Guide for computing CO_2 emissions Related to energy use

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This guide is intended to facilitate the calculations of industry-related greenhouse gas emissions by presenting the necessary coefficients and conversion factors in the form of easy-to-use tables. The examples below demonstrate this methodology and show users that there is a painless way to do these calculations.

With the application of increasingly stringent environmental policies and legislation, many engineers and managers are now being asked to assess their company's annual contribution to global warming. This is done by calculating the greenhouse gas emissions, or CO_2 equivalent emissions, including the emissions associated with energy use. Although relatively simple, all the steps involved in these calculations can be time-consuming and tedious, and errors may occur because of the many unit conversions that are required and the difficulty in obtaining certain types of data. Hence, we have prepared this practical guide, which sets out a simple method and provides examples and most of the information you will need to get through the calculations.

The first step in the computational process obviously consists in gathering together all of the energy bills for the year and extracting the volumes or quantities of each of the fuels used, along with the amount of electricity consumed. When the computation involves determining the environmental impact caused by adding or replacing equipment, an estimate of the adjusted consumption of each type of energy source is required.

In the second stage, you must convert the data provided on the energy bills into reference units, which will simplify the remaining calculations. Table 1 shows the energy content, expressed in megajoules (MJ) per unit of quantity or volume, for most types of energy carriers. Tables 2 and 3 can be used to convert the units of the values shown on your energy bills. Here are two examples illustrating the use of these tables:

Example 1: In a given company, it is estimated that a new process will require the use of 1 million pounds of steam during the year. How many m^3 of natural gas will be needed to produce this quantity?

In Table 1, we can see that the energy content of steam is 2,33 MJ/kg. Looking at Table 3, we see that 1 pound (lb) corresponds to 0,454 kg. The energy required to produce 1 million pounds of steam can now be determined through the following calculation:

Energy required
= 2,33 MJ/kg * 0,454 kg/lb * $1x10^6$ lbs
= $1,058x10^6$ MJ

Again, we can see from Table 1 that the energy content of 1 m^3 of natural gas is 37,23 MJ.

Volume of natural gas required
= $1,058x10^6$ MJ / 37,23 MJ/m^3
= 28418 m^3.

Example 2: A Quebec company wants to replace the energy it produces with its commercial boiler that uses No. 6 fuel oil by an equivalent output of energy that consists of 80% No. 2 fuel oil and 20% electricity. The current consumption level is 30 m^3. What quantities of No. 2 fuel oil and electricity will be required if the energy use is expected to remain constant?

By referring to the tables:

Quantity of energy used by the company annually
= 41,73 MJ/l of oil No.6 * 1000 l/m3 * 30 m3
= 1,252x106 MJ

Volume of No. 2 fuel oil required
= (0,8*$1,252x10^6$ MJ) / (38,68 MJ/l * 1000 l/m^3)
= 25,89 m^3

Quantity of electricity required
= (0,2*$1,252x10^6$ MJ) / (3,6 MJ/kWh)
= 69555 kWh

The third calculation stage involves assessing the CO_2 equivalent emissions associated with your company's energy consumption. Table 4 presents the emission factors for the main greenhouse gases (CO_2, N_2O and CH_4) emitted to the atmosphere resulting from the combustion of natural gas and light and heavy petroleum derivatives. Table 5 gives the CO_2 equivalent emission factors associated with electricity, by province (for the year 1998). These factors have been computed based on the contribution of every type of energy used to generate electricity. Lastly, Table 6 shows the global warming potential (GWP) of the main greenhouse gases (with CO_2 used as a reference). For fuels, the CO_2 equivalent emissions are determined by multiplying the quantity of each gas emitted by its GWP value. In addition, with regard to electrical energy, the equivalent emissions are provided directly since they come from a variety of sources whose contribution varies relative to the producing province. Here are two examples of the use of these tables:

Example 3: In example 1, it was estimated that 28418 m^3 of natural gas were needed to produce 1 million pounds of steam. If a commercial boiler were to be used, what equivalent emitted amount of CO_2 would correspond to this estimate?

