM2022

WEM2021 baseline scenario was used as the starting point to construct the new WEM2022 baseline scenario. Policies and other measures, which were implemented before 1.8.2022 and which affect the development of transport GHG emissions, were included in the WEM2022 scenario[3]. This means that many of those policies and other measures, which were included in the WAM2021 scenario of the *Roadmap to fossil-free transport,* were now implemented in the WEM2022 scenario.

[3] The assumptions on policies and measures included in WEM2022 were agreed with the Ministry of Transport and Communications and with the Traficom.

The impact of each measure was categorised either as having an impact on vehicle fleet, impact on kilometrage or impact on energy or fuel consumption. The modelled measures and their impacts are presented in Tables 2, 3 and 4 together with a brief description of the impact mechanism and underlying assumptions.

Table 2. Impacts of national policies and measures.

National policies and measures	**Impact on vehicle fleet, kilometrage or energy/fuel consumption**
Increased biofuel distribution obligation	Decreased biofuel consumption in 2022-2023 (annual percentages: 12%, 13.5%); Increased biofuel consumption from total fuel energy consumption from 2024 onwards (28%, 29%, 29%, 30%, 31%, 32%, 34% ->) (Finlex, 2022).
Biomethane and P2X-fuels included in biofuel distribution obligation	Starting from 2022, the share of biomethane in methane blend is assumed to increase annually by 5%-units until it reaches a level of 99%. Assuming biomethane remains cheaper than biodiesel, biodiesel consumption decreases as it is replaced by biomethane to comply with biofuel obligation (Sipilä et al., 2021).
Purchase incentive for battery electric passenger vehicles	A bonus of 2 000 €/vehicle is assumed to result in 5 250 new BEVs annually in 2022 and 2023 from the total budgeted bonus (Jääskeläinen, 2022). New vehicles do not increase the total number of total registrations, but replace other new registrations as follows: 59% petrol, 19% diesel, 1% CNG-bifuel and 21% plug-in hybrids.
Monetary incentive for ethanol and CNG-conversions (passenger vehicles)	A bonus of 200 €/ethanol conversion and 1 000 €/CNG-conversion is assumed to result in 3 391 flexifuel-vehicles and 332 CNG-bifuel vehicles in 2022 from the total budgeted bonus (Jääskeläinen, 2022; Traficom, 2022e). Converted vehicles are assumed to be originally petrol-powered passenger vehicles from years of 2000 – 2009[4].
Purchase incentive for battery electric and CNG-bifuel vans	An estimated bonus of 4 000 €/BEV and 2 000 €/CNG-bifuel-vehicle is assumed to result in 562 new BEVs and 375 new CNG-bifuel vans annually in 2022 and 2023 from the total budgeted bonus (Jääskeläinen, 2022).
Purchase incentive for battery electric and CNG-bifuel trucks	An estimated bonus of 18 000 €/BEV and 6 000 €/CNG-bifuel-vehicle is assumed to result in 83 rigid BEV-trucks (> 16 t) and 250 CNG-bifuel trucks (80% rigid and 20% articulated trucks, > 16 t) annually in 2022 and 2023 from the total budgeted bonus (Jääskeläinen, 2022).
Exemption from tax for zero-emission (0g CO_2) passenger vehicles	Tax exemption is assumed to support the transition to zero-emission vehicles. No direct impact could be modelled due to lack of data.
Monetary incentive for new charging and fuelling infrastructure	Increased number of charging and fuelling stations is assumed to support the transition to zero-emission vehicles. No direct impact could be modelled due to lack of data.

[4] Conversions of later vehicles than 2009 require proof of compliance with emission limits (Traficom 2023a).

National policy measures included those measures, which were either in force or, in case of monetary incentives, for which the Government finance was agreed on. Legislative measures were assumed to be realised as stated in the legislation, but not more than that (i.e., biofuels added in fuel blends to the extent that total required amount of biofuels sold during a year equals the distribution obligation).

The impact of policies on vehicle fleet was calculated as a change in the market shares of new registrations so that the impact was substitutive, not additive: the increase in the number of new registrations of one motive power resulted in decrease in the number of new registrations for the substitute motive power. The number of vehicles affected by policies were calculated based on the total budgets granted by the Government for each policy according to the information received from Jääskeläinen (2022). Statistics regarding the usage of budgets were also used to assess future changes, if information was available. In case of new policy measures, such as purchase incentives for BEV and CNG-bifuel vans and trucks, no statistical data existed; thus, we made estimates on how the incentive could be allocated to BEV and CNG-bifuel purchases.

Table 3. Impacts of EU's Fit For 55 measures.

EU's Fit For 55 measures	**Impact on vehicle fleet, kilometrage or energy/fuel consumption**
Stricter CO_2 emission limits for new passenger vehicles and vans in EU	We assumed a direct impact on new registrations in Finland: Average CO_2 emissions of new registrations will be -55% (passenger vehicles) and -50% (vans) in 2030 and -100% for both vehicle types in 2035 than in 2021 in Finland.
Alternative Fuels Infrastructure Regulation (AFIR) in EU	Increased number of charging and fuelling stations is assumed to support the electrification and hydrogenation of vehicles. No direct impact could be modelled due to lack of data.

Table 4. Impacts of other measures.

Other measures	**Impact on vehicle fleet, kilometrage or energy/fuel consumption**
Remote working (after COVID-pandemic)	An estimated decrease in passenger vehicle kilometrage of 830.8 Mkm/year is assumed by 2030 in the most probable future scenario by Metsäranta et al. (2021). Assumed a linear trajectory for the kilometre reduction starting from 0 km in 2022.
High-capacity transport (HCT) and digitalisation of logistics	As HCT-vehicles were allowed in Finland from 2019 onwards, articulated trucks up to 34.5 m of length can be used for transporting goods. This is assumed to reduce the total kilometrage of trucks, since the same amount of goods could be transported in lesser number of trucks. Digitalisation of logistics is assumed to support this transition and reduce kilometrage by 83.3 Mkm/year by 2030, assuming a linear trajectory starting from 0 km in 2022, although the

	impact is uncertain and questioned by the authors themselves (Valtioneuvoston Hankeikkuna, 2021c, d).
Transportation system development plans for cities	Cities' transportation system development plans contain various measures that promote walking, bicycling and public transport. We assumed a decrease in passenger vehicle kilometrage of 1 170 Mkm/year by 2030 and a linear trajectory starting from 0 km in 2022 (Valtioneuvoston Hankeikkuna, 2021e; Traficom, 2022d). Estimated kilometrage reduction included only those projects of which funding was secured.
Investment program on promoting walking and bicycling	Investment program includes similar, partially overlapping projects, which promote walking and bicycling in cities. We assumed a decrease in passenger vehicle kilometrage of 108.2 Mkm/year by 2030 and a linear trajectory starting from 2022 (Valtioneuvoston Hankeikkuna, 2021e; Traficom 2022c)

The data source for the impacts of measures was chosen in accordance with the requirements from the Traficom and the Ministry of Transport and Communications. The scope of this study did not include reassessing the impacts; if the data source included assessments of several scenarios, we selected the most plausible scenario that fits today's global and national environment to the best of our knowledge. The scope of the study also excluded any impact assessments regarding fuel taxation and its potential impact on vehicle kilometrage since the model does not include any price-related variables.

There are limitations of using external reports and assessments (i.e., grey literature) instead of scientific literature. Public reports can include very specific and relevant information regarding the operating environment and other circumstances in Finland, but these reports may include limited information or no information concerning assessed methodology, data and more detailed results. Also, unpublished data sources were used, which pose even more uncertainties as the publication and approval process are lacking. Regarding the data sources used in this study, it was common that only the impacts of measures or policies on GHG emissions were reported. The problem arises from the fact that decrease in the GHG emissions can be translated in many ways, like the actual impact on vehicle fleet, kilometrage or fuel consumption. The authors may have also used different assumptions regarding emission factors or may not have considered all the relevant GHG emissions in their assessment. Also, the results are often reported only as a change in 2030 or other milestone year compared with today's situation, without any trajectory from today to the milestone year. Hence, we were forced to make simple assumptions with linear trend in each case as described in Table 3, which does not necessarily depict the intended trajectory in the original data source.

There is a significant gap in the translation of the data source into an input data for the model, which could result in major uncertainties and, in the worst-case, wrong conclusions of the results.

3.2.2 Alternative scenarios

Many of the new EU policies affect especially the market shares of new registrations and imports of passenger vehicles. Therefore, we saw it important to study how the energy consumption and GHG emissions change, if the latest number of new registrations was less than in the new baseline WEM2022.

The assumption that new registrations increase from the level of 100 000 in 2021 up to 150 000 vehicles sold annually by 2050 can be considered less valid in scenarios where, for example, the supply of new vehicles is limited due to limited resources, or where prices of electric vehicles do not reach parity with prices of combustion engine vehicles, or where the population decreases instead of increases and the total vehicle fleet size would reach its peak.

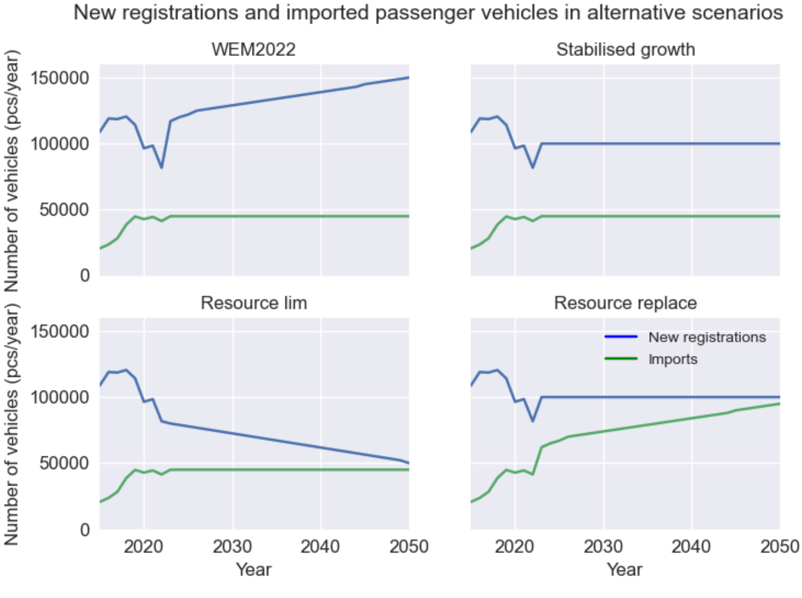

Figure 1. Development of total number of new registrations and imported passenger vehicles in the scenarios 2022 – 2050 including statistics from the years 2015 – 2022 (Traficom, 2023b, c).

Regarding the new registrations and imports, we constructed three plausible alternative scenarios. The storylines of the scenarios are as follows:

- **Stabilised growth**: Car sales are not increasing as expected due to slower population growth and economic situation. New vehicles are purchased and imported at approximately today's rate. New registrations of passenger vehicles remain at constant level of 100 000 vehicles/year.
- **Resource lim**: Resource scarcity affects the availability of battery minerals and other rare earth metals required for vehicle manufacturing. New

registrations decrease annually reaching a level of 50 000 vehicles/year by 2050. Vehicles are imported from abroad at today's rate.

- **Resource replace**: The same assumptions as in the Resource lim scenario, but the decrease in new registrations are replaced by imported passenger vehicles, of which annual level would increase from 45 000 vehicles/year in 2022 to 75 000 vehicles/year in 2050.

The only variables varied in the scenarios were the number of new registrations and imports of passenger vehicles. All other variables remained the same as assumed in the WEM2022 scenario.

4 Results

4.1 WEM2022-baseline

4.1.1 Vehicle fleet development

In 2022, Finland's vehicle fleet included total of 3.52 million vehicles that were in active traffic use. 2.75 million were passenger vehicles, 361 000 L-class vehicles, 337 000 vans, 94 000 trucks, and were 10 000 buses.

