Methodology

The goal of this part of the paper is to estimate emission factors as accurately as possible. First, we need to identify the transportation methods which are practically relevant in Norwegian society. We do this by combining our personal knowledge about transportation in Norway, and research from Statistics Norway. We will make estimates for walking, biking, driving cars, taking bus, ferry, trains, trams, metro, and airplanes (SSB, 2023a). Due to lack of adequate data, we will not consider snowmobiles and leisure boats, and other uncommon transport methods. To explain how we arrived at our estimates, we will first account for our research method, appropriate GHG-measurement, how we arrive at our estimates and the weaknesses of them. An overview of the parameters and calculation of them can be found in Table 6 at the end of this section.

Formula

The parameter for each mean of transportation is calculated according to the following formula:

$$CO^2 = km * ef$$

"CO^2" will represent the emissions as CO^2 equivalents, *"km"* is the distance travelled in kilometres and *"ef"* is the emission factor associated to each mean of transportation. "ef" is calculated by two main components indirectly: The amount of an energy source required to move a certain vehicle, distributed between passengers, one km, and the emissions connected with getting the energy to the vehicle. The distance travelled will be based on the Google transport data, while it is the *"ef"* that is modified for the different transportation options. In the following sections we will explain how we arrive at the different emission factors, *"ef"*. We acknowledge that the production and waste management of a vehicle also creates indirect emissions, but neglect these in our parameter as they are somewhat difficult to estimate without industry specific information.

Research method

For fossil fuel land vehicles, we use estimates calculated by the Norwegian Environment Agency (NEA, 2021) which are the Norwegian numbers used for emission accounting to the UN. For vehicles estimates not available in the report, we make estimates based upon the method used by the UK Department for Business, Energy & Industrial Strategy (BEIS, 2019) for reporting corporate GHG-emissions, with equivalent Norwegian values. For vehicles we lack either data or method for after the second step, we make the best educated estimate we can.

Measurement

Since our goal is to assist estimating GHG emissions we exclude non-GHG emissions from our analysis. Since there are several GHG types and they have different global warming potential we need to find a universal measurement for the relevant GHG. We will estimate GHG emissions as $CO2$ equivalents ($CO2$-eq) in regard to carbon dioxide ($CO2$), methane ($CH4$) and nitrous oxide ($N2O$) which accounts for 97% of all GHG emissions (EPA, 2023) and is practiced in research and by government departments (BEIS, 2019; NEA 2021).

Electric production and distribution

Since we will make estimates for several electric transport methods, we find it appropriate to explain how we arrive at the emissions per electricity unit for end-users. It is not possible to arrive at this estimate from NEA's report, so we use BEIS's (2019) method which consider production of electricity and losses due to transportation and distribution (T&D), but with Norwegian numbers.

Firstly, we need to estimate the emissions from producing electricity in Norway. Research from Ritchie & Roser shows that 91.7% of the Norwegian electricity comes from hydropower and 7.5% from wind (Rithie & Roser, 2022). In Norway, most of the electricity sources are renewable, and resultantly Norway only has emissions of 26 gCO2-eq/kWh production wise. Compared to other countries, Norway has a small absolute change in gCO2/kWh over the last two decades, see Figure 1. For this parameter we therefore assume historical data is a good predictor for future emissions from electricity. Based on this, we will use the electricity-production emission of 26 gCO2-eq/kWh for further calculations.

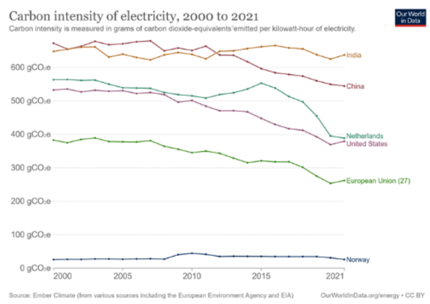

Figure 1: CO2-equivalents per kWh electricity, 2000 to 2021

Secondly, we need to estimate the loss of electricity from T&D electricity in the grid. Statnett, the Norwegian state-owned enterprise responsible for owning, operating, and constructing the stem power grid, refers to Statistics Norway's numbers for transmission and distribution losses. By using these we recalculate the loss to be 6.1326%, see Table 1 below (SSB, 2023b).

