SUOMEN ILMASTOPANEELI
The Finnish Climate Change Panel

EMISSIONS AND COSTS CALCULATOR FOR PASSENGER CARS – USER MANUAL AND BASIS OF CALCULATION

The Finnish Climate Change Panel

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1. PURPOSE AND BASIC PRINCIPLES

The emissions and costs calculator for passenger cars is an online calculator intended to support consumers in their passenger car purchase decisions. The calculator allows users to see the cumulative life-cycle greenhouse gas emissions and costs of different cars that use different power sources. The purpose of the calculator is to highlight the climate impacts of different options. Therefore, the calculator does not take into account any other impacts on the environment. The user can select 1–6 different car options to be compared. The smaller the greenhouse gas emissions, the better the car is for the climate. At the point where the cumulative emissions of different car options intercept, one option becomes superior to the other. The same also applies to costs.

The comparison is based on the user's assessment of the distance they drive in a year and the primary data provided for different car options. In terms of both emissions and costs, the calculator includes certain default data to help the user enter information and produce an end result. All primary data used in the calculation can be replaced with the specific details of different car models if they are known. Some primary data is shared by all cars that use the same power source. They are selected on the basis of the best current knowledge, but even this data can be modified in the user's personal analysis.

The calculator consists of the following sections:

- Distance driven in a year and service time in years
- Additional information and settings
- Vehicle-specific details
- Fuel data
- Default calculation data independent of the selected car
- The end result presented graphically and in table form

Cumulative Costs of Vehicles € *Cumulative Emissions of Vehicles kg CO2eq*

Figure 1. The calculator produces graphs that show the cumulative emissions and cumulative costs of different car options.

2. PRIMARY DATA AND USER INTERFACE

2.1. General

The default distance driven in a year is 14,000 km, which corresponds with the current annual mileage of the average car (Statistics Finland 2019).

Some fields and headings on the website feature an additional information icon that offers further help with using the calculator.

The graph or table representation of the emissions and costs analysis results for the compared car options changes as the primary data is changed.

Clicking on or “Show details” shows what additional data the user can enter into the section in question.

The “Add vehicle” button adds a new vehicle to the calculator. A vehicle can be deleted by opening its data and clicking on “Delete vehicle”.

The calculator works on the most common web browsers.

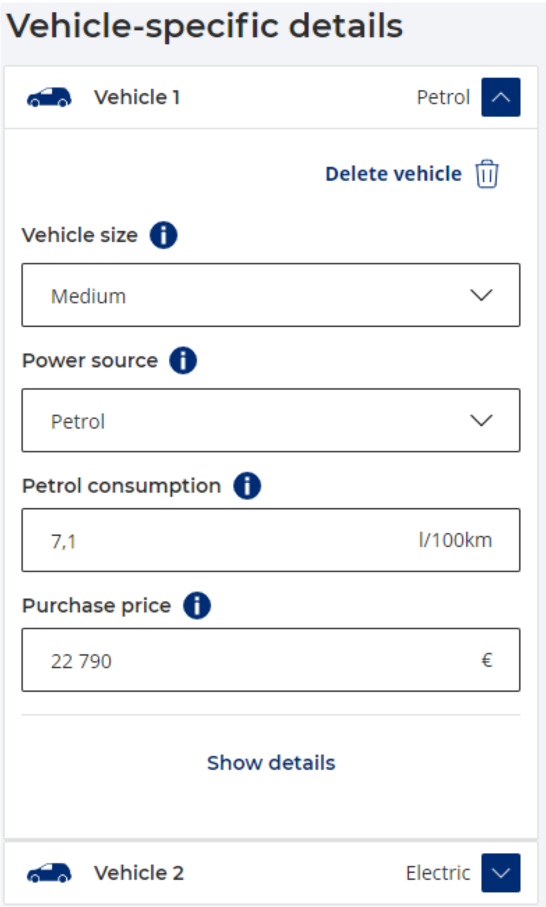
2.2. Additional information and settings

Settings can be found in the top right corner of the calculator. Clicking on ”Settings” shows the primary calculation data that is not vehicle-specific and that the user is expected to change only under exceptional circumstances. These are explained in more detail in section 2.6.

2.3. Vehicle-specific details

The user can select 1–6 different passenger car options to be compared. The number of vehicles can be changed by clicking on ”Add vehicle” and ”Delete vehicle”.

The key details to enter include vehicle size, power source, fuel consumption and purchase price. Additional information under ”Show details” make the calculation more specific and allow the user to enter other calculation parameters not included by default, such as the residual value of the vehicle. The user can also enter a nickname, e.g. the actual make and model, on the heading row of an individual vehicle.



The user must first enter the vehicle size category that provides the primary assumptions for evaluating the emissions generated during the manufacturing of the vehicle. The calculator features four passenger car size categories that mainly follow the common segment classification (see e.g. https://en.wikipedia.org/wiki/Car_classification). Examples of vehicle size categories:

- *Small vehicles* are compact cars with three or five doors, including vehicles in the A- and B-segments, such as Ford Fiesta, Volkswagen Polo, BMW i3 and Renault Zoe.
- *Medium vehicles* are the largest group represented in the calculator and include e.g. sedans, hatchbacks and estate cars in the C- and D-segments, such as Toyota Corolla, Volkswagen Passat, Audi A4, Nissan Leaf and Hyundai Ioniq.
- *Large vehicles* are minivans, suburban utility vehicles and vehicles that have a larger engine capacity and are heavier than conventional vehicles in the E-, M- and J-segments, such as Mercedes-Benz E, Tesla Model 3, Honda CR-V, Kia e-Niro, Opel Zafira and Mercedes-Benz B.
- *Executive cars* cover a varied group of vehicles. In the context of the calculator it can refer to sports cars, large suburban utility vehicles and other vehicles that require more natural resources to manufacture than conventional vehicles. This class features vehicles in the F-, S- and J-segments, such as BMW 7, Audi A8, Tesla Model S, Jaguar I-Pace, Porsche Taycan, Volvo XC90 and Tesla Model X.

Electric cars do not strictly follow the above classification, as electric cars usually belong to a size category larger than their outer dimensions would imply. This is due to the fact that, in addition to the body style and frame, the weight of the battery is a significant factor in determining the size category of an electric vehicle. The total mass of small electric cars is typically approx. 1,100 kg, medium-sized cars approx. 1,500 kg and large cars 1,800 kg. All vehicles with a total mass exceeding 2,100 kg can be interpreted as executive cars in this context. The manufacturing emissions data of cars with different power sources by size category is taken from the European Environment Agency publication (EEA 2018).

The primary power source is selected for each vehicle. The available options are petrol, diesel, natural gas, ethanol, electric, hybrid (petrol/diesel) and plug-in hybrid (petrol/diesel).

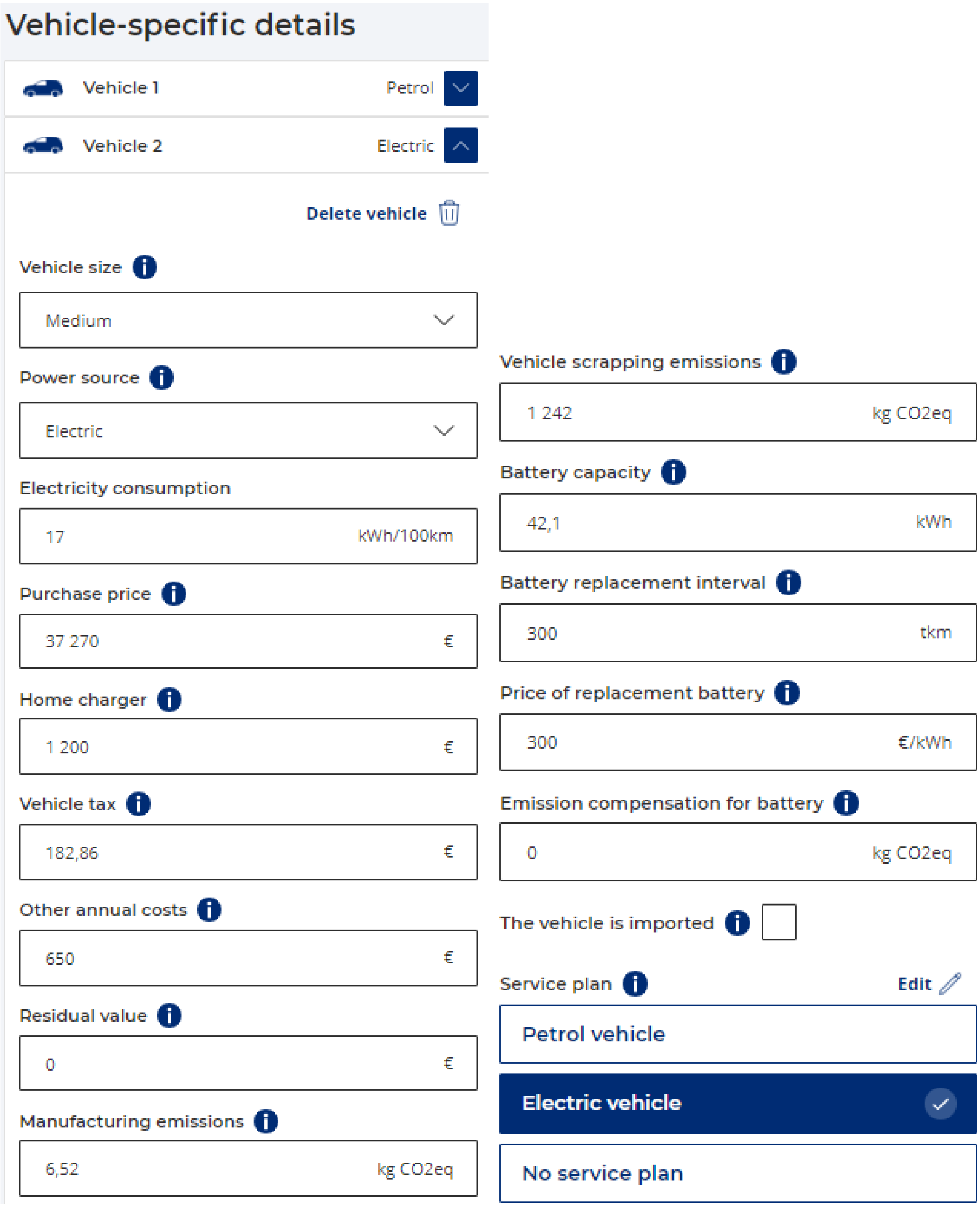
Gas vehicles can run on both natural gas or biogas, which is why there is no separate biogas option in the selection. In addition to petrol, an ethanol vehicle can run solely on E85 ethanol fuelled separately.