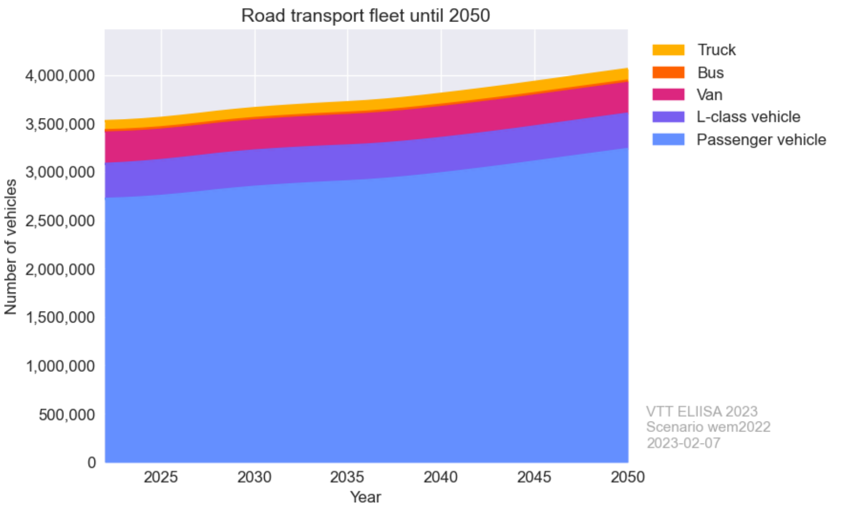

Figure 2. Development of road transport fleet per vehicle type in the WEM2022 scenario in 2022 – 2050.

In the WEM2022 scenario, the assumed passenger vehicle fleet will increase to 2.85 million vehicles by 2030. The entire vehicle fleet continues to increase in size nearly linearly until 2050 reaching 4.06 million vehicles in 2050 (Figure 2). The increase is mainly due to increase in the number of passenger vehicles, which accounted for 96% of the increase.

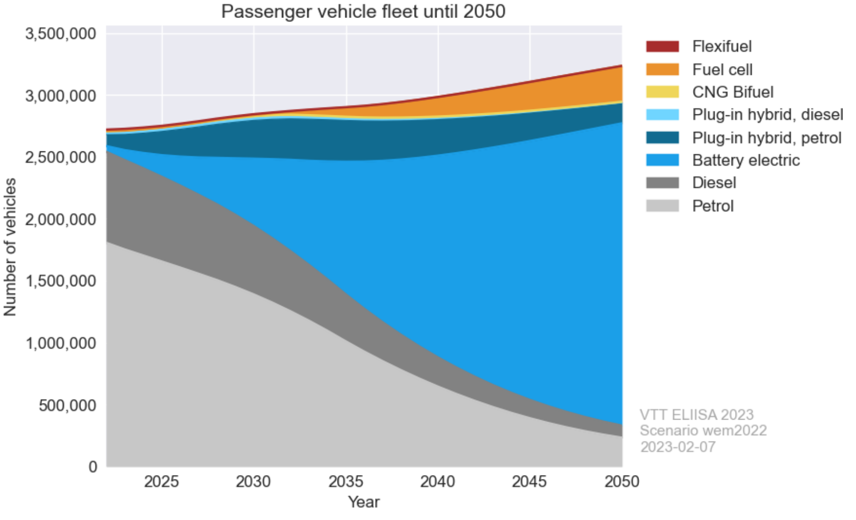

Figure 3. Development of passenger vehicle fleet per motive power in WEM2022 scenario in 2022 – 2050.

Electrification of vehicles proceeds in each vehicle type, although faster in passenger vehicles and vans than buses and L-class vehicles. By 2030, there are nearly 878 000 electric passenger vehicles in active use, of which 63% are fully electric (BEVs). Petrol remains the most common motive power in passenger vehicles until 2034 after which BEVs become the largest passenger vehicle group in Finland (Figure 3).

Another large group of vehicles in passenger transport are L-class vehicles (motorcycles, mopeds and quadricycles): the fleet size is 375 000 in 2030 making it the second most common vehicle type group in Finland. Majority of L-class vehicles are still petrol-powered in 2030 accounting for 87% of their fleet. There are 42 000 fully electric battery-powered L-class vehicles in 2030 of which 90% are mopeds, 8% motorcycles and 2% quadricycles. L-class fleet decreases slightly to a total of 366 000 vehicles by 2050.

Vans are the third largest vehicle type group having a fleet of 323 000 vehicles in 2030. They remain mainly diesel-powered in 2030 accounting for 83% of the entire van fleet. There are 49 500 BEV vans in 2030, of which 83% are fully electric and 17% plug-in hybrids. Van fleet increases slightly to a total of 327 000 vehicles in 2050.

Bus fleet increases 17% from 10 500 buses in 2022 to 12 300 buses in 2030. There are 2 800 fully electric buses in 2030 accounting for 23% of the entire bus fleet. Bus fleet continues to increase to 14 000 buses by 2050, of which over half are fully electric.

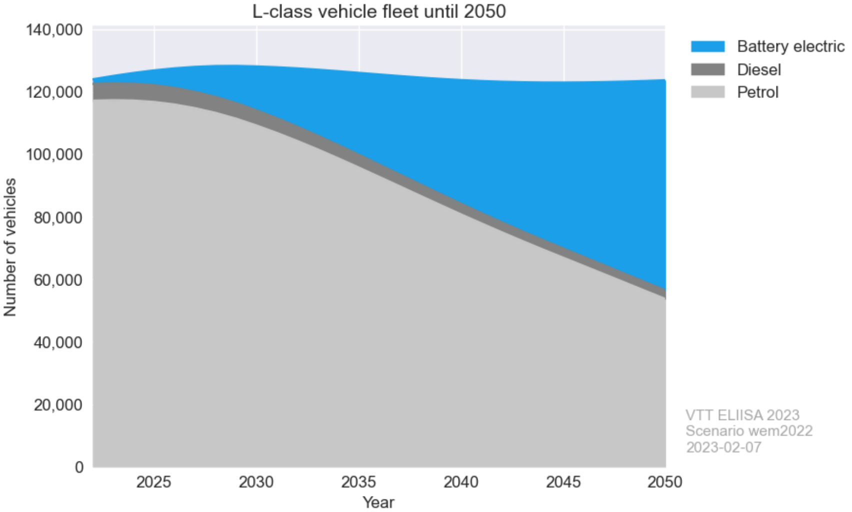

Figure 4. Development of L-class fleet (motorcycles, mopeds and quadricycles) per motive power in WEM2022 scenario in 2022 – 2050.

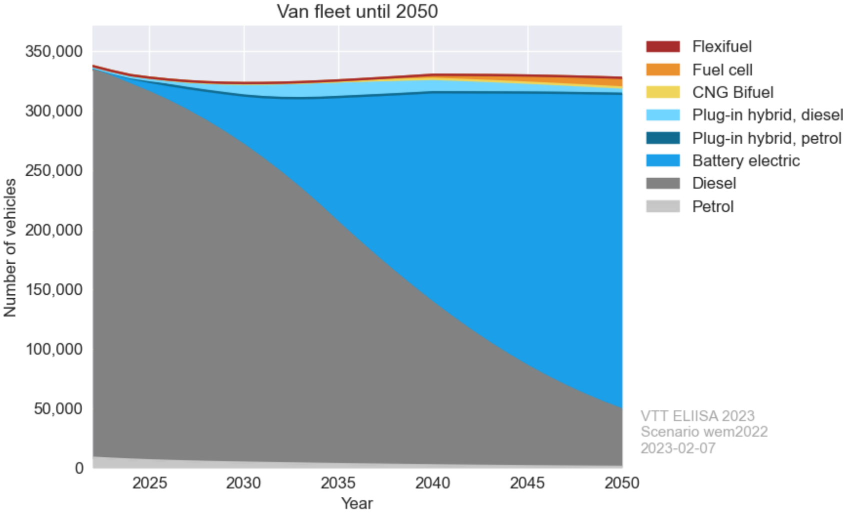

Figure 5. Development of van fleet per motive power in WEM2022 scenario in 2022 – 2050.

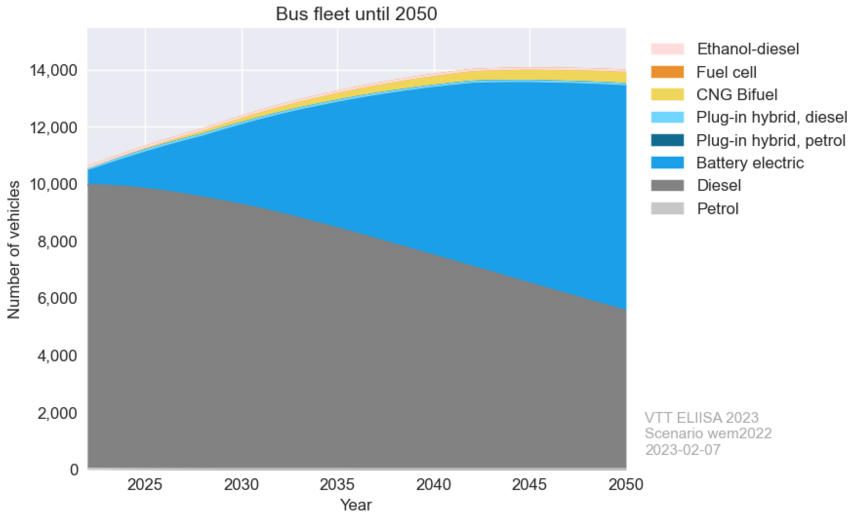

Figure 6. Development of bus fleet per motive power in WEM2022 scenario in 2022 – 2050.

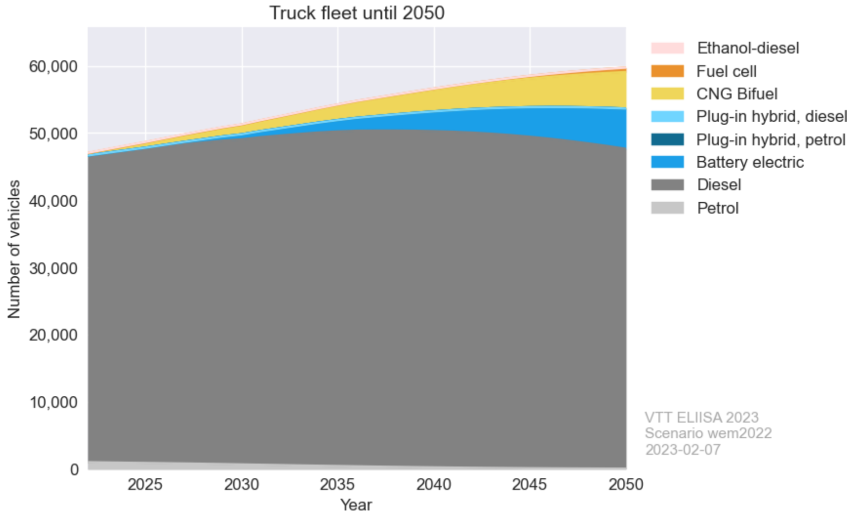

Figure 7. Development of truck fleet per motive power in WEM2022 scenario in 2022 – 2050.

The truck fleet increases from 94 000 trucks in 2022 to 103 000 trucks in 2030, and to 120 000 trucks in 2050. The main motive power remains to be diesel throughout the time horizon. Large-scale electrification of trucks will not take place during the modelled time period. There were 105 electric trucks in 2022, of which over 99% were smaller rigid trucks. Electric truck fleet increases 14-fold during the 8-year period from 2022 to 2030 to 1 500 vehicles. However, they account only for 1% of the entire truck fleet even then.

It is noteworthy to mention that in our scenarios, CNG-bifuel trucks are more common than electric trucks in 2030 and they remain nearly as common also in 2050. The share of electric trucks from the entire truck fleet in 2050 is only 10%, while at the same time electric buses for example account for 57% of the bus fleet.