Table 1: Distribution in the Norwegian Power Grid

	2022M11	2022M12	2023M01	2023M02
Total prodution of electricity	14326776	14856524	14146399	13788387
Calculated loss in the grid	878600	911088	867539	845583
% Distribution loss	0.061326	0.061326	0.061326	0.061326

The emissions per kWh for end users in Norway is given by the following equation:

$$\begin{gathered} Emissions\ for\ endusers = Emissions\ from\ electric\ generation * (1 + T\&D\ loss) \\ = 26g\ CO2eq * (1 + 0.061326) = \mathbf{26.16g\ CO2eq/kWh}. \end{gathered}$$

Parameters

Walking and biking

As there is no fuel needed to use these means of transportation, *the parameter for both walking and biking will be 0g CO2eq/km.*

In regard to *electric bikes*, we use an estimate based upon the most sold electric bike in Norway (E-wheels, 2023). Based on battery size and expected range, which gives 7.1Wh/km, emissions are equal *to 0.2gCO2eq/km.*

Motorcycles

We also make estimates for motorcycles based upon NEA's report, and several emission factors will also be relevant. Due to not differentiating between sizes, the estimate includes everything from mopeds to heavy motorbikes. Based upon the report we estimate that emissions from motorcycles are *163.5 gCO2eq/km.*

Passenger cars – diesel and gasoline:

Determining a single figure to represent the emissions of gasoline and diesel vehicles is a complex task, given the hundreds of different car brands, each with their unique emissions profiles based on factors such as weight, design, and fuel efficiency. Thus, it is necessary to identify a figure that reflects the average consumer's usage. In our analysis, we will focus on Norway, utilizing the average gasoline and diesel consumption per kilometre for vehicles in Norway. To obtain this data, we will reference to

Norway's National Inventory Report for 2021 (NEA, 2021), which provides information on the amount of GHG emissions produced per liter of fuel, as well as the average amount of fuel consumed per kilometre by a typical vehicle. It's worth noting that the table we used applies to an average vehicle and does not differentiate between new and old vehicles or different sizes.

It's also important to recognize that the emission factor we're using represents an average for driving on various road types. Therefore, local variations may exist depending on factors such as driving speed, frequency of acceleration, congestion, road incline, and others.

The emissions from diesel and personal cars are respectively 141.8gCO2eq/km and 155.5gCO2eq/km, for final calculations see Table 6 at the end of this section.

These numbers represent a passenger car with only the driver present in the car. There has not been any success in finding statistics showing the average number of passengers in a car. With more passengers in a car, the emission factor of CO2eq will be reduced, as the CO2eq will be spread between more passengers. Additionally, more passengers per car also reduces the number of vehicles used. If two people share one car, there will only be one car on the road instead of two. These are factors we would like to account for in our parameter, but which we not yet have been able to substantiate with statistical numbers.

Passenger cars – electrical:

Although the direct emission from an electric vehicle is zero, we want to take some of the indirect emissions into account when deriving the parameter for electric passenger cars (Scope 2). Today it is a common perception that electric vehicles have zero emissions. However, this perception fails to acknowledge the emissions related to producing and distributing electricity which will be the substantial part of the emissions from an electric vehicle. By including the indirect emissions into the parameter, we believe it gives a more accurate representation of the actual emission.

To estimate emissions from electric passenger cars we base our calculations on the methodology used by the Department for Business, Energy & Industrial Strategy in the UK (BEIS, 2019) for company reporting, with equivalent Norwegian numbers. The emission calculation for electric vehicles (EVs) is done in two parts. First, we have already calculated the emission for producing and distributing electricity (kWh) under "electric production and distribution". Secondly, we calculate the required electricity for transporting a vehicle a certain distance. The combination of these calculations will result in a parameter for the CO2eq emission per kilometer.