Here, a *hybrid* car refers to a mild hybrid or full hybrid vehicle. Full hybrids are capable of travelling on an electric motor alone, whereas in a mild hybrid, the electric motor merely assists the combustion engine and cannot move the vehicle on its own. Full hybrids and mild hybrids produce all energy they need from fuels and use electricity as a form of energy storage. They cannot be charged from an external source.

Plug-in hybrid vehicles differ from traditional full hybrids in that their energy comes partly from fuel and partly from externally charged electricity. A plug-in hybrid has a petrol or diesel engine in addition to an electric motor and a traction battery that can be charged from the mains through an external electrical connection.

On the basis of the selected vehicle size category and power source, the calculator provides default data on the vehicle purchase price (€), home charging station (€) and battery capacity (kWh). The user can change this default data to correspond with the vehicles they have chosen for comparison.

Clicking on ”Show details” allows the user to see the vehicle-specific details.



These details automatically include default data on size category and power source that the user can replace with model-specific data.

The model-specific *vehicle tax* can be retrieved from the Traficom vehicle tax calculator https://www.traficom.fi/en/transport/road/vehicle-tax-calculator. The calculator provides a rough estimate on the basis of prior empirical results from the Traficom calculator for each power source and vehicle size category.

Other annual costs. Here you can enter all other undefined annual costs, such as insurance policies, car washing and fuel additives (such as AdBlue). Maintenance and tyre change costs are entered separately for each service year under the section ”Service plan” below.

Data on the *manufacturing greenhouse gas emissions* of combustion engine cars and electric cars by size category is taken from the European Environment Agency publication (EEA 2018) (Figure 2). Based on the Ricardo reports (2011 and 2015), the manufacturing emissions of small, medium-sized and large hybrids and plug-in hybrids are by default 10% larger than those of similar combustion engine cars in the calculator. The manufacturing emissions of executive cars are assumed to be the same as of similar combustion engine cars by size category. Manufacturing emissions include all emissions of a new car, apart from those of the battery. The estimated emissions of the battery are based on battery capacity, which must be entered separately. The calculator's default capacities for plug-in and electric car batteries are based on information on vehicles in different size categories currently on the market, which is why the calculator's default battery capacities in different vehicle size categories are larger than those presented in Figure 2 (which dates back to 2015).

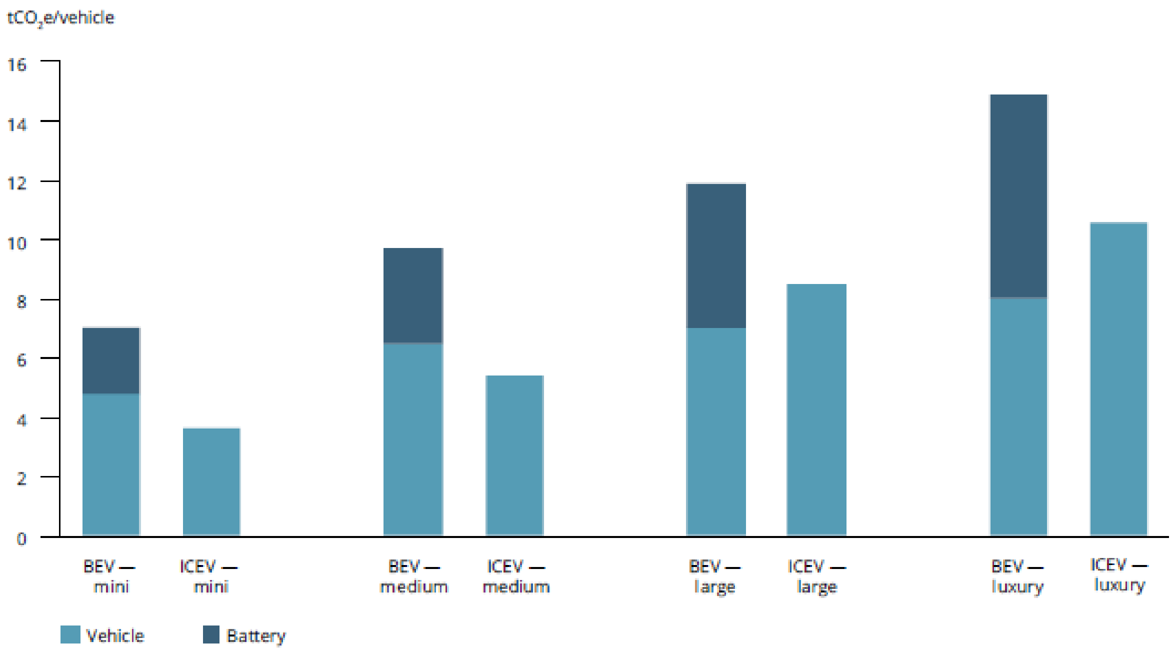


Figure 2. The total manufacturing and battery emissions of battery electric vehicles (BEV) and internal combustion engine vehicles (ICEV) in different size categories (source EEA 2018, original data Elligsten et al., 2016).

The battery emissions in Figure 2 no longer correspond to the life-cycle default emissions of battery manufacturing applied in the calculator, which are around 40% lower (70 g CO2eq/kWh) than those used in Figure 2 (around 115 g CO2eq/kWh). The current default emission for batteries is the average of the Bieker (2021) and Green NCAP (20221) publications (cf. appendix). This means that the battery emissions given in Figure 2 can be divided by two.

The battery capacity of plug-in hybrids and electric cars often varies even within the same model (e.g. long range models), so it is best to find out the battery capacity reported by the manufacturer and use it instead of the default data for a particular size category.

Battery replacement interval is ultimately a piece of user-specific primary data, although the default is 300,000 km for small and medium-sized batteries (under 50 kWh). Large batteries have a default replacement interval of 400,000 kilometres. The assessments are based on Bieker (2021). Even after these distances driven, there is around 80% of battery capacity remaining (Few et al., 2018). In practice, this means that battery replacement is not an option even with small vehicles.

Emission compensation for battery refers to a situation where old batteries are made available for further use and this activity generates emission benefits. It is clear that when an electric car purchased today reaches the end of its life-cycle, there will be ample opportunity to recycle the battery. The secondary use of batteries will also become more common (e.g. use as electricity storages for solar panels), which can help replace the use of fossil fuels. After being used for storage in a decentralised energy system, the raw materials of the battery can likely be recovered. EU legislation includes strict framework conditions for recycling (see appendix). There are notable uncertainty factors associated with the assessment of the emission compensation, but based on the information in the appendix, the moderate default emission compensation in this context is 20% of the emissions of the original battery. The emission compensation reduces the life-cycle emissions of the vehicle with the amount in question.

Vehicle scrapping generates its own emissions, and these emissions are also roughly assessed based on the EEA report (2018). The amount of emissions is minimal, and the same default value is used for all vehicle size categories.

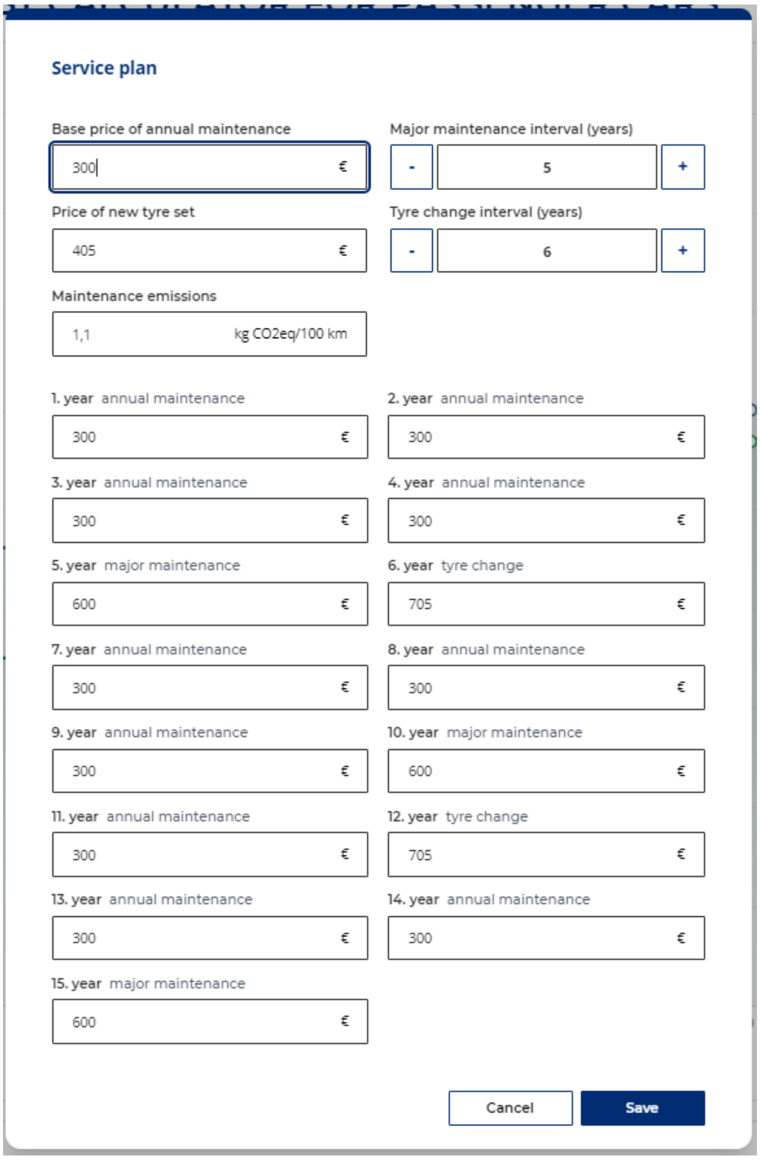
In terms of materials other than the battery, the recycling compensations of a vehicle at the end of its life-cycle are taken into account in the vehicle manufacturing emissions (EEA 2018).

The calculator assumes that the vehicles being compared have not been imported independently from abroad. In case of importing a used car from abroad, the user must tick the appropriate box in the user interface. As a result, the user must also provide specific data on the car tax. Otherwise, the car tax for the option is calculated automatically based on the entered purchase price.

The calculator allows for the car tax to be processed separately, although it is included in the purchase price of cars acquired in Finland. The user pays it in a similar manner as the VAT. The calculator section on car tax enables the comparison of cars imported from abroad. Car tax is not included in the purchase price of an imported car, in which case the calculator helps the user determine the relevant car tax. It is not used in the calculation as default. The starting point is n% of the purchase price. Precise factors can be found through the following link: https://autokalkulaattori.fi/data/data.json

The starting point is that the accurate purchase prices of the cars being compared are entered by the users themselves. The calculator provides indicative default values by size category and power source.