4.1.2 Kilometrage

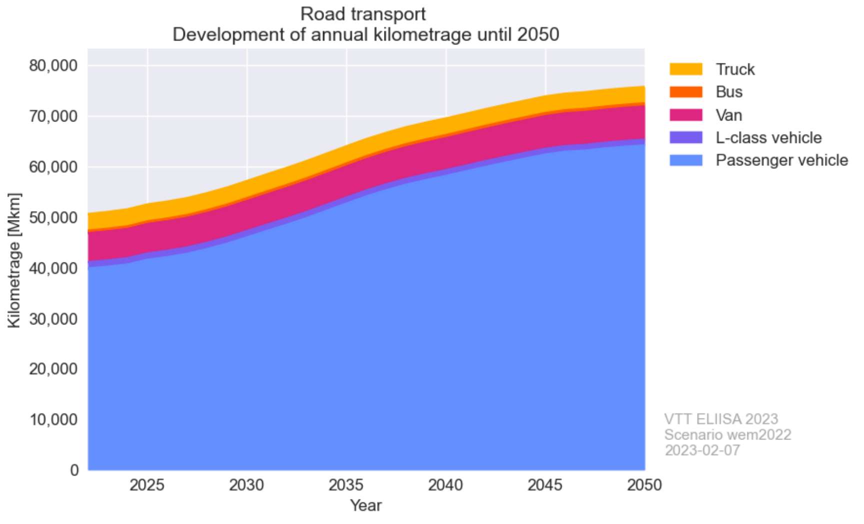

Figure 8. Development of annual kilometrage of all vehicles in WEM2022 scenario in 2022 – 2050.

Total modelled kilometrage of road transport in 2022 is 50 500 Mkm (million kilometres). Most of the kilometrage is driven using passenger vehicles (39 800 Mkm). Kilometrage of other vehicle types in 2022 is as follows: vans 5 800 Mkm, trucks 3 300 Mkm, L-class vehicles 1 200 Mkm and buses 500 Mkm (Figure 8).

Total kilometrage grows 13% by 2030 to 57 100 Mkm and 49% by 2050 to 75 700 Mkm. The rate of change slows down in the time period 2030 – 2050, after which total kilometrage reaches a more constant level.

Passenger vehicle kilometrage accounts for 97% of the total increase in kilometrage by 2050. The other vehicle types do not see a similar rapid increase in kilometrage, although the share of kilometres driven by electric vehicles increases in each vehicle category. This result is likely due to the underlying assumptions that electric vehicles have a larger annual kilometrage than other motive powers due to their relatively inexpensive driving when compared to the combustion engine vehicles (Traficom, 2021). Currently this assumption is modelled only for passenger vehicles and not for other vehicle types.

4.1.3 Energy consumption

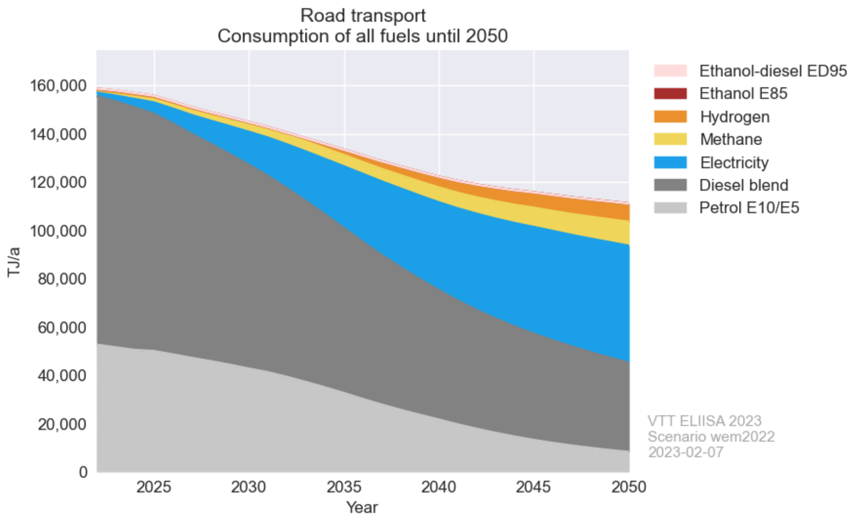

Figure 9. Energy consumption of road transport in WEM2022 scenario in 2022 – 2050.

In 2022, the modelled total energy consumption of road transport is 158 700 TJ (terajoules) (Figure 9). Most of the energy consumed is in the form of diesel (65%) and petrol blends (33%). Energy consumption decreases throughout the modelled time period approximately 1%-unit per year: decrease in energy consumption is 9% by 2030 (total consumption 144 800 TJ) and 30% by 2050 (total consumption 111 000 TJ). The decrease in energy consumption is likely due to the increase in the number of more energy efficient vehicles. Diesel remains as the primary energy source until 2045 when electricity becomes the single largest motive power used in road transport.

Total modelled electricity consumption in 2022 is 0.4 TWh (terawatt hours) (Figure 10). 94% of it is consumed by passenger vehicles, 3% by buses, 2% by vans and 1% by trucks. Electricity consumption increases nearly 10-fold up to 3.8 TWh by 2030. Even larger increase is seen in 2050, when electricity consumption reaches 13.5 TWh. Majority of electricity in road transport is consumed by passenger vehicles throughout the time period (94% in 2022; 87% in 2030; 82% in 2050), although the shares of other vehicles increase slightly.

Consumption of gaseous fuels increases steadily until 2050. Methane consumption is 0.3 TWh in 2022 but reaches 1 TWh in 2030 and increases up to 2.8 TWh in 2050 (Table 5). Over half of the methane is consumed by heavy-duty vehicles (47% by trucks and 10% by buses) already in 2022. The share of methane consumed by heavy-duty vehicles increases to a total of 99% by 2050. Most of it is consumed by articulated trucks.

Table 5. Energy consumption in WEM2022 scenario in 2022, 2030 and 2050 presented in litres of liquid fuels and terawatt hours (TWh) of electricity and gaseous fuels.

Source of energy	**2022**	**2030**	**2050**	**Unit**
Petrol (blend)	1 682	1 366	261	million litres
Diesel (blend)	2 980	2 459	1 070	million litres
E85[5]	18	11	0	million litres
ED95[6]	2	1	0	million litres
Electricity	0.4	3.8	13.5	TWh
Methane (blend)[7]	0.3	1.0	2.8	TWh
Hydrogen	0.0	0.1	2.1	TWh

Hydrogen consumption is nearly zero in 2022 since there are only two hydrogen vehicles in the official vehicle register. Yet, hydrogen sees a similar increase as methane in energy consumption starting after 2030 as fuel cell vehicles are assumed to breach the market.

The consumption of the fuel blends, which are accounted for in the biofuel obligation (petrol, diesel and methane blends), decreases throughout the time period (Figure 11). In 2022, 51% of those fuel blends are consumed by passenger vehicles, but their share decreases as the fleet electrifies. By 2050, passenger vehicles consume only 14% of fuel blends. Trucks become the largest fuel blend consumer after 2031 and are therefore the largest biofuel consumer due to the biofuel obligation when considering the quantity of fuel consumed.

[5] E85 is a blend of fossil petrol and ethanol or other biobased petrol-products with an average bio content of 84 vol-%.

[6] ED95 is a blend of ethanol and additive with an assumed bio content of 95 vol-%.

[7] Methane blend comprises of compressed natural gas (CNG), compressed biogas (CBG), and liquid natural gas (LNG).

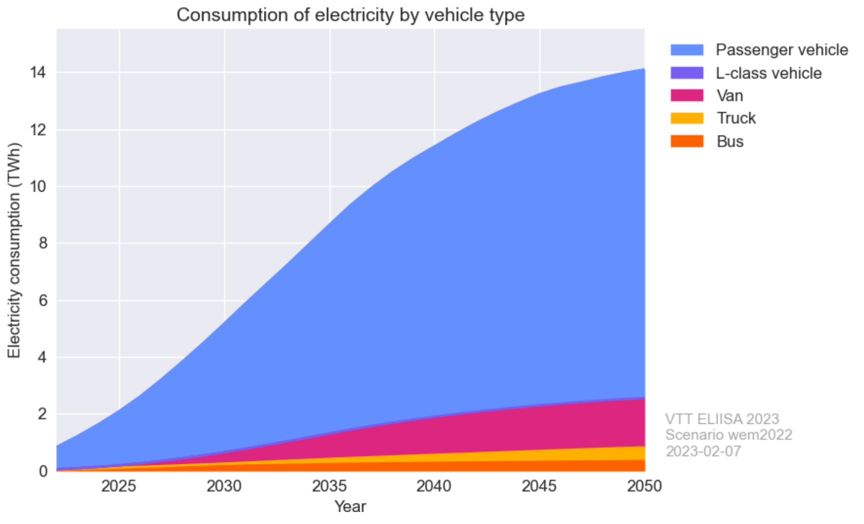

Figure 10. Electricity consumption by vehicle type in WEM2022 scenario in 2022 – 2050.

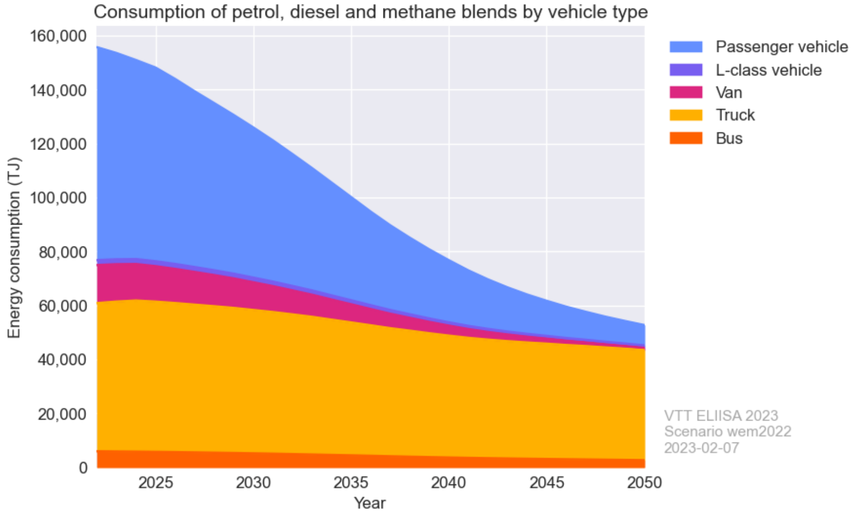

Figure 11. Consumption of petrol, diesel and methane blends by vehicle type in WEM2022 scenario in 2022 – 2050.

Biofuel consumption and its relative shares increase rapidly after 2023 due to the recent changes in legislation to overcome the energy crises and high fuel prices (Figure 12). The peak consumption of biofuels stays at around 45 000 TJ/year for road transport which will persist until 2032. As long as the biocomponent of petrol blend remains at around 10 vol%, any increase of the level of biofuel distribution obligation will result in increased demand for biodiesel, since there are not enough methane-powered vehicles that would consume enough methane to replace biodiesel. Biomethane, however, starts to replace increasingly larger shares of biodiesel after 2035, as methane becomes more common motive power in heavy-duty vehicles. Electrification of passenger vehicles would not bring an instant relief to the demand of biodiesel since most of the diesel blend is consumed by heavy-duty vehicles.

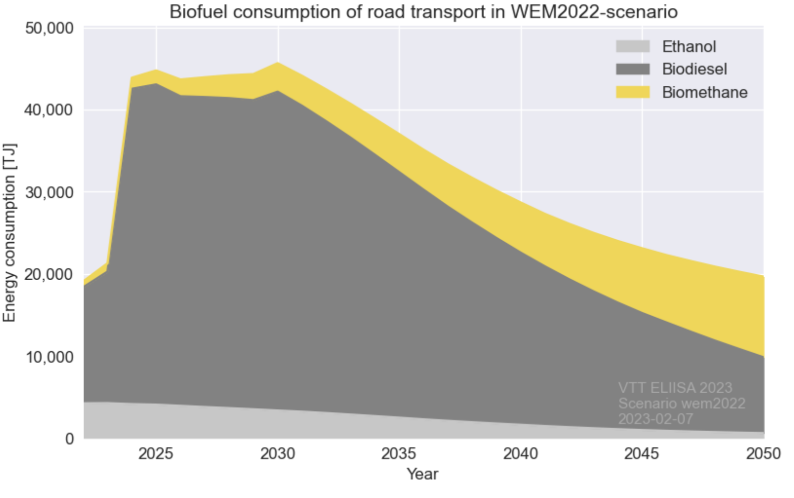

Figure 12. Biofuel consumption per fuel type of road transport in 2022 – 2050 in WEM2022 scenario.