To calculate the conversion factors for electric vehicles (EVs) we need to make a distinction between three types of cars which utilize electricity. The first group is battery electric vehicles (BEVs), also referred to as fully electric, which use electricity from the power grid. The next two groups are both hybrids, which utilize both fossil fuels and electricity. The difference is that plug-in hybrid electric vehicles (PHEVs) can use electricity from the grid, while the rest of the hybrids only use electricity generated by dynamos. We want to include hybrid cars as well, as they account for an increasing number of the carpark in Norway. Since the last category is included in the calculations from the National Inventory Report (NEA, 2021), we only need to calculate numbers for PHEVs and BEVs.

BEIS (2019) multiplies laboratory data with a constant due to differences in testing and real world, for electricity and gas respectively 40% and 35%, and uses this estimate for calculating the fuel usage. We use data from laboratory testing done by The US Environmental Protection Agency for information about car models. The lab-testing includes loss due to charging, and the testing protocol for EVs results in a combined estimate which considers the different conditions with driving in city and at the highway, cold- and warm-starting (Good, 2017). To calculate the weighted average with BEIS' methodology for EVs we use the best easily available information about the amount of different EV models. In addition, for PHEVs the BEIS uses the following formula dependent on the electric range of the model to calculate what amount of the total kilometer is fueled by electricity:

$$Share\ electric = 1 - 25/(25 + Electric\ range(km))$$

BEV

Norway is in a special situation regarding the purchase and use of battery electric vehicles. In 2022 79% of every new car sold was a BEV which makes 21% of all cars fully electric (SSB, 2023a; 2023c). As we want to calculate the weighted average electricity-use, we will use data regarding the different BEV models and their energy use (EPA, 2023b; NAF, 2023).

We found the number of cars of each of the top 10 most sold BEV-models in 2022 (Sagedal, 2023), which in total is equal to 51% of all BEVs sold in 2022 and 12% of all BEVs in Norway. We assume that the weighted average is representative of all new BEVs sold in 2022, and due to BEV sales from 2022 is equivalent to 23% of all BEVs (SSB, 2023a). Assuming similar growth in BEV sales in the next few years, the weighted average electricity use of the Top 10 most sold BEVs in 2022 is representative for all BEVs the next years. We find the weighted average electricity usage for BEVs to be 27.80 kWh/100km. For calculations we have used the following two formulas, and the results are presented in Table 2.

$$Testdata_{ADJ} = Testdata * (1 + \%\ dependent\ on\ fueltype)$$

$$Weighted\ average\ electricity\ use\ BEVs = \sum BEV\ Model\ wieght_i * Model\ Testdata_{ADJ}$$

Table 2: Calculation of weighted average emissions – BEV

	Weight of Norwegian cars (a)		Model testdata and adjustments (b&c)		Weight
Modell	Number of cars (a)	Weight %	Testdata kWh/100km	Adjusted (40%)	kWh/100km
Tesla Model Y	17356	0.2442	17.09	23.93	5.84
Volkswagen ID.4	11561	0.1626	20.73	29.03	4.72
Skoda Enyaq*	7133	0.1003	16.50	23.10	2.32
BMW iX	6127	0.0862	24.23	33.92	2.92
Volvo XC40	5279	0.0743	24.51	34.31	2.55
Hundai Ioniq 5	5044	0.0710	21.33	29.86	2.12
Audi Q4 e-tron	4928	0.0693	22.14	31.00	2.15
Audi e-tron	4740	0.0667	25.64	35.89	2.39
Polestar 2	4692	0.0660	19.57	27.40	1.81
Ford mustand Mach-E	4226	0.0594	22.56	31.59	1.88
Top 10 2023:	71086	0.5141		**Weighted average**	***28.70***
Total 2023	138260				
Total	599169	0.118641			

Sources:
a - https://elbil.no/hele-10-pa-topp-lista-er-elektrisk/
b - https://www.fueleconomy.gov/feg/download.shtml
c - https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020
*https://nye.naf.no/bilguiden/bilmodell/skoda-enyaq

Similar as our methodology for the passenger cars, we will not adjust the following parameter for the passenger load in each car. The electricity usage is multiplied by the electricity-production emission of 26.16 gCO2-eq/kWh.