The user can provide the costs of a specific annual service plan by clicking on . The user can either select the default service plans for electric or petrol vehicles or exclude service plans from the examination altogether by selecting “No”. By modifying the base price of annual maintenance and the price of the new tyre set and their intervals, the annual table is updated automatically, unless the user has changed the values manually.

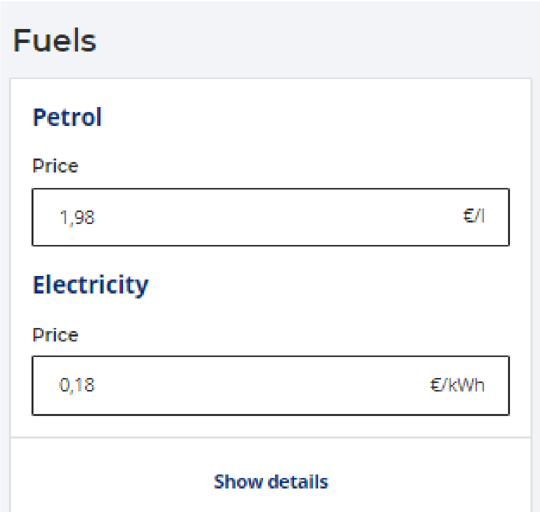


Costs outside maintenance measures are evaluated under ”Other annual costs”.

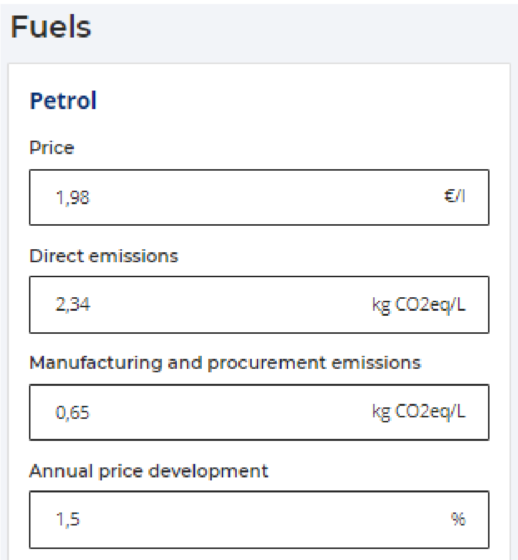
At the end of vehicle-specific data, the user has the opportunity to change the default calculation data that is not vehicle-specific. This data is discussed in section 2.2.

2.4. Fuel data

The calculator uses the fuel price information from autumn 2019 as default. The user can freely change these prices in accordance with the daily price situation.



Clicking on ”Show details” opens more fields that allow the user to enter emission factors and the annual price development:



The direct emissions of fuels refer to the emissions from the use of different fuels per unit. The LCA addition refers to the greenhouse gas emissions from the fuel raw material procurement and manufacturing (kg CO2eq/unit). In this context, the petrol and diesel emission factors do not include the emission impact of the biocomponent of fuels sold at distribution stations. It is calculated separately in accordance with the fuel blending ratio that changes over time (see section 4.1).

The direct and indirect emissions of petrol and diesel come from Lutsey (2017). The life-cycle emissions of natural gas are taken from the Ricardo report (2016). Leakage occurring during the procurement of natural gas is included, and it corresponds to the estimated situation in the Central European distribution network that includes gas coming from the Russian pipeline. In reality, the emissions from the production stage of natural gas vary by source. No accurate estimate is available on the emissions of Russian natural gas.

The default emission factors of biodiesel are the same as for regular diesel that include the biocomponent ratio derived from the biodiesel distribution obligation. This means that a user of biodiesel receives the same calculation result as a user of regular diesel. This solution is based on the calculation rules of Finland’s biofuel blending obligation and the fact that the global volumes of biodiesel with sustainable product chains are limited. The current rules of the Finnish petrol and diesel biofuel blending obligation lead to a situation where separately fuelled biodiesel does not create additional emissions reductions at the system level. If a driver does not separately refuel on biodiesel, the amount of biofuel corresponding to the distribution obligation will nonetheless be added into distribution. If a driver fills their tank with biodiesel, then the same amount of biofuel will not be blended into regular diesel (see also section 2.6. and appendix). Due to the limited availability of bio-based fuels, system-level thinking on the volume restricted by the distribution obligation is well-founded. No volume greater than the distribution obligation remains for distribution, as international demand directs it away from domestic use.

The calculator allows for a calculation based solely on biodiesel by changing the emission factor of the life-cycle greenhouse gas emissions of the biocomponent used in the diesel blending obligation under ”Settings” (see sections 2.6 and 5.2.2).

The life-cycle emissions of ethanol also vary greatly depending on the raw material source and process technology. In this context, the ethanol emission factor refers to the emissions of the separately sold high-blend ethanol (E85). There is currently no accurate data available on the average emission factor of ethanol sold separately in Finland. It is assumed to be waste-based and to reach an 80% emissions reduction advantage compared with the life-cycle emissions of petrol. Instead, the ethanol included in the blending obligation is assumed to meet the EU biofuel sustainability criteria (EU 2018), i.e. its life-cycle emissions reduction compared to petrol is 70%. Data on the life-cycle greenhouse gas emissions of ethanol used in the petrol blending obligation can be defined under “Settings” (see section 2.6).

Climate-sustainable transport ethanol is a globally scarce product, just like biodiesel. The amount of separately fuelled ethanol is also included in calculating the biofuel share of Finland’s distribution obligation. The more bioethanol is fuelled separately, the less biodiesel is blended into diesel. This is because, in practice, the current share of added ethanol in 95E10 petrol cannot be increased (see appendix). From the perspective of emissions control, however, adding waste-based ethanol is sensible as long as it is feasible from a financial or technical standpoint, as its emissions benefit is greater than that of field-based ethanol (see previous chapter). However, fully acknowledging the 80% emissions reduction of E85 fuel would send the wrong message to the user of the calculator.

For the above-mentioned reasons, the calculator applies a solution where the separate fuelling of E85 generates the following emissions: The amount of E85 ethanol (l) times its emission factor plus the emissions created when the E85 ethanol amount exceeding the biofuel share of the distribution obligation for the year in question reduces the same energy content of biodiesel from diesel fuel (see calculation formula in section 4.1). The emissions reduction in relation to petrol increases over time as the amount of biofuel in diesel increases along with the increase in the biofuel share of the distribution obligation. The ethanol share of E85 is assumed to be 80%, which is slightly higher than the assessment based on the Lipasto calculation system data (72%) made in 2016 (VTT 2017).

The life-cycle emissions of biogas vary greatly depending on the raw material source and process technology. According to information received from Gasum, the life-cycle emissions of the biogas they sell are currently 19 g CO2eq/MJ (Nevalainen, 2019). In terms of kilograms, this means 0.95 kg CO2eq/kg. The emission factor may change from the default value in the future, e.g. based on how much animal manure can be directed into biogas production. The biogas emission factor used in the calculator is 0.93 kg CO2eq/kg.

Biogas is currently included in the distribution obligation. This is why the emissions benefits of separately fuelled biogas are not fully allocated to the user of a gas vehicle. The emissions of separately fuelled biogas are evaluated as follows: the amount of refuelled biogas times its emission factor plus the emissions created when the biogas amount exceeding the biogas share of the distribution obligation for the year in question reduces the same energy content of biodiesel from the distributed gas (see calculation formula in section 4.1). The emissions reduction in relation to natural gas increases over time as the amount of distributed biocomponent increases along with the increase in the biofuel share of the distribution obligation.

The life-cycle emission factors of electricity represent the average emission factor of electricity production in Finland. In other words, they do not include the impact of imported electricity on the emission factors. The life-cycle emissions of imported electricity are likely to be lower than the life-cycle emission factors of electricity produced in Finland, as in recent years, more than 70% of electricity has been imported from the Nordic countries (Finnish Energy 2019) and electricity is expected to be imported from elsewhere than Russia in the future. For example, the life-cycle emission factor of Swedish electricity production in 2013 was around 2.5 times smaller than that of electricity produced in Finland (Moro and Lonza, 2018).

The default primary data for calculating the emissions of electricity use is the emission factor for the direct specific emissions of production that corresponds to the average emission factor for domestic electricity production in 2021 provided by Fingrid. It is defined in cooperation with Statistics Finland and Finnish Energy. At that time, the average of emission factors for electricity produced in Finland was 81 g CO2eq/kWh (Fingrid 2022). Based on Moro and Lonza (2018), the emission factor of raw material procurement and manufacturing of Finnish electricity is estimated to be 16 g CO2eq/kWh. This data represents the situation in 2014, which is why it can be assumed to have been somewhat smaller in 2021.

According to the WAM policy scenario of Lehtilä et al. (2021), the specific emissions of electricity are developing rapidly. According to the scenario, the specific emissions of direct emissions will fall below 10 g CO2eq/kWh already by 2030. In the calculator's default scenario this change is somewhat slower, and the direct specific emissions of electricity production experience a linear reduction from the 2023 value of 80 g CO2eq/kWh to 10 g CO2eq/kWh by 2035. The emissions will then fall to 5 g CO2eq/kWh by 2040 and remain on that level moving forward. The specific life-cycle emissions of other stages of electricity production develop from the 2023 value of 15 g CO2eq/kWh to 10 g CO2eq/kWh by 2035 and remain on that level.

