Chapter 2
Current Figures

In order to assess the benefits of our two models in terms of GHG emissions, we need to determine the emissions of the current, fossil fuels based, model. Similarly, the energy to wheel of the current model is required if we are to compute the needed electricity or hydrogen to power the equivalent traffic.

The GHG emissions of the electrical or hydrogen models comes in part, if not all, from electricity generation. Assessing the emissions of both models requires therefore the knowledge of the so-called "emissions coefficients." These numbers are simply the amount of GHG emitted when generating 1 Watt-hour of electricity from any given primary energy sources. They are common to both models and are therefore discussed in this chapter.

2.1 Energy to Wheels

According to the "Instituto Nacional de la Estadistica" (*ine.es*), there were 10,510,112 gasoline cars in Spain in 2011, and 11,763,255 diesel ones. The same source also gives the average amount of kilometers covered by each kind of cars: 10,486 for gasoline and 14,466 for diesel cars.

The "Instituto para la Diversificación de Ahorro y Energía" runs a database[1] gathering technical information on private cars sold in Spain. From there, we could compute their average consumption. The result is 6.55L/100 km for gasoline, and 5.53L/100 km for diesel cars.

These numbers allow to derive the total amount of energy provided to Spanish private cars in 2011. Considering an energy content of 32.18 MJ/L for gasoline and 35.86 MJ/L for diesel fuels [1], the total amount of energy provided to the tanks was,

[1] http://coches.idae.es/portal/BaseDatos/MarcaModelo.aspx.

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$$E_{t,gas} = 10{,}510{,}112 \times 10{,}486 \times \frac{6.55}{100} \times 32.18 = 2.32 \times 10^{11} \text{ MJ},$$
$$E_{t,die} = 11{,}763{,}255 \times 14{,}466 \times \frac{5.53}{100} \times 35.86 = 3.37 \times 10^{11} \text{ MJ}.$$

We now need to derive from these numbers the amount of energy at wheels level. To do so, we simply account for the various efficiencies from the tank to the wheels. These stem from the engine losses, and then from the mechanical losses between the engine and the wheels.

For gasoline engines, we consider an efficiency of 35 %. For diesel engines, an efficiency of 44 % [2]. In each case, the mechanical efficiency is taken as 80 % [3]. The chains of efficiencies are pictured in Figs. 2.1 and 2.2, for gasoline and diesel vehicles respectively, resulting eventually in a 28 % Tank-to-Wheels efficiency for gasoline, and 35.2 % for diesel.

Hence, the total amount of energy to wheels is,

$$\begin{aligned} E_{w,gas} &= 0.35 \times 0.8\ E_{t,gas} = 6.5 \times 10^{10} \text{ MJ}, \\ E_{w,die} &= 0.44 \times 0.8\ E_{t,die} = 1.19 \times 10^{11} \text{ MJ}, \\ E_w &= E_{w,gas} + E_{w,die} = 1.83 \times 10^{11} \text{ MJ} = 51.06 \text{ TWh}. \end{aligned} \tag{2.1}$$

Therefore, if the Spanish private car traffic was to be electrified or "hydrogenized," the energy provided to wheels would have to be 51.06 TWh in order for the traffic to be equivalent to the 2011 one. This number represents 20 % of the 260 TWh consumed in the country in 2013 [4].

Table 2.1 summarizes the results of this section.

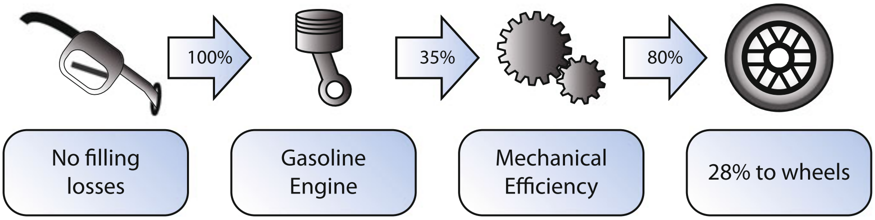

Fig. 2.1 Tank-to-Wheels efficiency for gasoline vehicles

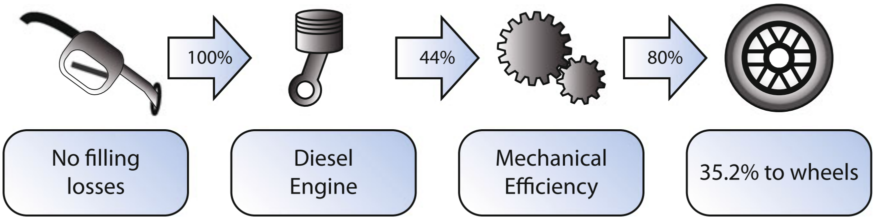

Fig. 2.2 Tank-to-Wheels efficiency for diesel vehicles

Table 2.1 Current state of the Spanish private cars traffic

	Number	km/year	L/100 km	E_{tank} (MJ)	E_{wheel} (MJ)
Gasoline	10,510,112	10,486	6.55	2.32×10^{11}	6.5×10^{10}
Diesel	11,763,255	14,466	5.53	3.37×10^{11}	1.19×10^{11}