For BEV's this gives the parameter 7.2g CO2 per kilometer.

PHEV

In Norway, 7% of cars are PHEVs, where most of them are fueled with gas (SSB, 2023a). Therefore, we will only make an estimate based on gas fueled hybrids based on BEIS's methodology. It is plausible that the number of PHEVs will not drastically change as the previous tax-benefits related to PHEVs were removed in 2020 (Hildonen, 2022).

We have limited available data for the number cars of the different PHEV-models and lab-data, so we are limited to the two most popular models sold in 2021 (Hildonen, 2022). They are equivalent to 5% of all PHEVs in Norway, which makes our weighted average weak, but the most accurate we can make with the available data. The calculations are the same as for BEVs with the distinction of doing them twice with respectively electricity and gas and modified with the amount of total km driven electric. The result is calculated from the following formulas, and the result is presented in Table 3.

$$Testdata_{ADJ} = Testdata * (1 + \%\ dependent\ on\ fueltype)$$

$$Share\ electric = 1 - 25/(25 + Electric\ range(km))$$

$$Weighted\ average\ electricity\ use\ PHEVs = \sum PHEV\ Model\ weight_i * Model\ testdata_{ADJ} * share\ electric$$

$$Weighted\ average\ gas\ use\ PHEVs = \sum PHEV\ Model\ weight_i * Model\ testdata_{ADJ} * (1 - share\ electric\ )$$

Table 3: Calculation of weighted average emissions – PHEV

	Weight of Norwegian cars (a)		Model testdata and adjustments (b&c)						Calculations			
			Electricity (kWh/100km)		Gas (L/100km)		EL Range		Average Gas		Average EL	
Modell	Amount	Weight %	Testdata	Adjusted (40%)	Testdata	Adjusted (35%)	Amount (km)	% of time el	Average L/100km		Average kWh/100km	
Toyota Rav4	6511	0.6784	22.3694	31.3171	6.19	8.3565	67.5924	0.7300	2.26	1.53	22.86	15.51
Volvo XC60	3086	0.3216	31.0686	43.4960	8.40	11.3400	56.3270	0.6926	3.49	1.12	30.13	9.69
Total Top 2 (2021):	9597	0.2516					**Weighted average**			***2.65***		***25.20***
Total (2021)	38,139											
Total in Norway	198841	0.048264694										

Sources:
a - https://bil24.no/%e2%80%92-starten-pa-slutten-for-hybrider/
b - https://www.fueleconomy.gov/feg/download.shtml
c - https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020

We find the weighted average electricity and gas usage for PHEVs to be respectively 25.20 kWh/100km and 2.65 L/100km. The emissions from PHEVs are combined by the two.

We estimate PHEV's have emissions equivalent to 88.4 gCO2eq/km, for final calculations see Table 6 at the end of this section.

Tram, Metro

Trams and/or metros are only available in Oslo, Bergen and Trondheim. Brenna (2021) calculated that the electricity used per pkm for respectively trams and metros are 0.12 and 0.15 kWh/pkm.

We estimate trams and metro have emissions equivalent to respectively 3.1 and 3.9 gCO2eq/km, for calculations see Table 2.

Trains

In Norway, the majority of trains are electric, with only a small portion of the railway network relying on diesel-powered trains. We therefore only calculate the emission factor for the electric trains.

Electric

According to the Norwegian Railway Directorate, the energy consumption of electric trains in Norway is around 80 kWh per train-kilometre (Jernbanedirektoratet, 2021). To determine the emissions per passenger-kilometre, we must also consider the average number of passengers per train and the average distance travelled. In 2021, the average number of passengers per train was 110 (SSB, 2023e). Assuming an average train trip distance of 50 kilometres, the energy consumption per passenger-kilometre can be calculated as 80 kWh/50 km/110 passengers = 0.01455 kWh per passenger-kilometre.