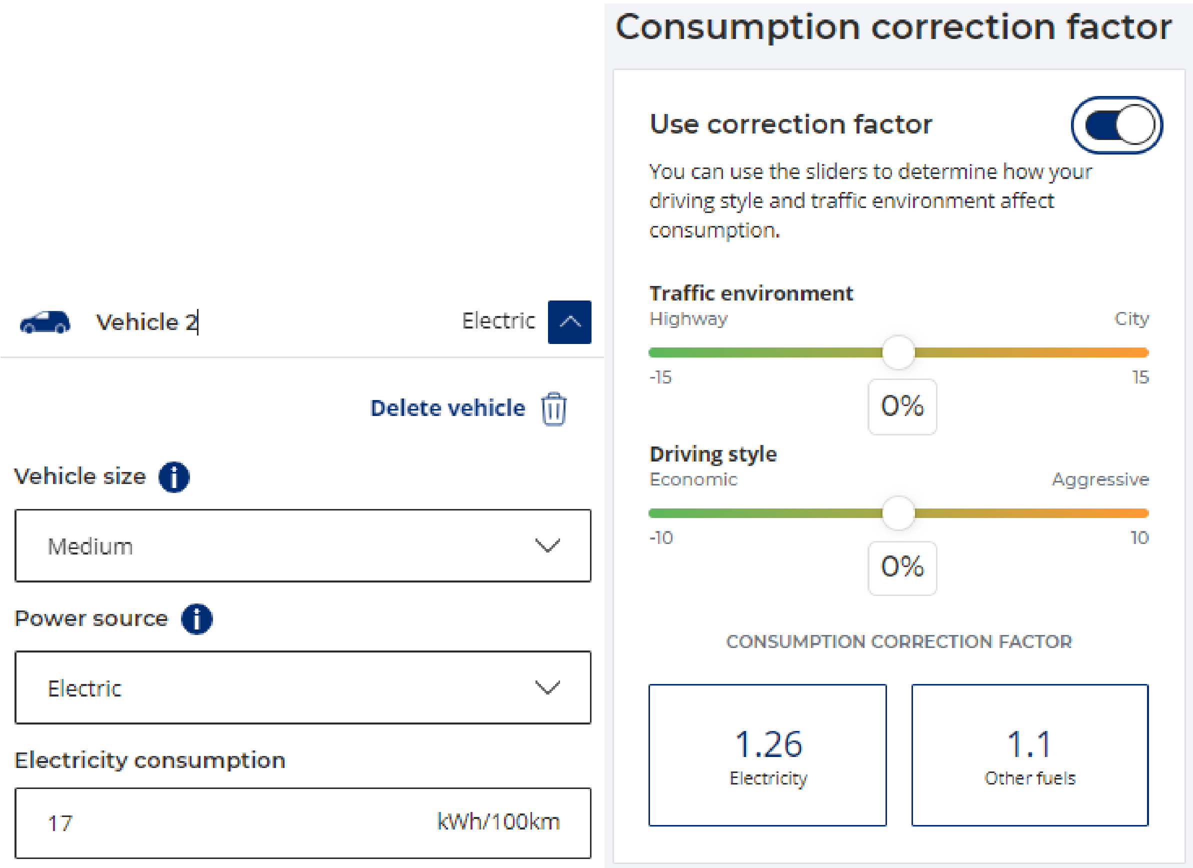
The user can provide a suitable future price development for different fuels. The default for all fuels is that their price will increase by 1.5% each year.

2.5. Vehicle consumption data

The user has the opportunity to provide consumption data for various fuel combinations per hundred kilometres driven. The assumption is that the data entered by the user corresponds with the actual consumption. Petrol refers to 95E10 petrol sold at service stations and, similarly, ethanol refers to E85 ethanol.

The user can also modify the consumption data provided by car manufacturers to reflect the actual consumption in cases where the values reported by the manufacturer are not targeted to Nordic conditions. The consumption correction factor can also be modified according to the user's driving style.

Manufacturers report vehicle consumption data only in accordance with the measurement standard WLTP. WLTP aims to describe the average driving conditions as accurately as possible, and in the EU, its CO2 value is corrected based on average temperatures. Combined consumption and the combined weighted consumption of plug-in hybrids act as good reference values for consumption. If the user already has a car that offers consumption values through its trip computer, these values should be used in the calculation.

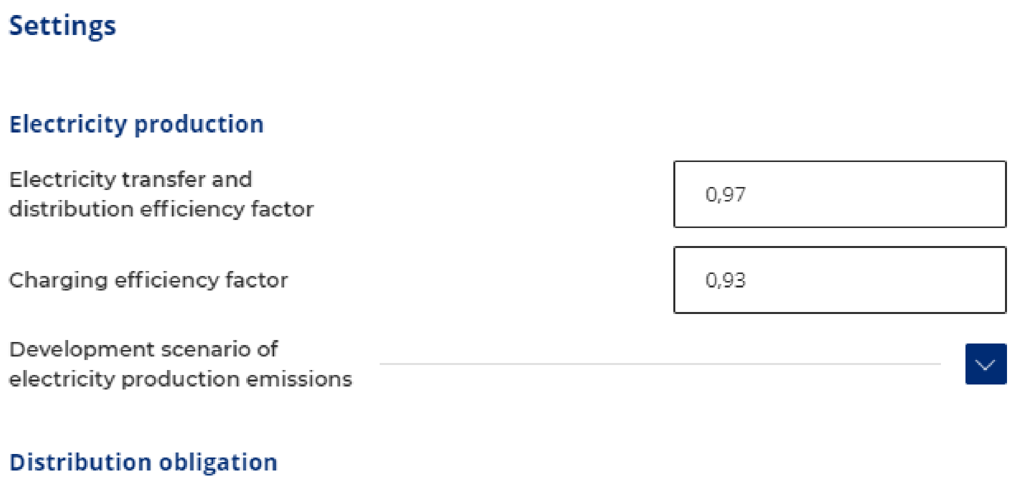


When using the consumption values reported by the manufacturer, the user can aim to specify the impact of driving behaviour and the traffic environment with the sliders provided.

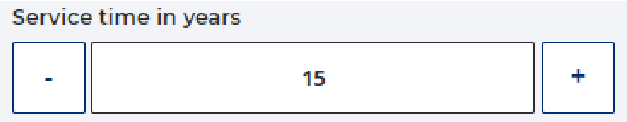
No temperature correction is carried out as default, as it has only a minimal impact on the emissions of combustion engine cars. When the user enters the previously realised consumption values in the consumption field, all factors impacting consumption will be taken into account.

2.6. Default calculation data that is not vehicle-specific

Clicking on ”Settings” (see section 2.2) shows the primary calculation data that is not vehicle-specific and that the user is expected to change only under exceptional circumstances.



By default, the calculator shows data for a period of 15 years. The time scale can be increased and decreased with the buttons provided.



The default setting of a bar graph can be changed into a line graph that is better suited for examining the differences between car options on a longer time scale in particular. The results can also be examined in table form by selecting “Table” in the buttons above the graphs.

There are three variables linked to the calculation of electricity production emissions. The default electricity transfer and distribution efficiency factor corresponds to the average situation of the Finnish electricity system (Honkapuro et al., 2015), i.e. it is 0.97, whereas the European average is 0.935 (Lutsey, 2017). Loss also occurs in the charging of electric cars. The calculator’s charging efficiency factor is 0.93, which corresponds with the European average (Lutsey, 2017).

The calculator assumes that the greenhouse gas emission factor of electricity production (kg CO2eq/kWh) develops as described in section 2.4 in the default basic scenario. The user can also provide their own emission factor scenario by storing annual values for each year under settings.

Table 1. Future development of the biofuel share of fuels used in the passenger car calculator.

Year	Petrol Ethanol %	Diesel Biodiesel %	Natural gas Biogas %	Fuel sold Biofuel share %
2023	10.0	17	50	13.5
2024	10.0	36	76	28
2025	10.0	37	78	29
2026	10.0	37	78	29
2027	10.0	38.5	80	30
2028	10.0	39.5	80.5	31
2029	10.0	40.5	81	32
2030	10.0	42.8	83	34
……	……	……	……	……
2050	10.0	42.8	83	34

The biofuel shares of fossil petrol and diesel are expected to develop in line with Finland's distribution obligation policies (Finnish Parliament 2022). The law states that the combined distribution amount of petrol and diesel must meet the distribution percentage describing the energy content of biofuels. However, the starting point for petrol vehicles is that current vehicles cannot run on petrol blends where the amount of ethanol exceeds 10%. Therefore, the assumption here is that 95E petrol is used from now on in the cars available for selection (default 10% ethanol). This is based on the assumption that no new petrol standard E20 will enter the market. The biofuel shares of diesel and biogas are extrapolated from the figures given in the low carbon roadmap for road transport WAM scenario up until 2030 (VTT 2021), after which the biofuel shares of the distribution obligation will remain unchanged (Table 1). If the user changes the value of the distribution obligation between 2030 and 2050, the values for the intermediate years are interpolated linearly.

Settings allow the user to separately enter the life-cycle emission factor of the biodiesel biocomponent (kg CO2eq), since it cannot be entered in connection with the fuel data (section 2.4). The life-cycle emissions of the diesel biocomponent per litre are assumed to be 80% lower than those of the combustion and manufacturing of fossil diesel. The starting point in Finland is that diesel is blended with 7% of traditional biodiesel (so-called FAME) that meets the emissions reduction requirements for new plants set in the RED directive (new plants must have 70% smaller emissions than fossil diesel). The rest of the biodiesel in the blending obligation is paraffinic diesel fuel that reaches an 80–90% emissions reduction in relation to traditional biodiesel (emission reductions reported by Neste and UPM Kymmene).

The calculator does not assume that the consumption of the vehicle changes along with the increase of biodiesel, as the energy contents of paraffinic biodiesels are equal to the energy content of fossil diesel (36 MJ/litre).

The settings also allow the user to change the life-cycle emission factor of the petrol biocomponent (ethanol) (kg CO2eq). Its value changes annually depending on the raw material base. In this context, the emission factor is expected to be 60% smaller on average than the life-cycle emissions of fossil petrol per litre.

The user can also change the energy content of different fuels.

Fossil fuels

Life-cycle emission factor of ethanol blended into petrol	0,90 kg CO2eq/L
Life-cycle emission factor of diesel biocomponent	0,69 kg CO2eq/L
Petrol energy content	32 MJ/L
Ethanol energy content	21 MJ/L

Furthermore, the following default data can be changed at the end of the settings:

Other details

Electric vehicle battery manufacturing emission factor	70 kg CO2eq/kWh
Annual cost decrease of new battery	4 %
Annual development of battery manufacturing emission factor (%)	3,35 %
Interest rate for tied-up capital	2 %

The default electric battery emission factor describes the greenhouse gas emissions generated in the battery raw material procurement and manufacturing. The emission factor varies greatly between different research results (ICCT 2018). The range of variation is 56–200 kg CO2eq/kWh, with the higher values applying to batteries manufactured in Asia. The cleanness of the energy used for manufacturing is a major contributing factor, which is why the battery manufacturing emissions vary between different countries and continents. In their studies, Romare and Dahllöf (2017) have estimated that energy emissions account for a minimum of 50% of the life-cycle emission factor of batteries. In this context, the calculator uses the average result of recent studies (Bieker, 2021; Green NCAP 2022), which is only 70 kg CO2eq/kWh (see appendix).