4.1.4 Greenhouse gas emissions

GHG emissions of road transport in Finland have decreased in the past 20 years, but at varying pace. After few years of decreasing trend, GHG emissions increased again in 2022 and peaked at 10.1 Mt CO_2eq (megatons of carbon dioxide equivalent) due to changes in biofuel distribution obligation. In 2022, passenger vehicles accounted for half (52%) of the GHG emissions, trucks 35%, vans 9%, buses 4% and L-class vehicles 1%. The assumed shares remain nearly at the same level in 2030 but change drastically by 2050 when trucks become the largest source of GHG emissions with a share of 68%. In 2050, passenger vehicles account only for 23% of road transport GHG emissions, buses 4%, vans and L-class vehicles 2%.

Major decrease in GHG emissions is seen by 2030, when GHG emissions drop to 6.3 Mt CO_2eq (Figure 13). GHG emissions continue to decrease to a level of 2.6 Mt CO_2eq in 2050. When compared to the GHG emissions of 2005, the GHG emissions decreased 47.4% by 2030. The national GHG emission reduction target for transport is 50% by 2030 when compared to 2005; based on our results, more policies and other measures are needed within the transport sector to reach the target.

The GHG emissions of all vehicle types decrease throughout the time period, except for trucks: their GHG emissions stabilise to a nearly constant level after 2030, since the major source of energy is diesel, of which CO_2-emission factor depends on the level of biofuels dictated by biofuel distribution obligation. Despite of that, trucks' GHG emissions decrease 41% by 2030 and 49% by 2050 compared to the current situation in 2022. The largest changes in GHG emissions are seen in vans (-53% in 2030, -94% in 2050) and in passenger vehicles (-34% in 2030, -88% in 2050).

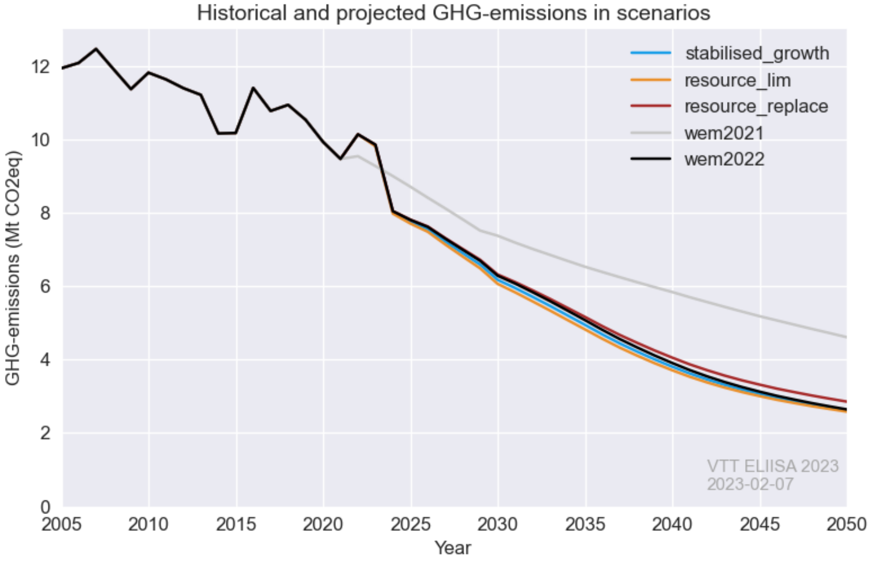

Figure 13. Historical GHG emissions of road transport in 2005 – 2021 (Official Statistics of Finland, 2022d) and development in the baseline and alternative scenarios in 2022-2050.

4.2 Alternative scenarios

4.2.1 Stabilised growth scenario

In Stabilised growth scenario, the number of new registered passenger vehicles was stabilised to a constant level of 100 000 vehicles/year and the number of imported vehicles remained at level of 45 000 vehicles/year.

The size of the passenger vehicle fleet decreases slightly by 2030 and the total passenger fleet size reaches 2.65 million vehicles. The fleet size continues to decrease until stabilising to a constant level of 2.5 million vehicles in 2040. There are 7% less passenger vehicles in 2030 and 22% less in 2050 compared to the corresponding years in the WEM2022 scenario. The relative composition of passenger fleet does not change significantly compared to the WEM2022, since the shares of motive powers were not varied in the scenario. However, due to the lower number of new registrations, there are fewer electric vehicles (BEV and PHEV) in the fleet: 0.76 million vehicles in 2030 and 2.0 million vehicles in 2050. There is a decrease of 0.11 and 0.62 million electric vehicles in 2030 and 2050, respectively, in Stabilised growth scenario compared to WEM2022 scenario. Despite this, the electric vehicle fleet would still reach the national target of 700 000 EVs in 2030 as stated in the *Roadmap to fossil-free transport*.

The stabilisation of the passenger vehicle fleet size will also stabilise the total kilometrage: by 2045, passenger vehicle kilometrage reaches its peak of 49 000 Mkm, whereas in the WEM2022 scenario the kilometrage continues to increase to 64 000 Mkm and beyond. The relative reduction of kilometrage of each motive power is directly proportional to the relative reduction of fleet size per motive power.

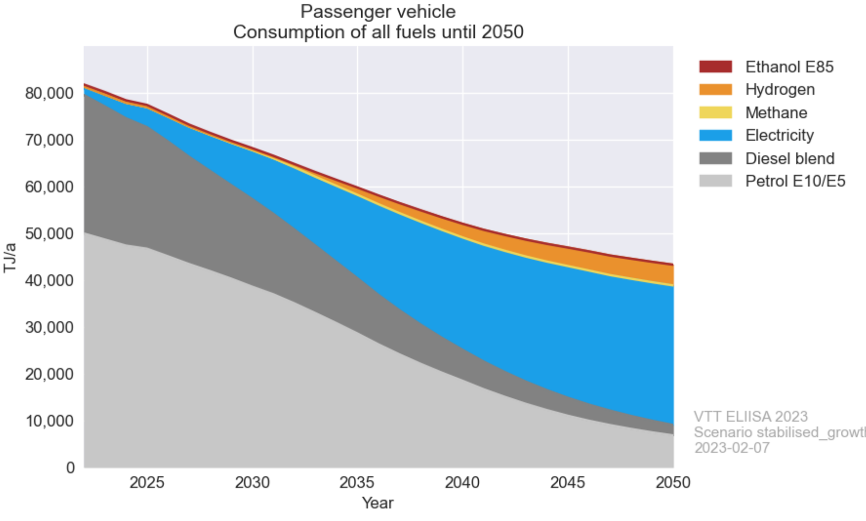

Figure 14. Energy consumption of passenger vehicles per fuel type in 2022 – 2050 in Stabilised growth scenario.

Energy consumption of passenger vehicles follows the reduction of kilometrage as depicted in Figure 14: in 2030, the consumption of all fuels is 68 200 TJ/a (changed by -6%), but the difference with the WEM2022 scenario grows larger in 2040 (52 000 TJ/a, changed by -15%) and in 2050 (43 200 TJ/a, changed by -22%).

Fuel consumption decreases as well: petrol blend consumption decreases 64 million litres, diesel blend consumption 10 million litres and methane blend consumption 686 t by 2030. This reduces the absolute amount of biofuels needed to fulfil the bio-obligation by total of 793 TJ which equals to a change of -2%.

GHG emissions of road transport are 6.2 Mt CO_2eq in 2030 and 2.6 Mt CO_2eq in 2050. When compared with the WEM2022 scenario, the decrease in GHG emissions is slightly faster in the Stabilised growth scenario: GHG emissions changed by -2% in 2030 and -1% in 2050. Although the smaller passenger vehicle fleet reduced the kilometrage and energy consumption, the GHG emissions did not decrease as much.

4.2.2 Resource lim scenario

In the Resource lim scenario, the number of new registered passenger vehicles decreased linearly from 81 698/year vehicles in 2022 down to 50 000 vehicles/year in 2050 and the number of imported vehicles remained at level of 45 000 vehicles/year. This implicates that nearly half of the new additions to the fleet are imports of the used vehicles of various ages in this scenario.

The passenger fleet decreases 13% by 2030 and 44% by 2050 in the Resource lim scenario compared to the WEM2022 scenario. There are 2.46 million passenger vehicles in 2030 of which 0.65 million are electric vehicles (BEV and PHEV) and only 1.81 million passenger vehicles in 2050 of which 1.4 million are electric.

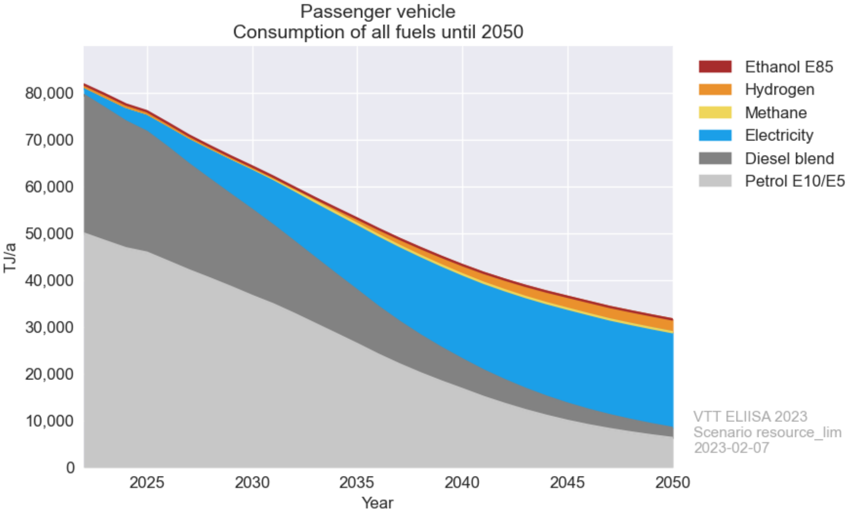

Figure 15. Energy consumption of passenger vehicles per fuel type in 2022 – 2050 in Resource lim scenario.

The reduction of kilometrage and energy consumption follows the same path as in Stabilised growth scenario: changes in vehicle fleet size are directly proportional to the changes in kilometrage and energy consumption. Total passenger vehicle kilometrage stops increasing right after 2022 and will stay at the level of 39 000 Mkm until 2040, after which it starts to decrease.

Energy consumption of passenger vehicles decreases rapidly: in 2030, the consumption of all fuels is 64 200 TJ and in 2050, 31 600 TJ (changed by -11% and -43% respectively, compared with the WEM2022). Petrol blend consumption decreases 127 million litres, diesel blend consumption 19 million litres and methane blend consumption 1 354 t by 2030 compared with the WEM2022 scenario. The absolute amount of biofuels needed to fulfil the bio-obligation decreases even more than in Stabilised growth scenario (1 580 TJ; changed by -3%).

Even though passenger vehicle fleet size, kilometrage and energy consumption decrease more in Resource lim scenario than in Stabilised growth scenario, the GHG emissions of road transport decrease at the same rate in both of the scenarios. The GHG emissions were 6.1 and 2.6 Mt CO_2eq in 2030 and in 2050, respectively.

4.2.3 Resource replace scenario

In the Resource replace scenario, the number of vehicles added to the fleet annually remained at the same level as in the WEM2022 scenario, but instead of increasing new registrations, the number of imported vehicles was increased annually from the level of 41 396 vehicles in 2022 to 94 992 vehicles in 2050. New registrations stayed at a constant level of 100 000 vehicles/year until 2050.