2.2 Current Emissions

Since we want to assess how lower, or not, GHG emissions would be within some alternative models of traffic, we need to determine the emissions of the current, fossil fuel-driven traffic. For Spain in the year 2011, the United Nations Framework Convention on Climate Change (UNFCCC, *unfccc.int*—Flexible GHG data queries) provides the following numbers,

- Total GHG emissions, road transportation, diesel oil: 63.52 Tg CO_2eq.
- Total GHG emissions, road transportation, gasoline: 15.99 Tg CO_2eq.

Unfortunately, data are not split by kind of transportation. The numbers above include motorbikes' and trucks' emissions as well. We shall thus compute private cars emissions, and contrast with the aggregated UNFCCC numbers for a coherence check.

For gasoline cars, GHG emissions amount to 2.36 kg CO_2eq/L. For diesel fuel, it is almost the same, namely, 2.63 kg CO_2eq/L [1]. Given the number of cars and kilometers reported in Table 2.1 for each kind of vehicle, we find,

- Total GHG emissions, private cars, diesel oil: 17.05 Tg CO_2eq,
- Total GHG emissions, private cars, gasoline: 24.72 Tg CO_2eq.

Hence,

$$\text{Total GHG emissions, private cars} = 41.77\ \text{Tg CO}_2\text{eq.} \tag{2.2}$$

This figure is coherent with the all-road transportation emissions given by the UNFCCC. It will be our reference for comparison with the coming hydrogen and electrical scenarios.

Noteworthily, the previous amount of GHG emissions per liter of diesel, or gasoline, makes perfect sense. Let us compute them from first principles. Considering roughly that 1 L of gasoline holds 1 kg of carbon, we find its combustion should release 1 kg of carbon atoms. And since combustion pairs up two oxygen atoms with one carbon atom, the resulting molecule of CO_2 weights 3.66 times as much as its carbon atom.[2] We therefore come to the rule of thumb that burning 1 L of gasoline should emit 3.66 kg of CO_2, which is not far from the actual figures used above (for an even more accurate result, one can consider that 1 L on gasoline holds only 0.7 kg of carbon).

[2] 1 mole of C is 12 grams. 1 mole of O is 16 grams. The 3.66 factor comes from $(12 + 2 \times 16)/12$.

2.3 Emission Coefficients

Within the electrical model, GHG are emitted when generating the extra electricity needed to run the electric cars. Within the hydrogen model, GHG are emitted when generating the hydrogen required. As we shall see in Chap. 3, there are many ways to do so, and many of them involve electricity.

One common point of our two models is therefore that both contemplate GHG emissions through electricity generation. In turn, electricity can be generated from fossil fuels, nuclear, wind, etc., each option emitting more or less GHG.

The amount of GHG emitted per Watt-hour generated is called the "emission coefficient," typically given in grams of CO_2 equivalent per kWh, or Teragrams per TWh.

The emission coefficients e_i are pictured in Fig. 2.3 and given in Table 2.2. They are the outcome of a large-scale literature review performed on the topic in Ref. [5] and are expressed in terms of their distribution with minimum, 25th percentile value, average, 75th percentile value and maximum.

Note that although they do not directly emit CO_2 when generating electricity, sun, hydro, biomass, wind, or nuclear energy are not strictly attributed zero emissions per TWh. The main reason why is that these numbers account for the full life cycle of the technologies considered. For example, it takes concrete and energy to build a