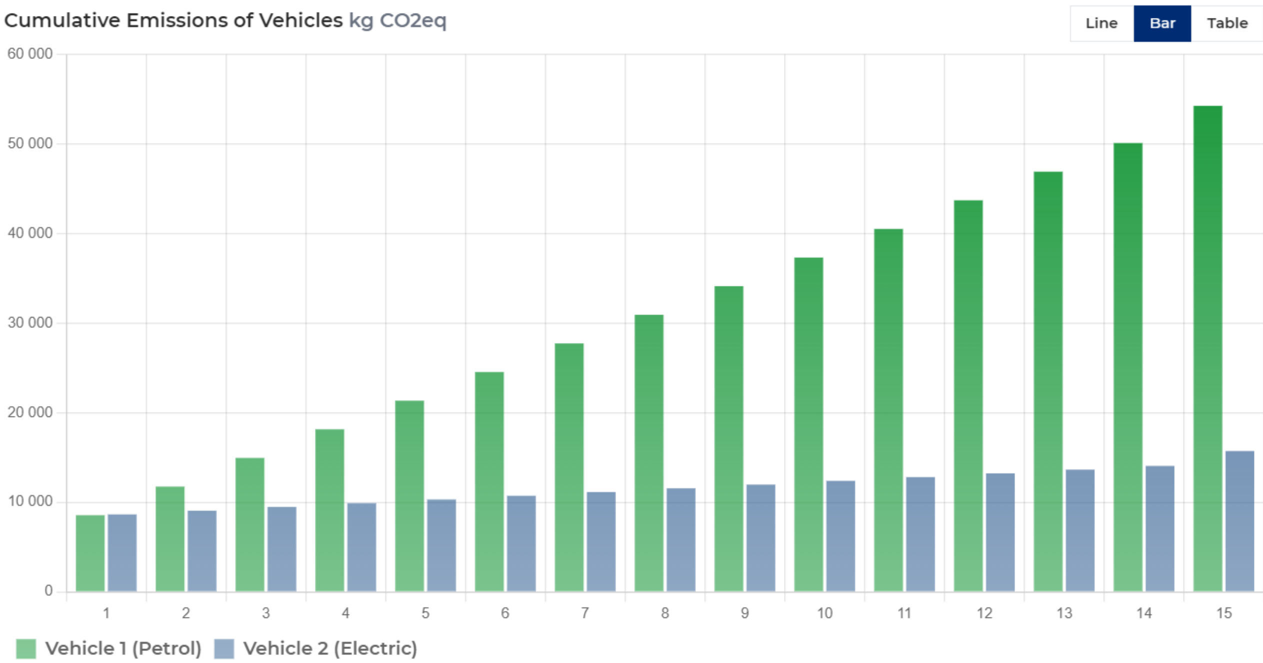
The estimated default price of a new battery corresponds to the current situation (€300/kWh) (see section 2.3). It is expected to decrease by around 4% annually. Similarly, the emission factor of battery manufacturing is expected to decrease by 3.35% annually.

The calculation of costs (see section 4.2) allows the user to modify the interest rate for tied-up capital. The default is 2%.

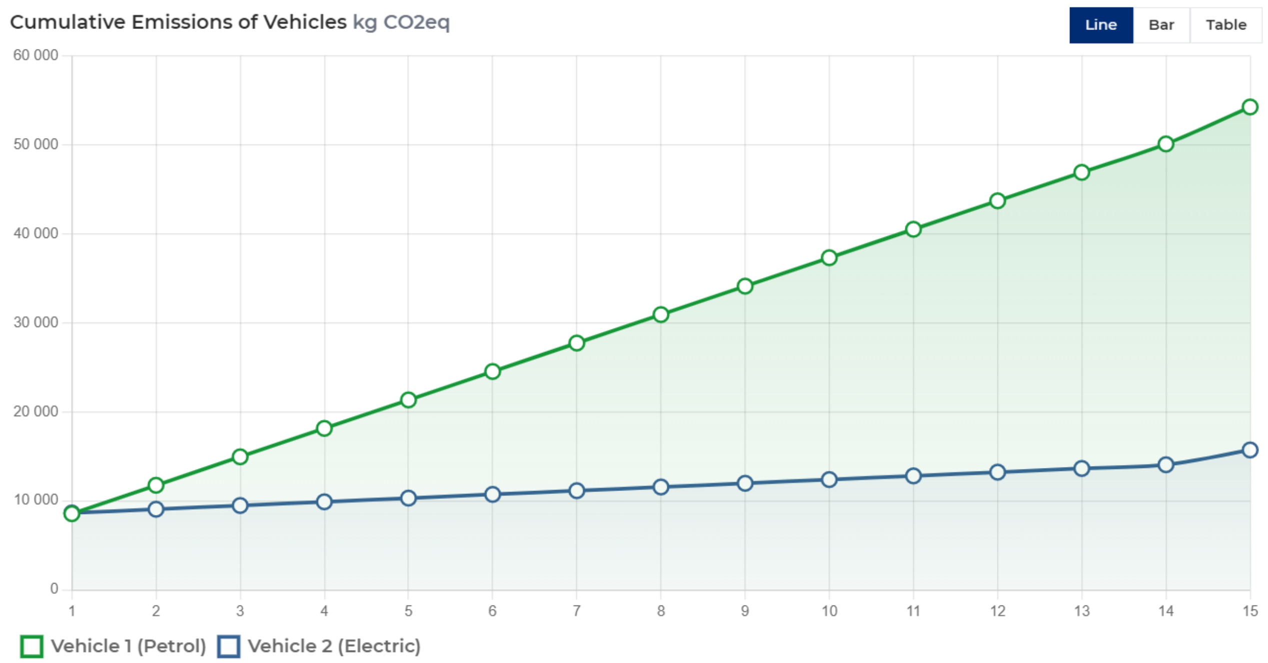
3. ANALYSIS RESULT AND ITS INTERPRETATION

The analysis of emissions is shown as default on the right side of the application. The life-cycle emissions of the different car options are added together for each year, showing the so-called cumulative emissions either as bars (default), lines or a table (the user can select between the graph, line or table representation) in relation to time. The smaller the greenhouse gas emissions, the better the car is for the climate. At the point where the cumulative emissions of different car options intercept, one option becomes superior to the other. The similar representation and interpretation of results applies to costs.

In the figure below, the emissions of an electric car become lower than those of a compared petrol car after only two years of use. The numeric values for each year can be viewed by placing the cursor on top of the bars or lines.



The line graph provides the same information as the previous bar graph, but in a more familiar manner. When using the line graph, you must note that selections providing similar results are shown on top of each other, which can make it difficult to separate the results between different vehicles.



The third option, the table, provides the cumulative emissions of vehicles for each year. The bottom row of the table describes the average annual emissions of the vehicle. Costs can also be examined as a table using the same logic.

Cumulative Emissions of Vehicles kg CO2eq

Line | Bar | Table

Year	Vehicle 1 (Petrol)	Vehicle 2 (Electric)
2023 (1)	8556	8644
2024 (2)	11752	9060
2025 (3)	14949	9477
2026 (4)	18145	9893
2027 (5)	21341	10310
2028 (6)	24538	10726
2029 (7)	27734	11142
2030 (8)	30930	11559
2031 (9)	34127	11975
2032 (10)	37323	12392
2033 (11)	40519	12808
2034 (12)	43716	13225
2035 (13)	46912	13641
2036 (14)	50108	14057
2037 (15)	54261	15716
Average Costs / Year	3617	1048

4. CALCULATION FORMULAS

4.1. Basis of emission calculation

The manufacturing emissions of cars with different power sources by size category are taken from the European Environment Agency publication (EEA 2018). The manufacturing emissions also contain the emissions of material procurement and manufacturing and the impact of car assembly and material recycling.

However, the values do not include the emissions of battery material procurement and manufacturing, nor the emission compensation for batteries. They are accounted for elsewhere in the calculation.

Assessment of life-cycle emissions

The emissions of each vehicle option after n service years are calculated as follows:

$GE_n(v)$ = VehicleME(v) + BatteryME(v) + $FE_1(v)$ + … + $FE_n(v)$ + VehicleS(v) + BatteryR(v) + BatteryS(v) + $MM_n(v)$ (1)

where

$GE_n(v)$ = greenhouse gas emissions of vehicle v as carbon dioxide equivalent tonnes after n service years (kg CO2eq)
VehicleME(v)= raw material procurement and manufacturing emissions and vehicle manufacturing emissions of vehicle v (kg CO2eq)
BatteryME(v)= raw material procurement and manufacturing emissions and battery manufacturing emissions of the electric battery of vehicle v (kg CO2eq)
$FE_i(v)$ = fuel use emissions of vehicle v in year i
VehicleS(v) = vehicle v scrapping emissions
BatteryR(v) = vehicle v electric battery replacement emissions (kg CO2eq)
BatteryS(v) = emission compensation due to the further use of the electric battery of vehicle v after scrapping (negative emissions, kg CO2eq)
$MM_n(v)$ = emissions from the maintenance measures of vehicle v after n service years (kg CO2eq).

Values for variables Vehicle ME(v), VehicleS(v) and BatteryS(v) in equation (1) are received directly as input data for each vehicle option. The emissions of replaceable batteries decrease linearly, being 60% of the original after 15 years. Here, the assumption is that battery technology keeps on developing and the energy emissions from battery manufacturing are reduced by 80%. It should be stated that in their studies, Romare and Dahllöf (2017) have estimated that energy emissions account for a minimum of 50% of the life-cycle emission factor of batteries.

Battery emissions are calculated as follows:

BatteryME(v) = life-cycle emission factor of vehicle v electric battery manufacturing (kg CO2eq/kWh) * battery capacity (kWh) (2)

Emissions from the use of 95E10 petrol fuel

The emissions from the use of 95E10 petrol (kg CO2eq) by vehicle v for each year i are calculated as follows:

$FE95E10_i(v) = [(SPC+VPC) * (1-SB_i) + (SEC_i+VEC_i)* SB_i]*DY*C\mathit{95E10}(v)/100$ (3)

where

$FE95E10_i(v)$ = 95E10 petrol fuel use emissions of vehicle v in year i
SPC = emission factor of petrol combustion (consumption) (kg CO2eq/litre)
VPC = life-cycle emission factor of petrol from oil procurement to distribution (kg CO2eq/litre)
SB_i = biofuel (ethanol) share (%) of the distribution obligation in year i
SEC_i = emission factor of ethanol combustion (consumption) (kg CO2eq/litre) in year i
VEC_i = life-cycle emission factor of ethanol from raw material procurement to distribution (kg CO2eq/litre) in year i
DY = distance driven in a year (km)
C95E10(v) = vehicle v 95E10 petrol consumption per 100 km (contains the distribution obligation share of ethanol).