We estimate trains have emissions equivalent to 0.4 gCO2eq/km, for calculations see Table 6.

Ferry

It has proven to be difficult to find recent and reliable information about the GHG emissions of domestic ferries. After some research on the subject, the group decided to base its parameter of a report from the Norwegian Institute of Transport Economics (Thune-Larsen et. al, 2009). The report was published in 2009 and we are questioning its relevancy in today's transportation methods.

However, this report clearly shows its calculations and assumptions, and since the assumptions holds, we find it reasonably to use for estimates.

In the report they stated that in 2004, the CO_2 emissions per passenger-kilometre from domestic ferries was 621g. However, the reports also calculated three different scenarios for possible reductions in the years 2020, 2035, and 2050: a “compromise-scenario”, a “low-emission-scenario” and a reference-scenario. Over the last few years, Norway has seen several introductions of electrical-ferries to the domestic routes. We therefore assume that we will have reached the “low-emission-scenario” in 2020. The average parameter for domestic ferries is therefore 559g CO_2 per passenger-kilometre (Thune-Larsen et.al, 2009). We are not able to estimate other GHG than CO_2, so we will use an estimate of 559gCO_2eq/pkm. This number is the average for both passengers traveling with and without cars. To adjust for this, we assume a car weight 1.4 tons and a human 75kg, so we calculate emissions for a *ferry car passenger and just a passenger* respectively to be *1,063.9gCO_2eq/pkm and 54.1gCO_2eq/pkm*.

Bus

When calculating CO_2 emissions from busses it is beneficial to divide into city-busses and long-range busses (known as coaches) because they vary greatly in how much CO_2 they emit. As mentioned above we are focusing on the Norwegian transport emission numbers, which will be the focus of the calculation for these parameters as well. Both city-buses and coaches can run on either diesel or electricity. However, today there are mainly diesel-fuelled buses in Norway and although investments in electric buses are increasing, they do not yet make up a substantial part of the Norwegian bus-fleet. We therefore only calculate a parameter for diesel-fuelled buses.

Diesel

According to Statistics Norway (SSB, 2016), a coach - fylkeskommunal buss - with Euro-6 technology emits 867.2gCO_2eq/km, for final calculations see Table 6 at the end of this section. We will additionally take into account the number of passengers aboard an average Norwegian coach. Statistics Norway calculates that the capacity utilization for coaches is 24% (SSB, 2023d). According to two of the major Norwegian bus-companies Boreal and Tide, the passenger-range is from between 45 – 60 for coaches. Due to the city busses only having a capacity for 44, we assume 44 is an adequate assumption (SSB, 2023d). With a capacity utilization of 24% in a bus with 44 seats, the number of passengers per bus is 10.56. To find the emission per passenger-kilometre we divide and find that the emissions form diesel buses are 82.1gCO_2eq/pkm

The parameter for a diesel bus is 82.1gCO_2eq/pkm

Airplane

Deciding the CO_2 emissions per passenger-kilometre is a complex calculation, depending on many different factors. These include, amongst others, the type of aircraft and its varying dimensions, passenger load, freight load, fuel burn rate etc. Giving a general parameter for the CO_2 emissions for aircrafts is therefore a highly advanced task, which we have decided to simplify in order to remain some control and overview of our project. We have therefore based the calculation of this parameter on the one airplane type that is most common on Norwegian domestic routes, the Boeing 737-800. The parameter is calculated from Table 4 and Table 5.