The size of vehicle fleet is nearly the same in the Resource replace as in the WEM2022 scenario: in 2030, there are 2.8 million passenger vehicles, and in 2050, 3.1 million passenger vehicles. The slightly smaller vehicle fleet is due to the fact that imported vehicles are generally older vehicles than new registrations and the removal rate of vehicle fleet depends on the number of vehicles in each age group. Older vehicles results in more removals, hence, a smaller fleet.

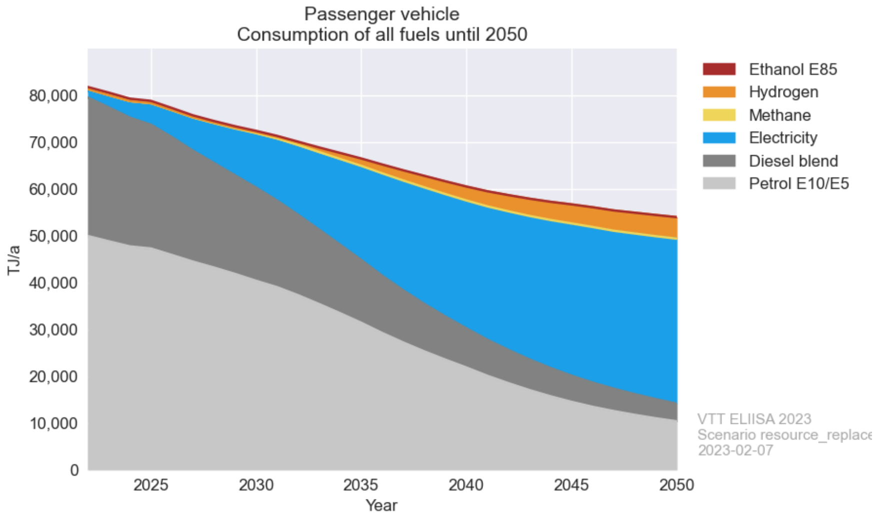

Figure 16. Energy consumption of passenger vehicles per fuel type in 2022 – 2050 in the Resource replace scenario.

Although the passenger vehicle fleet did not shrink, the relative shares of motive powers did change. Compared with the WEM2022 scenario, there are less BEV vehicles in 2030 (changed by -7%), but more PHEV vehicles (changed by +10%). The same applies for 2050: BEV fleet decreased by 12% and PHEV increased by 60%. In total, the number of electric vehicles (BEV and PHEV) remain nearly the same in 2030 as in the WEM2022 scenario, just the relative shares of BEV and PHEV changed due to the assumptions concerning the motive powers of imported vehicles. Another significant finding is that petrol and diesel fleet also increased compared with the WEM2022 scenario: the increase was 33% and 64% for petrol and diesel vehicles, respectively.

Total passenger vehicle kilometrage decreased when compared with the WEM2022: 45 700 Mkm in 2030 and 59 700 Mkm in 2050. However, energy consumption did not follow the decrease in kilometrage, since the number of less energy efficient vehicles increased in the Resource replace scenario compared with the WEM2022 scenario. Energy consumption of passenger vehicles decreases throughout the time period, but when compared with the WEM2022 scenario, energy consumption increased by 2030, but started to moderately decrease until 2050. However, the decreases in energy consumption was far higher in the Stabilised growth and Resource lim scenarios, where the fleet included more fully electric vehicles.

The decrease in kilometrage and energy consumption follow the same path as in the Stabilised growth scenario: changes in the vehicle fleet were directly proportional to the changes in kilometrage and energy consumption. Total passenger vehicle kilometrage stops growing right after 2022 and will stay on the level of 39 000 Mkm until 2040, after which it starts to decrease.

Petrol blend consumption decreases the least of all scenarios (6 million litres). Diesel and methane blend consumption increases to 25 million litres and 77 t in 2030 compared to the WEM2022. The absolute amount of biofuels needed to fulfil the bio-obligations actually increased: 233 TJ more biofuels are needed in 2030 compared with the WEM2022 scenario, and most of it as biodiesel.

The Resource replace scenario was the only scenario, in which GHG emissions of road transport decreased slower than in the WEM2022 scenario. The GHG emissions were 6.3 Mt CO_2eq in 2030 and 2.9 Mt CO_2eq in 2050 (changed by +1% and +8% compared to the WEM2022).

5 Discussion

Finland's GHG emissions from road transport have decreased, but until 2022, they decreased only 15% compared to 2005[8] level. GHG emissions decrease rapidly in the WEM2022 scenario and by 2030, the decrease is 47.4% compared to 2005 level. This is already closer to Finland's goal of achieving 50% GHG emission reductions in the entire transport sector by 2030 compared to 2005. In the previous WEM2021 scenario, road transport GHG emissions reductions were 40.9% (Valtioneuvoston Hankeikkuna, 2021a). An earlier, unpublished version of WEM2022 scenario[9] reported 49.4% GHG emission reduction for the same years, but the version included less precise estimation of CH_4 and N_2O emissions, lacked CO_2-emissions from urea consumption in later diesel vehicles and had a much smaller estimation of the number of petrol-powered quadricycles (Markkanen, 2022).

GHG emissions are controlled by biofuel distribution obligation

Electrification of vehicle fleet accelerates the GHG emission reductions, but it will take a long time until a full-scale transition to low and zero emission vehicle fleet is achieved. Until then, Finland's biofuel distribution obligation dominates both the direction and magnitude of GHG emission reductions of road transport. As seen in the Figure 13, the temporary decrease in the level of biofuel distribution obligation caused a significant increase in GHG emissions in the WEM2022 scenario for the years 2022 and 2023, although GHG emissions are expected to return to the previous, rather linear trajectory towards zero still before 2030s.

The controlling impact of biofuel distribution obligation on GHG emissions was also observed in the results of the alternative scenarios. To our surprise, there was little or no change in the GHG emissions compared to the WEM2022 scenario, even though the passenger vehicle fleet size, kilometrage and energy consumption changed considerably. The largest decrease in passenger vehicle fleet size was seen in the Resource lim scenario, in which the number of new registrations

[8] GHG-emissions of road transport were 11.93 Mt CO2eq in 2005 (Official Statistics of Finland, 2022d).

[9] See Acknowledgements for more information about the unpublished WEM2022 scenario.

continued to decrease from today's levels due to the assumed impact of resource scarcity on global vehicle manufacturing industry. Despite that passenger vehicle fleet was staggering -44% smaller in 2050 compared to the WEM2022, GHG emissions decreased as little as in the Stabilised growth scenario, only 1% less in 2050 compared to WEM2022. This outcome is partially explained by the large-scale electrification of passenger vehicle fleet, which is why the changes in passenger vehicle fleet did not cause significant GHG emission reductions within the entire road transport sector.

Varying the number of new registrations and imported vehicles showed how much the shares of motive powers of imported vehicles affect the vehicle fleet composition and consumption. It was surprising that imported vehicles in case of passenger vehicles have such an impact on the vehicle fleet projections; also, it was important to discover that the modelling choices regarding imported vehicles require improvement.

The changes of vehicle fleet composition seen in the Resource replace scenario were artifacts caused by modelling choices and assumptions; the shares of motive powers of imported vehicles are estimated to change with time, but the age distribution per motive power was assumed to remain at today's level throughout the time series. The assumption limits the model's capability to consider any indirect impacts of policies and other measures. More research is needed to define those aforementioned dependencies. The results concerning vehicle fleet composition in alternative scenarios should not be taken as facts, but to treat them as intermediate model outputs, which may contain uncertainties. Despite the potential uncertainties in vehicle fleet results, the GHG emissions of the road transport sector were more controlled by the biofuel distribution obligation than by the changes in passenger vehicle fleet size and composition.

The dynamic mechanism of biofuel obligation is complex, since it has the ability to balance the GHG emissions over the three fuel blends, i.e. petrol, diesel, and methane. One might wonder whether this mechanism affects adversely on other climate policies that aim to reduce GHG emissions of road transport. In Stabilised growth scenario, the GHG emissions were 2% smaller in 2030 compared to the same year in the WEM2022 scenario. However, if the GHG emissions from passenger vehicles are considered only, the reduction was 4%. It seems that when GHG emissions of passenger vehicles decreased, GHG emissions increased from other vehicles (Table 6).

A longer, but more thorough breakdown of a key observation from the results follows: In the Resource replace scenario, petrol and diesel vehicle fleet size increased due to the larger number of vehicle imports compared to the WEM2022. This in turn increased the total fuel consumption in road transport. GHG emissions of passenger vehicles increased due to larger fuel consumption, but GHG emissions of other vehicles decreased. The decrease was caused by a change in the calculated CO_2-emission factor of diesel blend. How is it possible that there is more diesel consumption, but CO_2-emission factor decreased? This is because of the increase in the number of imported vehicles: although there were more petrol-powered passenger vehicles in the Resource replace scenario than in the

WEM2022, the vehicles were older. Older models of vehicles are assumed to consume more fuel, but in the case of petrol, they are also assumed to be driven much less than e.g., electric vehicles. Less kilometrage results in smaller total consumption; hence, petrol consumption actually decreased despite the larger number of vehicles and larger amount of total fuel consumption. Less petrol blend consumption implies directly less ethanol consumption. To compensate for the decreased ethanol consumption, more biodiesel or biomethane need to be consumed to reach the required relative share of biofuels for each year due to distribution obligation. This is why the CO_2-emission factor of diesel blend decreased, as more biodiesel was distributed. Hence, it is important to acknowledge that the change in total GHG emissions always includes the net change, not the relative changes of emissions between vehicle types (Table 6).

Table 6. GHG emissions of passenger vehicles and of other vehicles in studied scenarios for 2030 and 2050 in Mt CO_2eq.

2030	Passenger vehicles	Other vehicles	Road transport total
WEM2022	3.47	2.81	6.28
Stabilised growth	3.33	2.84	6.17
Resource lim	3.2	2.87	6.07
Resource replace	3.49	2.82	6.31

2050	Passenger vehicles	Other vehicles	Road transport total
WEM2022	0.62	2.02	2.64
Stabilised growth	0.58	2.03	2.61
Resource lim	0.54	2.04	2.58
Resource replace	0.89	1.96	2.85

The functioning mechanism of biofuel distribution obligation is a key finding from this study, as the GHG emissions did not vary much in the alternative scenarios. The dynamic balancing of CO_2 emissionfactors leads to sometimes unexpected results, as CO_2 reductions caused by e.g., purchase incentive of electric vehicles are calculated. Any changes in the vehicle fleet that will result in change of consumption of petrol, diesel, or methane blends, will affect the CO_2 emissions of all the diesel vehicles in the fleet, since biodiesel is used as the balancing fuel when calculating the optimised biofuel consumption for each year.

The calculated CO_2 impact is always a combination of the impacts of two policies (policy in question and biofuel distribution obligation), and it will differ from a result that would be calculated as an isolated case only using fixed CO_2 emission factors. Isolated assessments, like performed in Jääskeläinen (2021), can give too optimistic results regarding the GHG emission reduction potential, since they have yet not considered the national level mechanism of biofuel distribution obligation.

Note that the conclusions made from the results depend on the assumptions made regarding the biofuel distribution obligation: it is also possible that the mechanism functions differently but determining it would require analysis of detailed fuel sales data from several past years. It would be beneficial to study the mechanism of biofuel distribution obligation further to improve modelling and decrease the uncertainties caused by modelling assumptions, and to study if more efficient and socially just GHG emission reductions could be achieved without biofuel distribution obligation.

Energy consumption

Energy consumption – and energy saving – has become more important topic than ever since the European energy crisis began in 2022. Fuel and electricity prices have varied greatly during a short period of time and our model is not capable to consider such sudden changes since the cost of driving is indirectly included via the national kilometrage projections. Hence, it should be noted that the modelled scenarios include the same assumptions for the costs of driving in each scenario and those assumptions are dated to the year 2021.