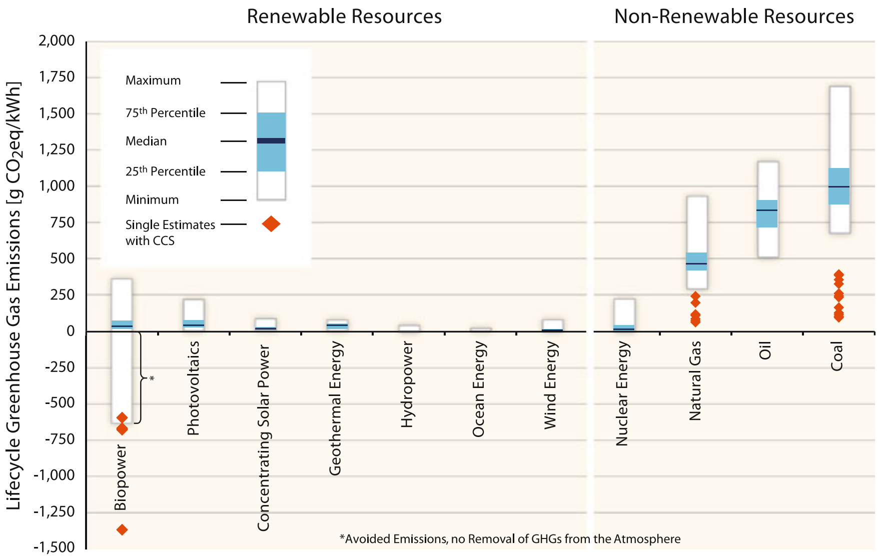

Fig. 2.3 Estimated GHG emissions coefficients throughout the life cycle (g CO_2eq/kWh) for different power generation technologies. "CCS = Carbon capture and storage" (Figure SPM.8 from [5], p. 19)

Table 2.2 GHG emissions coefficients e_i in Tg CO_2eq/TWh ([5], p. 982)

	Min	25th percentile	Average	75th percentile	Max
Coal	0.67	0.87	1	1.13	1.69
Oil	0.51	0.722	0.84	0.9	1.17
Gas	0.29	0.42	0.47	0.54	0.93
Sun	1.2×10^{-2}	4.3×10^{-2}	6.8×10^{-2}	0.11	0.3
Hydro	0	3×10^{-3}	4×10^{-3}	7×10^{-3}	4.3×10^{-2}
Biomass	0	0	6.8×10^{-3}	6×10^{-3}	6.08×10^{-2}
Wind	2×10^{-3}	8×10^{-2}	1.2×10^{-2}	2×10^{-2}	8.1×10^{-2}
Nuclear	1×10^{-3}	8×10^{-2}	1.6×10^{-2}	4.5×10^{-2}	0.22

dam or a nuclear power plant, and concrete production is a notorious GHG emitter.[3] It also takes energy to build solar cells or wind mills, etc.

We therefore find that once all operations related to electricity production have been accounted for, even "non directly GHG-emitting technologies," do emit some. It is nevertheless a fact that looking at the average values of the emissions coefficients in Table 2.2, one finds that such non directly GHG-emitting technologies, emit between 15 and 250 *less* GHG than coal.

Besides the non-zero value of the emissions coefficients for sun, hydro, biomass, wind and nuclear, their spread may also intrigue the reader. For example, we find a factor 25 for sun between the "max" and the "min" columns. Why isn't there one single column in Table 2.2? Mainly because when it comes to accounting for every possible emissions during the life cycle of a dam, for example, all authors don't always consider the same boundaries for their calculations. For example, it takes concrete to build a dam, but should we consider the emissions of the trucks carrying the concrete, on the top of the emissions generated by the concrete manufacturing itself? If yes, should we then account for the GHG emitted when building these trucks? And so on. The evaluation of the emissions resulting from the generation of the same Watt-hour may thus vary with the number of secondary processes accounted for.

In spite of such disparities, the coefficients extracted from many studies (296!) cluster around some average numbers. Yet, we chose to translate their spread into our calculations by presenting our scenario' emissions for each column of Table 2.2.

Finally, it is interesting to recognize that on a purely physical ground, the numbers featured in Table 2.2 for fossil fuels make sense. Let us compute, starting with oil, their order of magnitude:

[3]Nearly 0.8 tons of CO_2 per ton of cement produced. See [6], p. 758, 1345.

- 1 L of oil contains about 42 MJ, that is, 11.6 kWh.
- If the energy content of 1 L of oil could be perfectly translated into electricity, then 1 L of oil would generate 11.6 kWh of electricity. Assuming this is done with a 50 % efficiency, we find 1 L of oil generates 5.8 kWh of electricity.
- How much carbon do we emit in the process? Oil is mainly carbon. Let us simply consider that burning 1 L of oil releases 1 kg of carbon.
- We should therefore emit 1 kg of carbon to generate 5.8 kWh of electricity from oil. That is, $1000/5.8 = 171$ grams of carbon per kWh.
- Finally, and as noted above, each atom of carbon catches 2 oxygen atoms to form a CO_2 during the combustion. The molecular weight of CO_2 is 3.66 times that of carbon. We thus need to multiply our 171 grams of carbon by 3.66 to find the amount of CO_2 emitted.
- We finally get to $171 \times 3.66 = 627$ g CO_2/kWh, or 0.63 Tg CO_2/TWh, perfectly in line with the numbers presented.

As expected, emission coefficients for gas or coal are similar, order of magnitude wise, since their energy content is comparable. But when it comes to the other coefficients, like nuclear, solar, or wind, such back-of-the-envelope calculations are not performed so easily, because now, emissions only come from indirect processes such as power plant building, solar cells manufacturing, and so on.

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