Table 4: Calculation assumptions

Fuel burn	0.03litres per seat-km	sasgroup.net
Loading capacity	75%	sas.no
Total number of seats	186	norwegian.no
Jetfuel: liter to kg	1l jetfuel = 0.8kg	aviationbenefits.org
CO_2 in jetfuel	1kg jetfuel = 3.16kg CO_2	IATA, 2022

Table 5: Parameter calculation

Passenger load	Loading capacity * total number of seats	0.75*186	140
Total fuel burn, adjusted for passenger load	Fuel burn per set per km * total number of seats	0.03*186	5.58
Fuel burn per passenger, adjusted for passenger load	Total fuel burn/passenger load	5.58/140	0.04
Fuel burn per passenger, from litres to kg	1l of jetfuel = 0.08kg	0.04*0.08	0.032
Carbon emission per passenger per km	Combustion of 1kg jetfuel results in CO2 emissions of 3.16kg	0.032*3.16	0.101kg per pkm

There are several uncertainties regarding our measurement, and the airlines themselves will have more accurate information in regard to the different factors and calculations. Our calculated parameter of 101g per pkm, was therefore validated against the airlines' own calculators. A trip between Oslo and Bergen corresponds to 323 km. Our parameter would have given a total CO2 emission of 32.6kg. The SAS-calculator gives 43 kg CO2, while Norwegian's estimate is based of the International Civil Aviation Organization's emissions calculator and gives 52.3kg.

Although the ICAO-calculator shows that we have followed the same emission-calculations, our parameter gives a lower emission per passenger-kilometre. We believe the difference is based on the asymmetric information as they have an airport- and airplane-specific methodology. As we do not have such specific information in our calculation, our parameter is more uncertain, but we conclude that it is still sufficient for domestic flights.

The parameter for domestic air-travel is therefore 101g CO2 per passenger-kilometre.

Summary of the parameters

Table 6: summary of the parameters

	Walking	Biking	El-Cycles	Motorcycles	Gas car	Diesel car	BEV
CO2 (g/km)				95	151	140	
CH4 (g/km)*25				0.0016	0.0011	0.0068	
CH4 (gCO2eq/km)				0.04	0.0275	0.17	
N2O (g/km)*298				0.2298	0.0151	0.0056	
N2O (gCO2eq/km)				68.4804	4.4998	1.6688	
kWh/100km* 26.16			0.71				27.80
kWh (gCO2eq/km)			0.2				7.3
gCO2eq/km	**0**	**0**	**0.2**	**163.5**	**155.5**	**141.8**	**7.3**

	PHEV	Trams	Metro	Trains	Diesel Bus	Ferry car passenger	Ferry by-foot passenger	Planes
CO2 (g/km)	61.48				856			

*CH4 (g/km)*25	0.00265				0			
CH4 (gCO2eq/km)	0.06625				0			
*N2O (g/km)*298	0.0056				0.03763			
N2O (gCO2eq/km)	1.6688				11.21374			
kWh/pkm* 26.16	25.20	0.12	0.15	0.01455				
gCO2eq/km	6.6				867.2			
gCO2eq/pkm	**88.4**	**3.1**	**3.9**	**0.4**	**93.8**	**1063.9**	**54.1**	**101**

Emission factors used in calculations:
*EPA (2022)

Weaknesses in methodology

In the section above we have conducted thorough calculations of emission factors related to different transportations means, based on scientific and up-to-date information. However, in order to evaluate the credibility of the parameters, there are some important weaknesses that are worth mentioning.

First, the parameters represent an average of the different models available on the market. The emission factors are generalized to each mean of transportation, rather than specified to the different models. For example, we recognize that there are many different car models on the market. However, our parameter is generalized and will be valid for any car model the user was driving. Although the parameter is based on a number of different models, there is a high possibility that the parameter would have differed if every model was integrated in the calculations. These generalizations will apply for the other transportation methods as well. Resultantly the parameters are somewhat imprecise.

Secondly, some of the parameters have also been calculated based on simplifications of the actual transportation situation. Transportation includes a broad spectrum of options, models, and fuels, and makes calculations of generalized parameters a complex task. Our group has in some cases therefore decided to simplify the situation, either by excluding some models or fuels that are not very present in today's society, or by eliminating the many options/models and basing the parameter of only one model. This simplification reduces the realistic aspect of the methodology but was done in order to arrive at a credible parameter while still having an overview of the calculations.

Although these weaknesses reduces the accuracy of our methodology, we believe that the methodology still serves as a solid foundation for our GHG emission accounting application.