The total energy consumed by vehicles decreased approximately 1%-unit/year in the WEM2022 scenario. Electricity, methane, and hydrogen consumption increased as petrol and diesel consumption continued to decrease (Figure 9). The increase in methane consumption is caused by the small-scale "gasification" of the truck fleet, although hydrogen is seen promising in heavy-duty transport as well, as EU's proposal for alternative fuels infrastructure (AFIR) directive is expected to start developing the hydrogen fuelling network also in Finland. Diesel remains as the primary source of energy in road transport until 2045 even though passenger vehicle fleet is electrified rapidly. Heavy-duty vehicles consume a large share of the energy needed in road transport in the form of diesel and methane. This implies that also a large share of biofuels is consumed by heavy-duty vehicles.

Finland is not the only country aiming to decrease the direct GHG emissions from transport by using biofuels. In addition to road transport, maritime and air transport are large international users of diesel-based products. Extending the emission trading system to maritime transport fuels is expected to increase the demand for biodiesel even further, not to mention Finland's biofuel distribution obligation for non-road mobile machinery and residential oil heating. Competition for sustainably produced biodiesel will obviously increase in near future and if the supply cannot meet the demand, prices are expected to increase, which would also reflect on the costs of transport.

The number of new registrations and imported passenger vehicles were varied in the alternative scenarios to examine their impact on energy consumption. Total energy consumption of road transport decreased in scenarios, where the passenger vehicle fleet size either remained at the current level or decreased. However, the observed decrease in total energy consumption did not bring about large changes in the absolute amounts of biofuels needed to fulfil the bio-obligation during the next decade. Especially diesel consumption of passenger vehicles decreases rather rapidly already in the WEM2022 scenario and any further decrease in consumption creates a marginal impact, which is probably the main reason. The changes in biofuel consumption in all the alternative scenarios were relatively small and would not reduce the demand of biodiesel in the near future.

Limitations and uncertainty

There are several limitations and uncertainties regarding the results shown in this report. The uncertainties and limitations have been subjectively estimated by the authors. Uncertainties arise from the assumptions and modelling choices, and from the lack and poor quality of some input data.

There is a significant gap in the translation of the source data into an input data for the model, which could result in major uncertainties and, in the worst-case, wrong conclusions of the results. Reducing data-based uncertainties would require producing policy impact assessments and reports for road transport, which provide more detailed information concerning methodology, data and results.

The modelled results of vehicle fleet, energy consumption and mileage are more reliable for passenger vehicles and vans since EU's new CO_2 emission limits affect strongly on the market shares of new registrations. However, as seen from the results of the Resource replace scenario, the assumptions regarding age distribution of imported vehicles do have an impact on the results. To improve the model, more research is needed to better analyse the market of imported vehicles in Finland. In addition, we need to understand better how people's preferences change and respond to external factors such as policies and prices.

The fleet size of heavy-duty vehicles may be overestimated by the model. To assess the reliability of the vehicle fleet estimates, more information and data regarding the potential future changes in demand for public transport and logistics are needed. Probably the least reliable results concern the L-class fleet. There is very little data and future estimates on the future demands of motorcycles, mopeds and quadricycles considering how the transport systems are developing in cities. As many cities are aiming to become carbon neutral by 2030-2035, their transport systems need to be systemically developed to reduce transport-related GHG emissions. Defining the role of L-class vehicles in the future transport system requires more research also because they are, in some cases, capable of replacing passenger vehicles in passenger transport.

Kilometrage and energy consumption results depend directly on the vehicle fleet size and composition. Therefore, any uncertainties in the vehicle fleet estimation will increase the uncertainty of kilometrage and consumption results. The model does not contain dependencies between energy prices and kilometrage although such dependencies exist to some extent. Fuel prices, and therefore the cost of driving, is defined for passenger vehicles in the models used for National kilometrage projections (Traficom, 2021). As those projections were used as the inputs for our model, the cost of driving is only indirectly considered in the results. However, the costs are the same in each scenario, and any changes in the energy prices cannot be reflected in the driving behaviour and therefore in the GHG emission pathways.

Although the intermediate outputs of the model, namely vehicle fleet size, kilometrage and energy consumption, responded to the changes in the model input in alternative scenarios, GHG emissions did not vary greatly. Therefore, it is notable that GHG emissions of road transport are the most dependent on two factors: the fuel consumption and the level of biofuel distribution obligation. As the average annual kilometrage and energy consumption factors of vehicles were calibrated to the latest statistics, GHG emission results are considered to be more reliable than other model outputs to some extent since the relation of GHG emissions and biofuel distribution obligation is proven strong.

6 Conclusions

Finland's GHG emissions from road transport have decreased since policies and other measures have been implemented to reduce the GHG emissions. Updated baseline scenarios of the development of GHG emissions are crucial for assessing the effectiveness of current policies and for assessing the need for new policies to reach the national GHG emission targets. Currently, new regulations are initiated on the national and EU levels at a faster pace than the scenarios are being produced. This study aimed to provide an up-to-date WEM scenario for road transport GHG emissions and energy consumption in Finland including the updated policies and measures in force and to provide relevant recommendations for policy makers based on the results.

The new WEM2022-baseline showed that GHG emissions of road transport decrease rapidly in the WEM2022 scenario and by 2030, the decrease is 47.4% compared to 2005 level. Stricter CO_2 emission regulations of new passenger vehicles and vans and tighter national biofuel distribution obligation have made a significant impact on the GHG emission trajectory compared to the earlier baseline WEM2021. However, according to the latest assessments of the impacts of existing measures, the national GHG emission reduction target will not be met, and new effective policies are needed.

The vehicle fleet size was shown to increase together with the total kilometrage in the WEM2022 scenario, although energy consumption of road transport continues to decrease. Electrification of passenger vehicle fleet will bring substantial improvements in the energy efficiency of the vehicle fleet. However, diesel remains as the primary source of energy in road transport until 2045.

As the passenger vehicle fleet composition and size was varied in the alternative scenarios, GHG emissions did not change much although kilometrage and energy consumption responded to the variations. It seems that energy consumption and GHG emissions are decoupled to certain extent, since more energy is consumed in the form of electricity and the GHG emissions of electricity production are not accounted for in the transport sector in the national greenhouse gas inventories. Secondly, Finland's biofuel distribution obligation seems to control the final magnitude of GHG emissions within the developments depicted in the WEM2022 scenario.

The results of the study gave insights about how and where to target next to reduce GHG emissions even further. Many of the existing policies are focused on the passenger transport, even though the share of passenger vehicles' GHG emissions decreases from the current 52% to 23% by 2050 in the WEM2022 scenario. As large-scale electrification of passenger vehicle fleet occurs already in the new the WEM2022 scenario, the more and more of the GHG emissions of road transport are caused by light and heavy-duty vehicles. Therefore, new policies should be aimed especially at decarbonising heavy-duty transport by speeding up the change to battery electric and fuel cell trucks and by supporting the construction of charging and fuelling infrastructure at critical locations. Another factor that aids the idea of supporting electrification of heavy-duty vehicles more, is that they are primarily consumers of diesel fuel. That makes them most vulnerable to the financial impacts of the ever increasing global competition for the limited sustainable resources for biodiesel production. More research is needed whether the biofuel distribution obligation could have limits for the absolute amount of biofuels to ensure the availability for other transport modes as well. Availability and security of supply could also be improved by increasing domestic production of biofuels by supporting investments, as investment costs remains to be one of the largest factors affecting profitability of the biofuel production (Sipilä et al., 2021).

From an impact assessment point of view, biofuel distribution obligation is a seemingly effective way to reduce GHG emissions of road transport. However, the results showed that biofuel distribution obligation has a dynamic ability to balance CO_2 emission factors of petrol, diesel and methane blends. This may distort the comparison of GHG emission reduction potentials of policies, if this aforementioned dynamic balancing of the emission factors is not considered in individual policy impact assessments: too positive results of GHG emission reductions can be given to policies, of which actual impact could diminish when the entire road transport sector is considered.

It would be worth of studying whether other policies, like national emission trading system for road transport fuels, would result in more cost-efficient and socially just GHG emission reductions without biofuel distribution obligation or with limitations to it. Biofuel distribution obligation is anyway seen as a positive and currently needed climate policy, but the economic, environmental and social sustainability aspects as well as security of supply ought to be considered when assessing the impacts of increasing the level of biofuel distribution obligation. Overall, the Finland's current set of policies together with new policies from EU's FitFor55 package will create a long-lasting impact on the vehicle fleet composition, but to reach the national GHG emission targets, the authors urge for more sustainable measures and more transparent policy impact assessments.

Declaration of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A: Vehicle fleet development in WEM2022

Table A1: Passenger vehicle fleet in WEM2022 scenario by motive power.

Year	Petrol	Diesel	CNG-bifuel	FFV	PHEV	BEV	Fuelcell
2022	1 805 600	735 229	16 043	11 330	105 877	46 242	2
2023	1 752 279	720 999	17 498	13 867	140 848	80 967	8
2024	1 703 876	703 950	18 509	12 666	174 170	123 715	68
2025	1 655 258	684 207	19 417	11 493	205 508	174 458	190
2026	1 606 485	662 125	20 227	10 362	234 773	233 691	440
2027	1 556 492	637 906	20 932	9 283	261 428	300 616	944
2028	1 505 179	611 904	21 529	8 259	285 279	374 935	1 960
2029	1 449 281	583 179	22 031	7 299	306 108	456 021	4 008
2030	1 389 282	552 221	21 158	6 410	323 725	543 911	8 180
2031	1 323 751	519 509	20 089	5 467	336 608	638 355	14 768
2032	1 252 911	485 481	18 983	4 627	345 524	737 901	25 379
2033	1 176 932	450 564	17 843	3 887	350 406	840 897	41 386
2034	1 095 949	415 147	16 676	3 239	351 231	951 975	57 868
2035	1 010 061	379 569	15 487	2 679	348 025	1 071 156	74 487
2036	927 629	345 764	14 290	2 199	342 879	1 188 382	91 212
2037	850 082	314 530	13 099	1 790	335 933	1 303 207	107 991
2038	777 180	285 827	11 933	1 445	327 356	1 415 214	124 744
2039	708 753	259 598	10 799	1 158	317 345	1 524 016	141 353
2040	644 713	235 750	9 705	924	306 116	1 629 223	157 705
2041	585 028	214 162	8 664	732	293 902	1 730 450	173 689
2042	529 663	194 716	7 682	575	280 936	1 827 388	189 205
2043	478 566	177 259	6 762	449	267 438	1 919 802	204 168
2044	431 656	161 624	5 912	347	253 608	2 007 550	218 506
2045	388 852	147 666	5 130	267	239 627	2 091 430	232 281
2046	350 028	135 217	4 423	206	225 662	2 170 568	245 324
2047	315 042	124 130	3 786	158	211 846	2 245 027	257 608
2048	283 732	114 256	3 215	121	198 287	2 314 929	269 119
2049	255 900	105 465	2 710	93	185 081	2 380 448	279 856
2050	231 325	97 611	2 267	73	172 294	2 441 810	289 830

Table A2: L-class vehicle fleet in WEM2022 scenario by vehicle type and motive power.