In equation 3, the variables SPC and VPC are received directly from the calculator's default values that are shown to the user (view on page 8). These are expected to stay constant over time. The ethanol emission factor (SEC+VEC) presented in the same context corresponds to the default ethanol emission factor, where ethanol provides a 70% emissions reduction in relation to the life-cycle emissions of petrol. The emissions reduction of ethanol blended into 95E10 is also expected to stay at 70% in the future.

Emissions from the use of diesel and biodiesel

The annual emissions from the use of a diesel vehicle are calculated with an equation similar to 3 ($FED_i(v)$), but with the petrol and ethanol emission factors replaced with the diesel and biodiesel emission factors (SDC, VDC, SBDC, VBDC).

By default, the emissions of the separate fuelling of biodiesel are calculated in a similar manner as those of diesel (see section 2.5). The emissions impact of the separate fuelling of biodiesel without the impact of the distribution obligation can be calculated as shown in section 5.2.2.

Emissions from the fuel use of petrol and diesel hybrids

The emissions from the fuel use of petrol and diesel hybrid vehicles are calculated similarly as the fuel use emissions of petrol and diesel vehicles.

Emissions impact of E85 ethanol fuel

In accordance with section 2.5, the emissions impact of the separate fuelling of E85 ethanol fuel is created through the following calculations: First, the emissions of the used litres of E85 fuel are calculated according to equation 3 ($FEE85_i(v)$). The estimated ethanol share of E85 is 80%. The use of E85 ethanol creates an 80% reduction in the life-cycle emissions of petrol, i.e. SEC+VEC = 0.2 *(21/32)*(SBC+VBC), where (21/32) is the ratio of the energy contents of ethanol and petrol per fuel litre.

Second, the emission surcharge for E85 is calculated. It is caused by the extra ethanol replacing the use of biodiesel in diesel, i.e. the amount of ethanol that in year *i* exceeds the distribution obligation biofuel share and reduces the use of biodiesel by that same amount. This biodiesel replacement emission surcharge $ESBD_i(v)$ is added to the E85 emissions ($FEE85_i(v)$), which provides the total emission impact of the use of E85 by vehicle *v* for each year *i* ($TFEE85_i(v)$), i.e.

$$TFEE85_i(v) = FEE85_i(v) + ESBD_i(v) = FEE85_i(v) + SMFD_i(v)*[(SFDC+VFDC) - (SDC_i+VDC_i)] \quad (4)$$

where

$FEE85_i(v)$ = E85 ethanol fuel use emissions of vehicle *v* (DY*CE85(*v*)) in year i
$SMFD_i(v)$ = fossil diesel addition in the diesel distribution obligation amount caused by the use of E85 by vehicle *v* in year *i*
SFDC = emission factor of fossil diesel combustion (consumption) (kg CO2eq/litre)
VFDC = life-cycle emission factor of fossil diesel from biodiesel procurement to distribution (kg CO2eq/litre)
SDC_i = emission factor of diesel combustion (consumption) (kg CO2eq/litre) within the distribution obligation in year *i*
VDCi = life-cycle emission factor of diesel within the distribution obligation from biodiesel procurement to distribution (kg CO2eq/litre) in year *i*
DY = distance driven in a year (km)
C*E85(v)* = vehicle *v E85* ethanol consumption per 100 km.

Equation (4) SMFD allows the calculation of the energy contents of petrol and ethanol in a litre of E85. Petrol energy content PE = 32*(1-0.80) = 6.86 MJ and ethanol energy content EE = 21*0.80 = 16.8 MJ. In other words, the calculation assumes that a litre of E85 contains 80% volume of ethanol and the rest petrol. In percentage terms, one E85 litre contains 28% of petrol energy and 72% of ethanol energy. In each year i, according to the distribution obligation, the biofuel share should be X_i% of the distributed fuel. The exceeding ethanol amount (EE-(PE+EE)*X_i) of the refuelled amount of E85 by vehicle *v* (DY*CE85) causes additional fuelling of fossil diesel as follows:

$$SMFD_i(v) = ((EE-(PE+EE)*X_i)/X_i)*DY*CE85(v)*23.2/36 \quad (5)$$

where 36 is the diesel energy content (MJ/l) and 23.2 is the E85 energy content (MJ/l).

Emissions from the fuel use of gas vehicles

The total fuel use emissions of gas vehicle *gv* are calculated based on the amounts of natural gas, biogas and petrol used per 100 km:

$$TFEi(gv) = [(SNGC+VNGC) * CNG(gv) + TFEBG_i(gv) + (S95EC*V95EC)*C95E(gv)]*DY/100 \quad (6)$$

where

SNGC = emission factor of natural gas combustion (consumption) (kg CO2eq/kg)
VNGC = life-cycle emission factor of natural gas from gas procurement to distribution (kg CO2eq/kg)
CNG(*gv*) = gas vehicle *gv* natural gas consumption (kg) per 100 km
TFEBGi(*gv*) = total emission impact of gas vehicle *gv* biogas consumption in year *i*
S95EC = emission factor of 95E petrol combustion (consumption) (kg CO2eq/litre)
V95EC = life-cycle emission factor of 95E petrol from oil procurement to distribution (kg CO2eq/litre)
C95E(*gv*) = gas vehicle *gv* 95 petrol consumption (l) per 100 km
DY = distance driven in a year (km).

Biogas is currently covered by the distribution obligation. Therefore, the overall impact of biogas use is formed by the use emissions and the indirect emission surcharge created as the amount of biogas exceeding the distribution obligation reduces the biodiesel share of distributed diesel. The use of natural gas in road transport is so minimal that the change is expected to take place in the amount of distributed biodiesel. The calculation of the total biogas emissions impact (TFEBGi(*gv*)) of gas vehicle *gv* in each year *i* is carried out similarly as in connection with E85 ethanol (equation 4) i.e.

$$TFEBG_i(gv) = FEBG_i(gv)+ ESBD_i(gv) = FEBG_i(gv) + SMFD_i(v)*[(SFDC+VFDC) - (SDC_i+VDC_i)] \quad (7)$$

where

$FEBG_i(gv)$ = biogas use (DY*KPK(*gv*)) emissions of vehicle *gv* in year *i*
ESBD*i*(*gv*) = emission surcharge due to the replaced biodiesel from the biogas used by vehicle *gv* in year *i*
$SMFD_i(v)$ = fossil diesel addition in the diesel distribution obligation amount caused by the use of biogas by vehicle *v* in year *i*
SFDC = emission factor of fossil diesel combustion (consumption) (kg CO2eq/litre)
VFDC = life-cycle emission factor of fossil diesel from biodiesel procurement to distribution (kg CO2eq/litre)
SDC_i = emission factor of diesel combustion (consumption) (kg CO2eq/litre) within the distribution obligation in year *i*
VDCi = life-cycle emission factor of diesel within the distribution obligation from biodiesel procurement to distribution (kg CO2eq/litre) in year *i*
DY = distance driven in a year (km)
CBG(v) = vehicle *v* biogas consumption (kg) per 100 km.

SMFDi(*v*) is otherwise calculated with equation (5), but the energy ratio (21/36) is replaced with the biogas/diesel ratio (50/36), in which case the biogas consumption in kilograms is converted into diesel litres.

Emissions from the fuel use of electric cars and plug-in hybrids

In the case of plug-in petrol hybrids, the emissions caused by driving are calculated based on the electricity acquired outside the vehicle and the amount of petrol used. Petrol emissions are calculated using equation 3. The emissions of purchased electricity consumed are calculated in a similar manner as for electric vehicles (*ev)*. They are calculated as follows:

FEi(*ev*)= [(SEP + VEF) * (1/EPE) *(1 ECE)] * EC(*ev*) * DY/100 (8)

where

- SEP = direct emission factor of electricity production (kg CO2eq/kWh)
- VEF = life-cycle emissions of fuels used in electricity production (kg CO2eq/kWh)
- EPE = electricity procurement system efficiency factor
- ECE = electricity charging efficiency factor
- EC(*ev*) = vehicle *ev* electricity consumption (kWh) per 100 km
- DY = distance driven in a year (km).

The emissions of a plug-in diesel hybrid are calculated the same way as those of a plug-in petrol hybrid. Petrol is just replaced with diesel.

4.2. Cost calculation

The cumulative costs of a vehicle include the purchase cost, i.e. investment cost, car tax, vehicle tax, annual costs and, in the case of electric cars, battery replacement. Annual costs include refuelling or charging costs, vehicle tax, interest on the investment and maintenance. The interest charge of the investment is calculated with a 2% interest on the purchase price of a vehicle.

In addition to the above, a residual value can also be estimated for the vehicle. It is not included in the calculator as default, but the user can choose to enter a residual value for the vehicle to the dedicated field. As a result, the calculator will deduct the entered amount from the last year of the selected examination period.

Calculation formula for the cumulative costs of the use of an electric car:

$$\mathrm{CC_n(ev) = INV - RV + CT + RC + \sum_{i=1}^{n}\left(W_{c,i}C_i + M_i + VT_i + r^{\mathit{i}} * (INV - RV)\right)} \quad (9)$$

where

- CC_n(ev) = cumulative costs of using an electric car for *n* years, €
- INV = purchase price, i.e. investment cost, €
- CT = car tax, €
- RV = residual value, €
- RC = battery replacement cost, €
- $W_{c,i}C_i$= electricity price €/kwh times energy consumption kwh/year, i.e. charging costs, € per year
- M = maintenance costs, € per year
- VT = vehicle tax, € per year
- r = interest on the investment, %
- n = examination period in years.

For plug-in hybrids:

$$\mathrm{CC_n(h) = INV - RV + CT + \sum_{i=1}^{n}\left(W_{f,i}C_i + W_{\mathit{c},i}C_i + M_i + VT_i + r^{\mathit{i}} * (INV - RV)\right)} \quad (10)$$

where

- $CC_n(v)$ = cumulative costs from use other than electric for *n* years €
- INV = purchase price, i.e. investment cost, €
- CT = car tax, €
- RV = residual value, €
- $W_{f,i}K_i$= fuel price €/l times fuel consumption l/year, i.e. fuelling costs, € per year
- $W_{c,i}C_i$= electricity price €/kwh times energy consumption kwh/year, i.e. charging costs, € per year
- M = maintenance costs, € per year
- VT = vehicle tax, € per year
- r = interest on the investment, %
- n = examination period in years.

For other vehicles:

$$CC_n(v) = INV - RV + CT + \sum_{i=1}^{n}\left(W_{f,i}C_i + M_i + VT_i + r^i * (INV - RV)\right) \quad (11)$$

where

- $CC_n(v)$ = cumulative costs from use other than electric for *n* years €
- INV = purchase price, i.e. investment cost, €
- CT = car tax, €
- RV = residual value, €
- $W_{f,i}K_i$= fuel price €/l times fuel consumption l/year, i.e. fuelling costs, € per year
- M = maintenance costs, € per year
- VT = vehicle tax, € per year
- r = interest on the investment, %
- n = examination period in years.

