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ENE425: Sustainable Energy
Transport Carbon Emissions App: Methodology Analysis

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Introduction

When seeking to calculate the total CO_2e emissions for any means of transportation, it is necessary to determine exactly what one wants to find out. For instance, it is possible to conduct life-cycle assessments (LCA) of the different means, which can give an overview of the total CO_2e emissions from all the stages of the means of transport's life-cycle, like the stages of production, operation and end-life (Golsteijn, 2020). Additionally, to get more precise calculations, it's also possible to include other factors, such as the production CO_2e emissions of the car's fuel type. Today's means of transport are using different energy sources to power their combustion engines, such as petrol, diesel, LPG, jet fuel, marine fuel, biofuels, synthetic fuels, electricity, and hydrogen or different hybrid-solutions combining these energy sources. For instance, all-electric cars do not directly emit any CO_2e during transportation (Minnesota Pollution Control Agency, 2021), and it is thus necessary to conduct life-cycle assessments to get an overview of their total carbon footprint in order to compare them with cars using other types of energy sources. When calculating emissions, it is important to know that the preciseness of the calculations is depending on what and how many factors that are included: the more factors included, the more precise the calculation is. However, we are here limiting ourselves to scope 1 emissions, i.e., only direct emissions during use of the vehicle.

Our focus

In this paper we will focus on how to calculate the basic transport carbon emissions, and we will therefore only include the most basic factors. The means of transport that we are looking into are land (cars, buses, motorbikes, rail), aviation, and maritime means of transport. For each, we tried to find 3 figures: the **carbon emission factor** of the fuel used, i.e., how much CO_2e, in kg, are emitted per liter of fuel consumed; the **fuel consumption** of the means of transport, i.e., the number of fuel liters consumed for 100 km traveled; and the **distance traveled**, in km. Some additional factors will also prove to be pertinent to the precision of the calculation and will be expanded upon in the different sections, but the main equation will be:

*Carbon Emission Factor (kg/L) * Fuel Consumption (L/100 km) * Transportation Distance (km)*

(FleetNews, 2022)

For every all-electric means of transportation, we consider the carbon emission factor to be null, for they emit zero CO_2e *direct* emissions (Logan, Nelson, McLellan, & Hastings, 2020; U.S. Department of Energy, 2021). In order to comprehend more easily the difference of emissions between the means of transportation, we will compare the carbon emissions they each emit on a travel between Bergen and Stavanger, as most of the means of transport can be used there, through its own route. In each section, we will try and use this equation to calculate it, and precise the different factors influencing these emissions for each mean of transport.

Land transport

In this section we will only use petrol, diesel and hybrid-solutions as power sources. For fuel consumption and emission factor, we will use the data collected by the (U.S. Department of Energy, 2021), which, converted, gives this table:

Average Fuel Consumption by Major Vehicle Category			
Vehicle Type	**L/100KM Petrol**	**L/100KM Diesel**	**L/100 km Hybrid**
Transit Bus	71.28	63.57	
Car	9.72	8.62	3.9*
Motorcycle	5.35	4.83	

Carbon Emission Factor (kg/L)	
Diesel	2.66
Petrol	2.3
Hybrid**	1.78

*Because of the difficulty finding an average fuel consumption for a hybrid car, this number is based on a Toyota Hybrid (ZVW30) (Kiseleva, Kaminskiy, & Presnykov, 2020).

** Hybrid vehicles have zero tailpipe emissions when running only on electricity (U.S. Department of Energy, 2021).

Car

The fastest route from Bergen to Stavanger is 210 km, but this includes both travelling by land and by sea with a ferry. As the ferries on this route take up approximately 30.5 km, we subtract this from 210 km and the distance from Bergen to Stavanger by land is 179.5 km. Given this distance we calculate the following when using the information in the table above:

1. *Diesel: 2.66 kg/L * 8.62/100 km = 0.257 kg per passenger km or* 179.5 km = 46.16 kg of* CO_2
2. *Petrol: 2.3 kg/L * 9.72/100 km = 0.223 kg per passenger km or * 179.5 km = 40.13 kg of* CO_2
3. *Hybrid: 1.78 kg/L * 3.9/100 km = 0.069 per passenger km or * 179.5 km = 12.46 kg of* CO_2

Among other things that one could account for, the CO_2 emissions also depend on the engine type, as newer cars are more efficient than older ones (European Parliament, 2019). Weight is also a factor that will influence the emissions, as heavier cars burn more fuel, while higher RPM (revolutions per minute) also result in higher emissions, giving automatic cars an advantage of less pollution. Cabrera Serrenho, Norman, & Allwood, 2017) (Majid, Mohsin, & Shihnan, 2014)

Motorcycles

Most mopeds and motorcycles produced nowadays by major brands are petrol-fueled, and no major market expansions of hybrid or fully electrical models have occurred in Europe. Hence, our calculation assumption is going to be based on that only petrol motorbikes circulate in Norway, for ease of modelling. So, the emissions for an average engine motorcycle (between 250 and 750 cm^3) motorbike would be:

*2.30 kg/L * 5.35 L / 100 km= 0.123 kg per passenger km or *179.5 km = 22.09 kg for our route*

Bus

It is said that taking any kind of public transport is better in terms of carbon emissions than taking the car. Of course, this is not because the bus emits less than the car, but rather because the emissions are then ***divided*** by the number of persons using the bus. However, in Norway, and due to the rising number of electric cars on the one hand and the drop in City buses use during the Corona crisis, City buses were as of 2020 emitting more CO_2e per passenger km than individual cars: 90g versus 60g (Engendal, Rothe, & Lyle, 2021). Statistics Norway indicates an average of 10.39 persons per city bus. To continue the example of a Bergen-Stavanger trip, and using once again the same equation but divided by the number of bus passengers:

*(2.66 kg/L * 63.57 L/ 100 km * 179.5 km) / 10.39 = 34.2 kg of CO_2e per person or 0.191 per km.*

But now let's assume that 30 persons are taking this bus:

*(2.66 kg/L * 63.57 L/ 100 km * 179.5 km) / 30 = 11.84 kg of CO_2e per person or 0.066 per km.*

This shows how much the ecological benefit of public transportation depends on it being used by many people. As a matter of interest, here the threshold number of users, so that taking the bus is a better option than using the car here, would be 8 persons.