Year	Moped		Motorcycle		Quadricycle		
	Petrol	BEV	Petrol	BEV	Petrol	Diesel	BEV
2022	128 157	4 052	185 261	105	37 895	5 382	187
2023	128 277	6 653	180 538	190	42 945	5 395	236
2024	127 755	9 763	175 968	313	47 714	5 382	243
2025	126 516	13 464	171 539	499	52 016	5 344	297

2026	124 579	17 735	167 240	758	55 806	5 283	361
2027	122 054	22 478	163 026	1 143	59 007	5 199	434
2028	119 148	27 488	158 866	1 677	61 558	5 089	514
2029	115 945	32 688	154 694	2 430	63 416	4 960	599
2030	112 469	38 056	150 459	3 447	64 554	4 822	697
2031	108 857	43 457	146 169	4 721	65 304	4 670	816
2032	105 131	48 876	141 791	6 276	65 696	4 514	957
2033	101 340	54 267	137 376	8 060	65 760	4 356	1 117
2034	97 494	59 613	132 923	10 069	65 527	4 197	1 317
2035	93 600	64 925	128 490	12 231	65 056	4 040	1 562
2036	89 671	70 190	124 080	14 543	64 424	3 887	1 851
2037	85 748	75 363	119 714	16 973	63 687	3 742	2 185
2038	81 847	80 435	115 388	19 516	62 856	3 605	2 609
2039	77 987	85 394	111 109	22 167	61 973	3 475	3 129
2040	74 181	90 228	106 923	24 863	61 076	3 354	3 737
2041	70 412	94 954	102 892	27 534	60 192	3 243	4 439
2042	66 695	99 563	99 013	30 176	59 247	3 147	5 328
2043	63 090	104 005	95 288	32 776	58 243	3 059	6 411
2044	59 593	108 273	91 725	35 327	57 177	2 982	7 686
2045	56 224	112 367	88 316	37 823	56 039	2 919	9 157
2046	52 981	116 280	85 060	40 261	54 631	2 864	11 021
2047	49 874	120 008	81 945	42 642	52 940	2 814	13 281
2048	46 901	123 551	78 969	44 964	50 948	2 772	15 944
2049	44 064	126 916	76 126	47 219	48 649	2 735	19 011
2050	41 359	130 106	73 420	49 407	46 179	2 707	22 345

Table A3: Van fleet in WEM2022 scenario by motive power.

Year	Petrol	Diesel	CNG-bifuel	FFV	PHEV	BEV	Fuelcell
2022	8 347	325 981	1 112	17	239	1 569	0
2023	7 483	320 905	1 489	17	498	2 839	0
2024	6 757	315 066	1 803	17	953	5 094	0
2025	6 154	309 165	2 073	17	1 650	8 542	0
2026	5 655	302 404	2 275	17	2 557	13 028	9
2027	5 217	294 780	2 408	17	3 674	18 548	28
2028	4 838	286 306	2 470	17	5 002	25 097	56
2029	4 506	276 964	2 467	17	6 537	32 663	93
2030	4 210	266 756	2 394	17	8 272	41 233	140
2031	3 940	255 676	2 316	17	9 653	51 280	196
2032	3 681	243 731	2 227	17	10 670	62 771	262
2033	3 434	230 930	2 131	17	11 322	75 668	337
2034	3 189	217 296	2 028	17	11 594	89 847	514
2035	2 943	202 835	1 919	17	11 483	105 262	794
2036	2 713	188 745	1 806	17	11 321	120 334	1 174
2037	2 497	175 049	1 689	16	11 103	135 018	1 655
2038	2 292	161 787	1 570	15	10 834	149 256	2 238

2039	2 098	149 005	1 454	15	10 504	163 087	2 819
2040	1 913	136 736	1 337	15	10 118	176 448	3 397
2041	1 740	125 028	1 222	15	9 688	188 307	3 931
2042	1 576	113 912	1 108	14	9 220	199 567	4 458
2043	1 421	103 421	1 001	14	8 720	210 184	4 978
2044	1 275	93 579	897	14	8 195	220 123	5 480
2045	1 139	84 401	799	14	7 658	229 362	5 968
2046	1 016	75 889	708	14	7 118	237 877	6 436
2047	899	68 047	624	14	6 577	245 674	6 882
2048	794	60 862	545	14	6 044	252 765	7 304
2049	698	54 319	473	13	5 525	259 171	7 700
2050	609	48 389	409	12	5 028	264 915	8 068

Table A4: Bus fleet in WEM2022 scenario by motive power.

Year	Petrol	Diesel	CNG-bifuel	ED95	PHEV	BEV	Fuelcell
2022	18	9 950	69	0	2	550	0
2023	14	9 922	87	0	2	808	0
2024	11	9 880	106	0	2	1 074	0
2025	9	9 815	125	0	2	1 348	0
2026	7	9 735	143	0	2	1 629	0
2027	6	9 634	161	0	2	1 917	0
2028	5	9 515	180	0	2	2 208	0
2029	4	9 397	201	0	2	2 533	0
2030	4	9 263	222	0	2	2 860	0
2031	4	9 121	243	0	2	3 187	0
2032	4	8 964	264	0	2	3 512	0
2033	4	8 797	283	0	2	3 835	0
2034	4	8 618	300	0	2	4 153	0
2035	4	8 439	316	0	2	4 468	0
2036	3	8 256	332	0	2	4 777	0
2037	3	8 065	346	0	2	5 081	0
2038	3	7 872	361	0	2	5 376	0
2039	3	7 680	375	0	2	5 664	0
2040	3	7 487	388	0	2	5 943	0
2041	3	7 292	401	0	2	6 214	0
2042	3	7 098	413	0	2	6 477	0
2043	3	6 903	423	0	2	6 690	0
2044	3	6 705	432	0	2	6 894	0
2045	3	6 509	441	0	2	7 092	0
2046	3	6 311	448	0	2	7 275	0
2047	3	6 120	455	0	2	7 453	0
2048	3	5 927	462	0	2	7 624	0
2049	3	5 736	468	0	2	7 788	0
2050	3	5 544	475	0	2	7 946	0

Table A5: Rigid truck (single-trailer truck) fleet in WEM2022 scenario by motive power.

Year	Petrol	Diesel	CNG-bifuel	ED95	PHEV	BEV	Fuelcell
2022	2 056	65 886	499	119	0	104	0
2023	1 979	65 960	740	117	0	247	0
2024	1 903	66 173	968	115	0	331	0
2025	1 830	66 445	1 178	112	0	441	0
2026	1 755	66 774	1 374	108	0	575	0
2027	1 683	67 167	1 555	105	0	735	0
2028	1 595	67 610	1 716	101	0	918	0
2029	1 501	68 111	1 864	96	0	1 126	0
2030	1 400	68 534	1 986	89	0	1 355	0
2031	1 300	69 190	2 131	84	0	1 626	0
2032	1 201	69 767	2 276	76	0	1 921	0
2033	1 104	70 273	2 424	71	0	2 238	0
2034	1 010	70 716	2 567	64	0	2 576	0
2035	921	71 098	2 711	61	0	2 937	0
2036	831	71 349	2 853	56	0	3 312	0
2037	744	71 485	2 993	50	0	3 705	0
2038	663	71 647	3 134	46	0	4 112	0
2039	587	71 814	3 274	42	0	4 534	0
2040	520	71 965	3 411	39	0	4 967	0
2041	457	72 099	3 547	36	0	5 412	0
2042	399	72 200	3 685	33	0	5 873	0
2043	347	72 248	3 820	31	0	6 341	0
2044	301	72 252	3 957	30	0	6 817	0
2045	262	72 203	4 096	29	0	7 304	0
2046	227	72 102	4 235	28	0	7 796	0
2047	199	71 945	4 373	27	0	8 293	0
2048	174	71 738	4 515	26	0	8 796	0
2049	152	71 479	4 657	25	0	9 301	0
2050	133	71 170	4 800	24	0	9 812	0

Table A6: Articulated truck (multi-trailer truck) fleet in WEM2022 scenario by motive power.

Year	Petrol	Diesel	CNG-bifuel	ED95	PHEV	BEV	Fuelcell
2022	2	25 275	168	2	0	1	0
2023	2	25 906	239	2	0	6	0
2024	2	26 448	314	2	0	15	0

2025	2	26 890	396	2	0	28	1
2026	2	27 341	484	2	0	45	3
2027	2	27 687	579	2	0	66	6
2028	2	27 931	676	2	0	91	10
2029	2	28 083	777	2	0	121	16
2030	2	28 149	884	2	0	155	27
2031	2	28 244	1 020	2	0	200	45
2032	2	28 259	1 170	2	0	253	68
2033	2	28 315	1 337	2	0	313	96
2034	2	28 405	1 520	2	0	381	129
2035	2	28 420	1 716	2	0	456	167
2036	2	28 478	1 929	2	0	535	210
2037	2	28 465	2 156	2	0	621	258
2038	2	28 390	2 394	2	0	711	311
2039	2	28 248	2 647	2	0	808	369
2040	2	28 053	2 913	2	0	911	432
2041	2	27 803	3 190	2	0	1 021	498
2042	2	27 509	3 477	2	0	1 134	568
2043	2	27 174	3 775	2	0	1 250	643
2044	2	26 801	4 083	2	0	1 372	723
2045	2	26 399	4 399	2	0	1 498	808
2046	2	25 962	4 720	2	0	1 627	899
2047	2	25 500	5 050	2	0	1 757	991
2048	2	25 014	5 383	2	0	1 894	1 085
2049	2	24 507	5 723	2	0	2 031	1 183
2050	2	23 982	6 071	2	0	2 169	1 285

Appendix B: Kilometrage development in WEM2022

Table B1. Kilometrage by vehicle type in WEM2022 scenario in millions of kilometers (Mkm).

Year	Passenger vehicle	Moped	Motor-cycle	Quadri-cycle	Bus	Van	Rigid truck	Articulated truck	Total
2022	39 784	192	833	200	468	5 766	1 513	1 770	50 527
2023	40 124	196	812	223	481	5 786	1 510	1 815	50 947
2024	40 563	200	792	245	494	5 808	1 508	1 854	51 465
2025	41 493	204	773	265	506	5 835	1 501	1 860	52 437
2026	42 022	207	755	282	518	5 854	1 495	1 864	52 998
2027	42 676	210	738	297	530	5 876	1 490	1 869	53 686
2028	43 605	213	722	308	541	5 899	1 493	1 873	54 655
2029	44 665	216	706	317	553	5 928	1 498	1 878	55 762
2030	45 916	219	692	322	566	5 959	1 500	1 882	57 055
2031	47 180	222	678	325	578	5 994	1 520	1 878	58 374
2032	48 418	224	666	327	586	6 026	1 532	1 876	59 654
2033	49 724	226	654	327	594	6 060	1 542	1 871	60 999
2034	51 152	229	643	326	602	6 096	1 536	1 866	62 450
2035	52 592	231	633	324	609	6 133	1 529	1 862	63 912
2036	53 999	233	623	322	613	6 172	1 519	1 856	65 337
2037	55 225	234	614	320	613	6 207	1 505	1 851	66 569
2038	56 319	236	606	317	613	6 245	1 497	1 846	67 680
2039	57 227	238	599	315	613	6 281	1 485	1 839	68 597
2040	58 050	239	592	313	613	6 315	1 473	1 834	69 429
2041	58 943	241	586	312	613	6 347	1 459	1 831	70 333
2042	59 851	242	581	311	614	6 374	1 455	1 827	71 255
2043	60 694	243	576	311	614	6 403	1 457	1 822	72 120
2044	61 503	244	571	312	614	6 425	1 459	1 820	72 947
2045	62 293	245	567	313	614	6 456	1 469	1 814	73 771
2046	62 831	246	563	315	613	6 477	1 469	1 810	74 325
2047	63 074	247	560	317	614	6 504	1 473	1 806	74 595
2048	63 494	248	557	320	613	6 527	1 468	1 802	75 029
2049	63 830	249	554	323	613	6 550	1 466	1 797	75 383
2050	64 105	249	552	327	612	6 570	1 454	1 793	75 663

Appendix C: Energy consumption development in WEM2022

Table C1. Energy consumption by vehicle type in WEM2022 in Terajoules (TJ).