5. EXTENDED USES OF THE CALCULATOR

5.1. Sensitivity analyses

The default data in the calculator can be modified, and the results for both emissions and costs are shown to the user immediately in the graphs.

The origin of the charging electricity has a great impact on the emissions of an electric car. A sensitivity analysis can be carried out e.g. by selecting between extremes where electricity is produced by wind power (10=0+10 g CO2eq/kWh), coal (1,390=1,029+361) g CO2eq/kWh) or with the average European electricity emission factor (351 = 296 + 45 g CO2eq/kWh). The life-cycle emission factors of wind and coal come from Koffi et al. (2017). The average emission factor for European electricity production is taken from the EEA publication (2018) (EU20 direct emission factor in 2016) and for life-cycle upstream emissions from Moro and Lonza (2018).

There are great uncertainties related to electric car batteries, mainly depending on their origin. Batteries manufactured in Asia have the highest emissions due to the high emissions of the electricity used for battery manufacturing there. For the purposes of a sensitivity analysis, a suitable range of variation for the emission factor of battery manufacturing is 60–100 kg CO2eq/kWh (cf. section 2.6).

There can be great variation in the manufacturing emissions of cars within the same size category, even within the same power source. This is why the comparison of car options should also evaluate the sensitivity of the end result by modifying the manufacturing emission factors.

The emission factors of biofuels vary due to manufacturing technology and raw materials, the impact of which can be examined by modifying the emission reduction e.g. with a 60–80% range of variation in relation to fossil fuels.

5.2. Impact assessment of the separate use of biodiesel, ethanol and biogas

5.2.1 Impacts of the distribution obligation

The objective of the distribution obligation is to promote the use of sustainable and renewable fuels in place of motor petrol, diesel oil and natural gas in transport. The fuel distribution obligation that determines the total volume of renewable energy in distribution in Finland is defined in law. In terms of the calculation, the key sections of the distribution obligation are the following:

1. Share of renewable fuels: Legislation specifies the development of the renewable energy share in the energy consumption of transport fuel end-use. The minimum share is defined in the EU Renewable Energy Directive (RED II). Finland has settled on a target of increasing the share of renewable energy sources in transport fuel end-use that is more ambitious than the EU requirement. Finland aims to reach a 34% share of renewable fuels in transport by 2030 (Act 13.4.2007/446, section 5). Within the distribution obligation, energy from renewable sources refers to biofuels or biogas produced or manufactured from biological raw materials, or other renewable liquid and gas transport fuels of non-biological origin, such as synthetic transport fuels manufactured with renewable energy (e.g. so-called electrofuels). Biodiesel, ethanol and biogas are also currently covered by the distribution obligation.

2. Biofuel sustainability criteria: Ensuring that the biofuels used meet the sustainability criteria of the RED II directive is also required by law. These criteria include e.g. reducing greenhouse gas emissions and using sustainable raw materials. The calculator assumes that the ethanol and biodiesel used in transport in Finland have 80% lower life-cycle emissions than their fossil counterparts. This means a roughly 10% higher emission reduction than required from biofuel manufacturers by the RED II directive (the basis of the default values for Finland are described in more detail in section 2.6).

The realisation of the distribution obligation at the distributor level requires that fuel distributors comply with the requirements and objectives set in legislation. Distributors can comply with their obligations in various manners. For the time being, Finland does not enable the trade of emission allowances in relation to the fuel distribution obligation, but distributors can cooperate and transfer portions of their obligations (Energy Authority, 2023, section 2.14). This means that a distributor can transfer a portion of their obligation to another distributor. This transfer can take place e.g. when distributor A has exceeded their renewable fuel distribution obligation and distributor B has not been able to meet theirs. Distributor A can transfer a portion of their excess to distributor B. As a result, both distributors meet their obligations. The transfer of obligation portions allows distributors to realise their distribution obligations in a flexible manner. The need for these transfers mainly arises when a distributor is unable to meet their obligation. In such cases, the portion of the obligation to be filled is taken from the biofuel share of the distributor who enables the transfer. In other words, this scenario does not create new emissions benefits within Finland's borders.

If during a calendar year a distributor has released more renewable fuels to consumption than required by the distribution obligation act, the distributor may take the exceeding portion into account in the calculation of the distribution obligation for the following calendar year. However, that amount may be a maximum of 30% of the energy content of the distribution obligation for the calendar year during which the excess took place. Similarly, if during a calendar year a distributor has released more biofuels, biogas or other renewable liquid and gas transport fuels of non-biological origin to consumption than required by the distribution obligation act, the distributor may take the exceeding portion into account in the calculation of the additional obligation for the following calendar year. However, that amount may be a maximum of 30% of the energy content of the additional obligation for the calendar year during which the excess took place. Due to the above-mentioned flexibility, the annual biofuel amounts may vary considerably, but looking at the development of biofuel amounts in transport over several years, it corresponds with the annual development of the distribution obligation quite accurately. The calculator does not take into account the annual variation in biofuels.

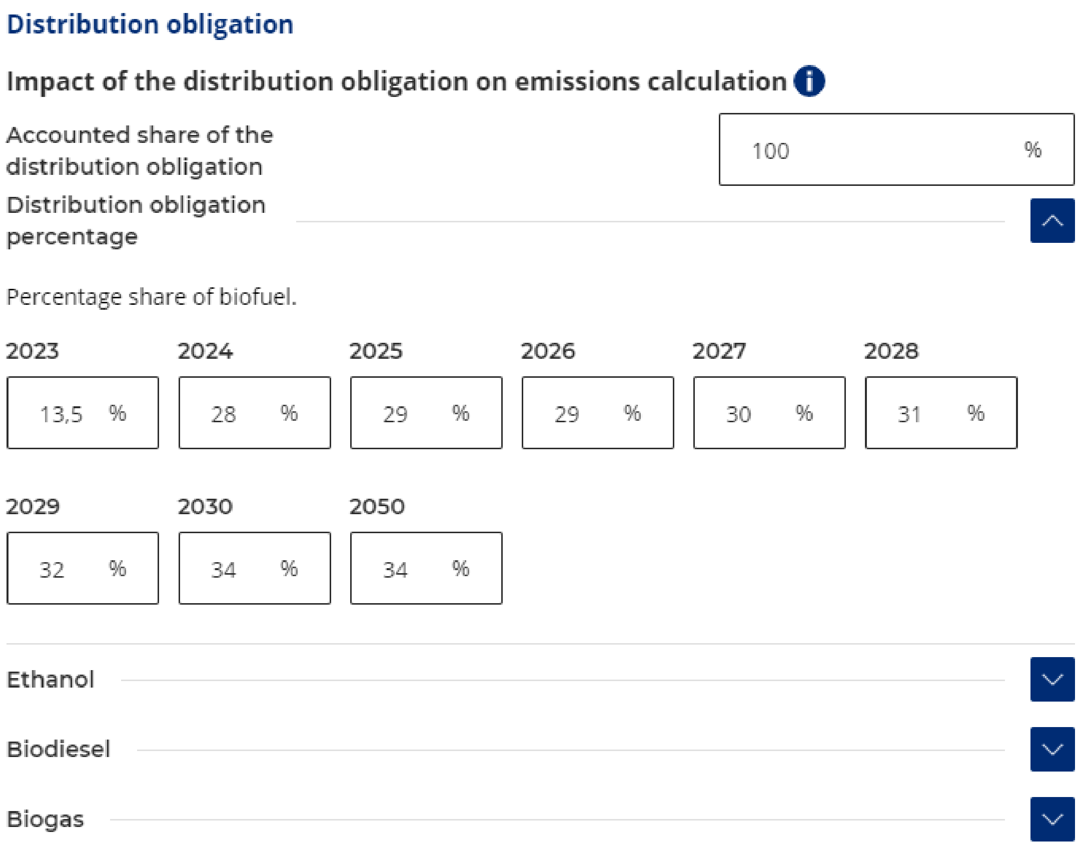
Biofuels are more expensive than fossil fuels, which is why distributors have aimed to optimise their costs by only adding the legally required amount of biofuels to distribution. Furthermore, a distributor may find it tempting to sell the product used as biocomponent with a better price across Finnish borders and buy transfers of obligation portions from another distributor to meet their distribution obligation. Information about the origins of distributed biofuel components and their amounts is not public, which is why the calculator is unable to use the actual life-cycle emission reductions realised in Finland.

As the separate sales of biofuels are included in the distribution obligation, all of the above leads to a situation where the share of biofuels in transport use does not exceed the number defined by the distribution obligation. Therefore, the separate fuelling of biofuels does not necessarily achieve the emission benefit that would be realised were it not for the possibility of obligation portion transfer.

Nonetheless, a distributor must also ensure that the obligation portion transfers meet the requirements of legislation and international regulations. The distributor must also analyse how meeting the obligation with the help of transfers impacts their reputation, customer relationships and long-term competitiveness. The ever-changing market situation may also make it difficult to evaluate the prices of foreign sales of own products and the transfer of obligation portions. This means that the distributor must carefully monitor the market situation and assess the overall impact in both the short and long term. For these reasons, it can be legitimately assumed that market-based operations are not necessarily realised with full optimisation of economic aspects, in the long term in particular. However, the calculator's default value describes the current situation where the emission reduction generated by the separate fuelling of biofuels fully replaces the biofuel share added to fossil fuels. The situation may be different in the future, should distributors release more biofuels into distribution than legally required. The separate fuelling of biofuels becoming more common may speed up this development.

5.2.2 Assessment of the emissions impact of separate fuelling from the user's perspective

For the above-mentioned reasons, the calculator accounts for the system-level emission impact of the separate use of biodiesel, biogas and ethanol (E85), where the emission surcharge returned by the distribution obligation is added to the life-cycle emissions of biofuels (distribution obligation numbers provided in section 2.6). Should the user wish to see the calculated emissions of said fuels without the impact of the distribution obligation, the user can disable this system-level default calculation (accounted share of the distribution obligation changed to 0%), in which case the calculation only uses the life-cycle emission factors of the biofuel production.