Rail

CO_2 emissions of a railway system vary, with many factors influencing emission of CO_2 per km travelled, such as the frequency of stops, the propulsion system, the train length, etc. Although the majority of train routes in Norway are already electrified, there are still some fossil-fueled long-distance routes, such as the longest train route in Norway: the Nordland line (Trondheim - Bodø), with a length of 734km and 43 stations is a relatively significant polluter. Differences in emission of CO_2e between electric and diesel propulsion trains are amplified when it is required to accelerate the vehicle to maximum speed than to maintain its speed or because of multiple stops requiring to repeat the acceleration phase, causing emissions to be intense compared with a direct city-to-city route. With a 50% train car load utilized by passengers, the CO_2e emissions per passenger kilometer for such trains are approximately 0,045kg (Behrens, 2010). So, for a passenger taking a trip in one of these few diesel railway lines of Norway, for a distance similar to the road one from Bergen to Stavanger (179.5 km), their average carbon emissions for that distance would be 8.0775 kg.

Aviation

In 2019, the total CO_2 emissions from the aviation industry were estimated to be 15 million tons according to IATA (IATA, 2020), accounting for roughly 2 % of the total global CO_2 emissions with a steadily increasing percentage. To calculate these CO_2 emissions, we have developed a distance-based methodology that estimates the emissions of one passenger. The methodology is developed to only require one user input, whereas the rest of the inputs will be based on industry averages for typical inter-European short-haul flights. For the aircraft type we have chosen to use Boeing 737, with a capacity of 183 economy passengers, as the most common passenger aircraft type in Norway (Frafjord & Topdahl, 2017; SAS, 2021).

CO_2 per passenger *= 3.16 * (total fuel burn kg/km * km travelled)/number of seats occupied*

BGO-SVG emissions *(with 50% occupancy) = 3.16 * 4.315 * 159.9 / 91,5 = 23.44 kg or 0.146 per passenger km*

3.16 is the constant that represents the CO_2 emissions in kilogram from burning one kilogram of kerosene jet fuel (ICAO, 2018). This factor varies by short- or long-haul flights. Total *fuel burn* is calculated to be 4.315 kg/km, based on the Boeing 737-800 (fuel consumption per seat = 0.029 L/km = 0.029*0.8 = 0.0232 kg/km times 183 for total (SAS, 2021). *Kilometers travelled* are given by the user.

This calculation can only be seen as an approximation of actual emissions. Other factors that were not included in the model include the type of flights (short- and long-haul), radiative forcing (other harmful emissions caused by aviation), climate effects from emissions happening at a higher atmospheric level (thus creating a multiplier effect), increased use of biofuel, airport infrastructure and individual cargo and load factor of airplanes (Hill, et al., 2019; My Climate Foundation, 2019)

Maritime transport

As with the other means of transport, the emissions from ferries differ depending on the characteristics of the ferry. Hereafter we will look at the emissions from vessels in use. Because the distance and tonnage are often exogenous, the only impressionable factor in the equation is the specific emission factor, and this is typically linked to characteristics like fuel type, engine fuel efficiency, the ferry's propulsion efficiency and weight.

For our specific example, travelling from Bergen to Stavanger, one needs to take the ferry for approximately 30.5 km of two separate trips. On the northernmost ferry route, the ferries are hybrid and run on a combination of natural gas and electricity, with the battery contributing to emission reductions through, amongst other things, peak shaving, while on the southernmost ferry route ferries run solely on gas. For simplicity we assume an emitted 0.128 kg of CO_2 per passenger kilometer, according to the British Department for Business, Energy and Industrial Strategy's calculation for ferry emissions (BBC, 2019).We therefore estimate CO_2 emissions on this combined route to be 0.128 kg * 30.5 km = 3.904 kg for the ferry use in the Bergen – Stavanger route (Vidas, 2021).

Conclusion

It can be a quite challenging task to calculate scope 1 emissions of vehicles, i.e., direct emissions generated only from the vehicles' operation and circulation, given all the different engines, vehicle weights, types of fuels and physics dynamics behind combustion and operation. Given our assumptions and the emission factors for means of transport, for a passenger km in a diesel car 0.257 kg of CO_2e are emitted, while similar petrol cars emit 0.223 kg per passenger km. Hybrid cars emit the lowest level of individual transport CO_2, with 0.069 kg of CO_2e emissions per passenger km. Lastly, an average engine petrol-fueled motorcycle would emit 0.123 kg of CO_2e emissions per passenger km. With regards to collective transport, a diesel train would emit 0.045 kg of CO_2e emissions per passenger km, while buses would emit an average of 0.191 kg of CO_2e emissions per passenger km. A passenger km by ferry would emit 0.128 kg of CO_2e, while an aircraft emits an average of 0.146 kg of CO_2e per passenger km. The calculations were based on average occupation of public means of transport, as given by the referenced authorities sources. More complex factors to be considered in the emissions calculations were selectively omitted, for ease of calculation.

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