Year	Passenger vehicle	Moped	Motor-cycle	Quadri-cycle	Bus	Van	Rigid truck	Articulated truck	Total
2022	81 745	168	1 312	347	6 050	14 136	20 216	34 701	158 674
2023	80 504	167	1 274	389	6 034	13 923	20 084	35 508	157 883
2024	79 167	164	1 238	428	6 027	13 680	19 937	36 148	156 789
2025	78 648	160	1 203	463	6 006	13 409	19 695	36 091	155 675
2026	77 078	155	1 169	494	5 973	13 088	19 437	35 948	153 342
2027	75 477	149	1 136	520	5 927	12 752	19 171	35 768	150 899
2028	74 250	142	1 103	540	5 869	12 401	18 982	35 533	148 821
2029	73 132	135	1 070	554	5 817	12 048	18 787	35 275	146 819
2030	72 145	129	1 036	563	5 747	11 689	18 549	34 936	144 794
2031	71 100	122	1 000	568	5 675	11 333	18 521	34 415	142 733
2032	69 914	115	964	570	5 574	10 974	18 385	33 926	140 422
2033	68 755	109	927	569	5 469	10 621	18 249	33 420	138 119
2034	67 670	103	889	567	5 360	10 276	17 932	32 937	135 733
2035	66 571	97	851	562	5 256	9 934	17 618	32 487	133 375
2036	65 405	92	813	555	5 135	9 615	17 287	32 034	130 937
2037	64 275	87	777	548	4 987	9 316	16 920	31 628	128 539
2038	63 196	82	741	541	4 851	9 050	16 649	31 266	126 375
2039	62 113	77	705	533	4 731	8 807	16 344	30 895	124 205
2040	61 085	73	671	525	4 615	8 586	16 048	30 583	122 185
2041	60 165	69	639	517	4 511	8 390	15 758	30 314	120 364
2042	59 425	65	609	509	4 416	8 212	15 574	30 089	118 900
2043	58 752	62	581	500	4 333	8 057	15 478	29 867	117 629
2044	58 186	59	555	491	4 257	7 909	15 384	29 712	116 552
2045	57 722	56	531	482	4 186	7 790	15 378	29 532	115 676
2046	57 178	53	509	471	4 117	7 675	15 284	29 367	114 654
2047	56 511	51	489	457	4 056	7 581	15 229	29 253	113 626
2048	56 073	48	470	441	3 989	7 495	15 085	29 136	112 737
2049	55 641	46	453	423	3 927	7 420	14 979	29 022	111 911
2050	55 233	45	437	403	3 861	7 351	14 782	28 938	111 048

Table C2. Energy consumption by fuel type in WEM2022 in Terajoules (TJ).

Year	Petrol blend	Diesel blend	E85	ED95	Methane blend	Electricity	Hydrogen
2022	52 574	102 892	446	42	1 182	1 538	0
2023	51 485	101 829	550	38	1 544	2 438	0
2024	50 407	100 437	506	34	1 910	3 494	2
2025	49 959	98 228	470	30	2 249	4 734	5
2026	48 550	95 639	423	26	2 534	6 157	13

2027	47 090	92 749	379	23	2 812	7 818	30
2028	45 741	89 950	337	20	3 070	9 642	61
2029	44 286	87 189	299	17	3 314	11 593	121
2030	42 684	84 387	263	14	3 507	13 699	241
2031	41 156	81 325	226	11	3 688	15 895	431
2032	39 249	78 156	192	9	3 918	18 167	732
2033	37 130	74 970	161	7	4 163	20 512	1 176
2034	34 910	71 612	135	6	4 415	23 014	1 642
2035	32 563	68 301	112	4	4 684	25 596	2 114
2036	30 077	65 038	92	3	4 921	28 199	2 607
2037	27 752	61 867	75	2	5 208	30 547	3 087
2038	25 570	58 968	60	2	5 516	32 703	3 556
2039	23 520	56 166	48	1	5 833	34 635	4 001
2040	21 574	53 546	39	1	6 169	36 427	4 430
2041	19 549	51 250	30	1	6 458	38 218	4 857
2042	17 727	49 161	23	0	6 820	39 903	5 265
2043	16 031	47 268	18	0	7 192	41 466	5 654
2044	14 502	45 523	14	0	7 580	42 911	6 022
2045	13 115	43 937	11	0	7 972	44 272	6 369
2046	11 882	42 437	8	0	8 288	45 368	6 671
2047	10 792	41 015	6	0	8 695	46 199	6 919
2048	9 820	39 575	5	0	9 097	47 077	7 164
2049	8 936	38 233	4	0	9 506	47 849	7 385
2050	8 143	36 880	3	0	9 921	48 518	7 583

Table C3. Energy consumption by fuel type in WEM2022 in millions of litres and terawatt-hours.

Year	Petrol blend million litres	Diesel blend million litres	E85 million litres	ED95 million litres	Methane blend TWh	Electricity TWh	Hydrogen TWh
2022	1 682	2 980	18.0	1.7	0.3	0.4	0.0
2023	1 647	2 950	22.2	1.6	0.4	0.7	0.0
2024	1 613	2 923	20.5	1.4	0.5	1.0	0.0
2025	1 598	2 859	19.0	1.2	0.6	1.3	0.0
2026	1 553	2 784	17.1	1.1	0.7	1.7	0.0
2027	1 507	2 700	15.3	0.9	0.8	2.2	0.0
2028	1 464	2 619	13.6	0.8	0.9	2.7	0.0
2029	1 417	2 540	12.1	0.7	0.9	3.2	0.0
2030	1 366	2 459	10.6	0.6	1.0	3.8	0.1
2031	1 317	2 370	9.1	0.5	1.0	4.4	0.1
2032	1 256	2 278	7.7	0.4	1.1	5.0	0.2
2033	1 188	2 184	6.5	0.3	1.2	5.7	0.3
2034	1 117	2 086	5.5	0.2	1.2	6.4	0.5
2035	1 042	1 990	4.5	0.2	1.3	7.1	0.6
2036	962	1 894	3.7	0.1	1.4	7.8	0.7

2037	888	1 802	3.0	0.1	1.4	8.5	0.9
2038	818	1 717	2.4	0.1	1.5	9.1	1.0
2039	753	1 635	2.0	0.1	1.6	9.6	1.1
2040	690	1 558	1.6	0.0	1.7	10.1	1.2
2041	625	1 491	1.2	0.0	1.8	10.6	1.3
2042	567	1 430	0.9	0.0	1.9	11.1	1.5
2043	513	1 375	0.7	0.0	2.0	11.5	1.6
2044	464	1 324	0.6	0.0	2.1	11.9	1.7
2045	420	1 277	0.4	0.0	2.2	12.3	1.8
2046	380	1 233	0.3	0.0	2.3	12.6	1.9
2047	345	1 191	0.3	0.0	2.4	12.8	1.9
2048	314	1 149	0.2	0.0	2.5	13.1	2.0
2049	286	1 110	0.1	0.0	2.6	13.3	2.1
2050	261	1 070	0.1	0.0	2.8	13.5	2.1

Appendix D: GHG emission development in WEM2022

Table D1. GHG emissions by vehicle type in WEM2022 scenario in kilotonnes of carbon dioxide equivalent (kt CO_2eq).

Year	Passenger vehicle	Moped	Motor-cycle	Quadri-cycle	Bus	Van	Rigid truck	Articulated truck	Total
2022	5 233	11	89	23	377	899	1 285	2 215	10 132
2023	5 051	11	87	26	362	862	1 242	2 209	9 850
2024	4 456	11	84	28	263	624	916	1 656	8 039
2025	4 346	11	82	31	252	592	881	1 609	7 802
2026	4 196	10	79	33	248	574	868	1 602	7 610
2027	4 008	10	77	34	236	539	835	1 552	7 291
2028	3 836	9	74	36	224	503	805	1 499	6 988
2029	3 664	9	72	37	213	468	777	1 447	6 687
2030	3 469	8	70	37	196	421	727	1 353	6 281
2031	3 315	7	67	38	190	396	726	1 328	6 068
2032	3 141	7	64	38	184	371	723	1 306	5 833
2033	2 955	6	62	38	178	346	720	1 284	5 589
2034	2 763	6	59	38	173	319	712	1 262	5 332
2035	2 565	6	56	37	168	292	705	1 243	5 072
2036	2 359	5	53	37	162	265	698	1 226	4 806
2037	2 167	5	51	36	156	240	690	1 210	4 555
2038	1 988	4	48	36	151	217	687	1 195	4 326
2039	1 820	4	45	35	146	195	682	1 179	4 107
2040	1 662	4	43	35	142	175	678	1 165	3 904
2041	1 505	3	41	34	138	157	676	1 156	3 711
2042	1 364	3	38	34	135	141	679	1 147	3 540
2043	1 233	3	36	33	132	126	686	1 137	3 386
2044	1 114	2	34	32	130	112	693	1 129	3 248
2045	1 007	2	32	32	128	99	704	1 119	3 124
2046	911	2	31	31	125	88	710	1 110	3 008
2047	826	2	29	30	123	78	719	1 101	2 907
2048	749	2	28	29	121	69	723	1 090	2 811
2049	680	1	27	27	118	61	729	1 079	2 723
2050	619	1	25	26	116	54	731	1 069	2 640

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VTT Technology 413

Title	**Scenarios for greenhouse gas emissions and energy consumption of road transport in Finland** Exploring the impact of existing policies
Author(s)	Johanna Markkanen, Arttu Lauhkonen & Anni Niemi
Abstract	This study explored how the greenhouse gas (GHG) emissions and energy consumption of road transport in Finland develops over time under the current policy setting. As the implementation of new policies and other measures presented in the Roadmap to fossil-free transport proceeds, the earlier scenarios have become outdated. To provide relevant recommendations for policy makers, updated scenarios of GHG emission pathways are needed. We defined the current sets of policies and other measures that aim at reducing GHG emissions of road transport. A new deterministic model ELIISA was developed that combines simulation of vehicle fleet, kilometrage and energy consumption and optimisation of biofuel consumption. ELIISA model was used to construct the new baseline scenario WEM2022 for road transport GHG emissions and energy consumption in Finland using the former baseline WEM2021 as the base. The results showed that GHG emissions of road transport will reduce more rapidly in WEM2022 than in WEM2021 scenario. However, the national GHG emission reduction target for road transport will not be met. New policies from EU's FitFor55 package will create a long-lasting impact on the vehicle fleet composition, but to reach the national GHG emission targets, the authors urge for more sustainable measures and transparent policy impact assessments.
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VTT Technology 413

Nimeke	**Tieliikenteen kasvihuonekaasupäästöjen ja energiankulutuksen skenaariot Suomessa** Nykyisten toimenpiteiden vaikutus
Tekijä(t)	Johanna Markkanen, Arttu Lauhkonen & Anni Niemi
Tiivistelmä	Tässä työssä tutkittiin tieliikenteen kasvihuonekaasupäästöjen (khk) ja energiankulutuksen kehitystä Suomessa nykyiset politiikka- ja muut toimenpiteet huomioiden. Fossiilittoman liikenteen tiekartan toimenpiteiden toimeenpanon johdosta aiempi tieliikenteen perusennuste on kuvaa jo vanhentunutta tilannetta. Päivitettyjen skenaarioiden avulla voidaan tuottaa poliittisille päätöksentekijöille ajankohtaisia suosituksia lisätoimenpiteistä. Päivitetyn perusennusteen tuottamiseksi määritimme tieliikenteen khk-päästöjen vähentämiseen tähtäävät nykytoimenpiteet ja niiden vaikutukset olemassaolevia taustatietoja hyödyntäen. Uusi deterministinen malli ELIISA luotiin tieliikenteen skenaarioiden tuotantoa varten - ELIISA yhdistää ajoneuvokannan, ajosuoritteiden ja energiankulutuksen simuloinnin biopolttoaineiden kulutuksen optimoinnin khk-päästöjen laskemiseksi. Perusennuste päivitettiin ELIISA-mallilla hyödyntämällä aiempaa WEM2021-perusennustetta lähtötietona. Tulokset osoittivat tieliikenteen khk-päästöjen vähenevän nopeammin uudessa WEM2022-perusennusteessa. Tästä huolimatta kansallisia khk-päästövähennystavoitteita tieliikenteelle ei nykytoimenpiteillä saavuteta. Uudet FitFor55-paketin EU-direktiivit saavat aikaan pitkäkestoisen muutoksen ajoneuvokannan koostumukseen, mutta kansallisen khk-päästövähennystavoitteen saavuttamiseksi tarvitaan yhä tehokkaampia ja kestäviä politiikkatoimenpiteitä sekä läpinäkyvämpiä politiikkatoimenpiteiden vaikutusarvioita tieliikenteen khk-päästöjen vähentämiseksi.
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