Distribution obligation
Impact of the distribution obligation on emissions calculation
Accounted share of the distribution obligation
100 %
Distribution obligation percentage
Percentage share of biofuel.
2023
13,5 %
2024
28 %
2025
29 %
2026
29 %
2027
30 %
2028
31 %
2029
32 %
2030
34 %
2050
34 %
Ethanol
Biodiesel
Biogas

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APPENDIX: PERSPECTIVES ON ALTERNATIVE POWER SOURCES

Electricity

Electricity can be produced with low emissions with the help of renewable energy sources and nuclear power, and its quantity is not limited by the scarcity of sustainable raw materials. This is a key argument for viewing electric driving as a viable partial solution on the path towards emission-free passenger car transport. For example, the Finnish energy industry believes that the current emissions of electricity will be cut in half in the coming decade and become marginal in the 2030s (Finnish Energy 2018). For this reason, the emissions from driving electric cars will decrease faster than those of petrol and diesel over time, regardless of the related biofuel mixing obligation. This is of particular interest in Finland, where cars have a long service life. If the current situation remains unchanged, a vehicle purchased today will be decommissioned only in 2040.

The greenhouse gas emission factor of mains electricity produced in Finland is already on average nearly three times lower than the European average. In 2016, the emissions of Finland's electricity production were 113 g CO2 per each kWh produced, whereas in EU28 the figure was 296 g/kWh, when calculating emission factors based on the primary energy method (EEA 2018a). The electricity network losses are also smaller in Finland in relation to Europe (Moro and Lonza, 2018). It should be added that fuel procurement increases the electricity production emissions by around 20% in relation to the previous direct emissions (Moro and Lonza, 2018).

Another great benefit of electric driving is that it generates zero local emissions, which still are a problem in the urban environment in Finland causing harm to health. The health-related harms of centralised electricity production are only a fraction of the harms caused by transport in Northern Europe (Stanaway et al., 2018). Electric driving will also reduce traffic noise in built-up areas.

The challenges of electric driving include the price of batteries and the emissions generated during their manufacturing. Because of the batteries, the manufacturing of electric cars has higher life-cycle emissions than that of combustion engine cars in a similar size category (Figure 1). However, the emission intensity of batteries has declined faster than anticipated. In the electric car life-cycle report of the European Environmental Agency (EEA 2018b), the assessed average life-cycle emissions of battery manufacturing were still around 111 kg CO2eq/kWh. Romare and Dahllöf (2017) evaluate that the life-cycle emissions of batteries manufactured in Asia are 120–150 kg CO2eq/kWh. The report reached the conclusion that around 50% of battery emissions are caused by the electricity used in their manufacturing.

Bieker (2021) estimates that the average life-cycle emission intensity of batteries manufactured in Europe and the United States in 2021 was only 60 kg CO2eq/kWh, and of those manufactured in China 68 kg CO2eq/kWh. Assessment made with the Green NCAP LCA tools provides average emissions of 77 kg CO2eq/kWh (Green NCAP 2022).

The International Council on Clean Transportation (ICCT 2018) predicts that the electricity production emission factor in most battery manufacturing countries will reduce by over 30% by 2030, which would mean a 17% emissions reduction in battery manufacturing. If electricity is produced with zero emissions, the battery emissions per kWh are cut in half.

When batteries are decommissioned, they typically have 70–80% of their charge capacity left. ICCT (2018) highlights the second-life applications of batteries, e.g. as storage for electricity produced with renewable energy sources. The fossil-based energy emissions that can be avoided by this storage method simultaneously reduce the battery manufacturing emissions. ICCT (2018) has suggested that this compensation could be several dozen per cent of the manufacturing emissions of the original battery.

As electric cars become more common, the recycling of batteries will improve and the related technology develop, so that even small amounts of the battery raw material can be recovered. Romare and Dahllöf (2017) have evaluated that improved recycling will cut the life-cycle emissions of batteries by 7–17%. Bieker (2021) has suggested that the emission compensation of recycling would be around 14–25% of the battery manufacturing emissions. In turn, Green NCAP has assessed the benefits of recycling to be around 14% of the battery manufacturing emissions.

Battery technology is expected to develop so that a 50% higher energy density could be reached in less than 10 years. Furthermore, the service life of batteries will increase (ICCT 2018).

Regardless of the many positive expectations regarding batteries, the issue is that batteries require great amounts of special metals. Mining operations cause many environmental problems that are not related to climate change (see EEA 2018b). Even if the recycling of batteries is improved, the amount of virgin metal concentrates needed will become immense due to the high demand for new cars.

Certain metals, such as lithium, can become scarce resources for batteries, restricting the global domination of electric cars. Despite this risk, climate policy has placed great hopes on electric cars, and they are viewed to have the greatest scalability potential in low-carbon passenger car transport. The full realisation of this wish will nonetheless require a transformation in battery technology, making it not dependent on scarce material resources.

The purchase prices of electric cars are expected to fall to the level of combustion engine cars in the latter half of the coming decade. Through cheaper fuel and maintenance costs, drivers of electric cars already have the opportunity to reach smaller overall driving costs over time.

Natural gas and biogas

Climate policy favours gas-operated vehicles because of their ability to use biogas. Natural gas and biogas are used by specifically manufactured bi-fuel vehicles that can also run on petrol as necessary. Petrol cars can also be affordably retrofitted to become gas-operated.

Natural gas is methane that can achieve approximately 20% smaller greenhouse gas emissions than petrol when examining the direct combustion emissions alone. The difference becomes clearly smaller when examining the life-cycle greenhouse gas emissions of natural gas and petrol (Ricardo, 2016). The product chain of natural gas involves methane leaks that weaken the greenhouse gas balance of natural gas. The natural gas sold in Finland comes from Russia, and the accurate amounts of loss are unknown. Natural gas is abundantly available, but its high emissions mean that it is not a solution for low-carbon transport.

The emission reductions of biogas in relation to fossil fuels depend on the production technology and the origin of the raw material. The ranges of variation for the greenhouse gas reductions of biogas given in the RED directive are 14–78% for biowaste and 72–202% for liquid manure (EU 2018). The net negative emissions of liquid-manure-based biogas are due to its use preventing the methane emissions of manure.

The current volume of biogas in Finland can be multiplied. Mutikainen et al. (2016) have assessed the technical and financial potential of biogas to be 9.3 TWh, which would meet the needs of around 1.5 million passenger cars. It would be sensible to direct some of this biogas potential into heavy-duty transport where electrification can otherwise be challenging. For these reasons, increasing the use of biogas in passenger cars is a clear partial solution on the path towards low-carbon transport.

Ethanol

Ethanol is mixed into the petrol sold at distribution stations. The 98 octane 98E5 petrol contains a maximum of 5% of ethanol, and the 95 octane 95E10 petrol a maximum of 10%. The origin of this ethanol varies, but the average ethanol mix must meet the greenhouse gas emission reduction criteria of the EU Renewable Energy Directive (RED) (EU 2018). On a global scale, the increase in the use of sustainable ethanol is restricted by the competition between farm-based ethanol fuel and food production.

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Increasing the use of ethanol in petrol is hindered by the lack of a suitable standard. There is a need for standards E20 or E30 to define the petrol quality requirements and analysis methods to enable adding a maximum of 20% or 30% of ethanol into petrol. These are not currently under way, however. In addition to the standard, there is a need for vehicles that could utilise the higher ethanol mix. Current cars are designed for 95E10 petrol. For the above-mentioned reasons, the emissions of current petrol passenger cars will not decrease despite the increase in the biofuel blending obligation (see biodiesel), as their fuel composition will remain practically unchanged in the future.

A high-blend ethanol fuel (E85), containing 50–85% volume of ethanol and the rest motor petrol, is sold separately in Finland. For now, this ethanol is highly waste-based, reaching maximum greenhouse gas emission reductions of up to 85% in relation to petrol.

The E85 fuel can be used in so-called flexible fuel vehicles that also have the option of using regular petrol. Furthermore, an E85 conversion kit can be installed to newer petrol cars that allow them to run on E85 fuel. There is no assessment available on the potential of the waste-based bio raw material base, but its quantity is nonetheless very limited in relation to the demands of the car stock.

Biodiesel

A maximum of 7% of fatty acid methyl ester that contains oxygen can be mixed into diesel. This so-called FAME diesel component can be manufactured from vegetable fat or oil. This biodiesel has limited prospects of reducing the greenhouse gas emission of diesel due to the low blending volume.

Paraffinic diesel oil can be used in diesel cars in place of fossil diesel oil without volume restrictions. Paraffinic diesel oils include, among others, the renewable diesel fuels developed by Neste, i.e. the NexBTL fuels, and the pine oil based BioVerno diesel of UPM-Kymmene.

Finland aims to increase the share of biofuel energy content to 34% of the total energy content of motor petrol, diesel oil and biofuels released to consumption by a distributor by 2030 and to maintain this level moving forward (Finnish Parliament 2022). Paraffinic biodiesel plays a crucial role in Finland’s target for the biofuel blending obligation, as FAME biodiesel component and bioethanol increases in transport are limited. In practice this means that the amount of paraffinic biodiesel components in diesel distribution in 2029 is three times larger than currently.

In Finnish road traffic, diesel is used significantly more than petrol due to the demand of heavy-duty transport. According to Statistics Finland (2019), in 2017 Finnish road traffic consumed 56,489 TJ of petrol in relation to 106,636 TJ of diesel. The electrification of heavy-duty transport is more challenging than that of passenger cars, which is why climate-sustainable biodiesel is a viable way for heavy traffic to reduce its carbon emissions.

As the sustainable raw material base of paraffinic biodiesel is limited and its use should be primarily directed into heavy-duty transport, using merely paraffinic biodiesel in passenger car traffic is not a scalable solution on the path towards climate-sustainable passenger car traffic.

Hydrogen

Though the hydrogen economy is seen as a future low-carbon solution, it has not yet arrived. Hydrogen is suitable as an energy source for electric cars. It can be produced from water using energy, it acts as an energy storage and the raw materials do not create a bottleneck as with batteries. Instead of impurities, the energy use produces water.

The first serially manufactured hydrogen vehicles are on the market, but their price is still far from electric cars that use a battery. The wider transport use of hydrogen is prevented by the high costs of hydrogen production and distribution. Hydrogen distribution would involve building an entirely new infrastructure, and as an easily escaping substance, hydrogen is challenging to process.

Power-to-X

Still under development, Power-to-X technology enables the manufacturing of synthetic fuel to replace fossil fuels. The raw material is carbon dioxide from air, hydrogen from water or nitrogen from air. The manufacturing process requires a great deal of energy that should be produced with zero emissions. The methane, methanol and dimethyl ether produced can be used in the engines of current ships, lorries and passenger cars.

The issue with Power-to-X is the price of the products. If the costs can be sufficiently reduced, the fuel would offer immense potential for scalability on the path towards carbon-neutral transport. It could utilise the existing vehicle stock and fuel distribution systems.

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