In example 1, it was estimated that $1,058x10^6$ MJ (energy content of 28418 m^3 of natural gas) were required to produce 1 million pounds of steam. From Table 4, it can be seen that the emission factors for natural gas are 49,68 t/TJ for CO_2, 0,52 kg/TJ for N_2O and 1,1 kg/TJ for CH_4 (commercial boiler). In addition, the GWP values for these gases are 1, 310 and 21, respectively. Given that a tonne equals 1000 kg and a megajoule equals 1x10^{-6} tera-joule (TJ), the CO_2 equivalent emissions can be computed as follows:

CO_2 equivalent emissions per TJ =
=1 * 49,68 t/TJ * 1000 kg/t + 310 * 0,52 kg/TJ + 21 * 1,1 kg/TJ
= 49864 kg/TJ
= 49,864 t/TJ

Total CO_2 equivalent emissions
= 49,864 t/TJ * 1,058x10^{6} MJ * 1x10^{-6} TJ/MJ
= 52,76 t

Example 4: In example 2, a Quebec company using a commercial boiler had a consumption of 30 m^3 of No. 6 oil which has been replaced by 25,89 m^3 of No. 2 oil plus 69555 kWh of electric power. We want to compute the corresponding change in CO_2 equivalent emissions. After the changes, what would the difference be for a company located in Alberta?

Referring to tables 4 and 5, we can see that the factors for heavy oil are 3090 kg/m^3 for CO_2, 0,013 kg/m^3 for N_2O and 0,06 kg/m^3 for CH_4. The corresponding factors for light oil are 2830, 0,013 and 0,026. The factor for electric power in Quebec is 0,009 t/MWh and that for Alberta is 0,915. Since one megawatt-hour is equal to 1000 kilowatt-hours, the calculations are as follows:

CO_2 equivalent emissions <u>before</u> the changes, in Quebec and in Alberta
= 30 m^3 * (1 * 3090 kg/m^3 + 310 * 0,013 kg/m^3
+ 21 * 0,06 kg/m^3) / 1000 kg/t
= 92,86 t

CO_2 equivalent emissions <u>after</u> the changes in Quebec
= 25,89 m^3 * (1 * 2830 kg/m^3 + 310 * 0,013 kg/m^3
+ 21 * 0,026 kg/m^3) / 1000 kg/t + 69,555 MWh * 0,009 t/MWh
= 73,39 + 0,626 t
= 74,01 t

Variation in CO_2 in emissions in Quebec
= 74,01 - 92,86
= -18,85 t (reduction)

CO_2 equivalent emissions <u>after</u> the changes in Alberta
= 25,89 m^3 * (1 * 2830 kg/m^3 + 310 * 0,013 kg/m^3
+ 21 * 0,026 kg/m^3) / 1000 kg/t
+ 69,555 MWh * 0,915 t/MWh
= 73,39 + 63,64 t
= 137,03 t

Variation in CO_2 emissions in Alberta
= 137,03 - 92,86
= 44,17 t (increase)

This example shows that the values for greenhouse gas emissions associated to the energy use vary substantially depending on the province and the energy sources involved.

For more information on energy efficiency and reducing CO_2 emissions in the industry and buildings, you can contact Natural Resources Canada's CANMET Energy Diversification Research Laboratory at the following Internet address: http://cedrl.mets.nrcan.gc.ca. If you are interested in automating the calculations, Natural Resources Canada's Office of Energy Efficiency (OEE) has developed a tool for computing CO_2 equivalent emissions; this is a Microsoft Excel file that operates in Windows. The file is available at the following Internet address: http://oee.nrcan.gc.ca. The computing guide presented in the article and the OEE tool should only be used to help estimate CO_2 emissions. Enjoy your calculations!

Table 1: Energy Contents

Electricity	Hydro	3,6	MJ/kWh
	Nuclear (typical value)	11,6	MJ/kWh
Steam		2,33	MJ/kg
Natural gas		37,23	MJ/m^3
Ethane (liquid)		18,36	MJ/l
Propane (liquid)		25,53	MJ/l
Coal	Anthracite	27,7	MJ/kg
	Bituminous	27,7	MJ/kg
	Sub-bituminous	18,8	MJ/kg
	Lignite	14,4	MJ/kg
	Average domestic use	22,2	MJ/kg
Petroleum products	Aviation gasoline	33,62	MJ/l
	Motor gasoline	34,66	MJ/l
	Kerosene	37,68	MJ/l
	Diesel	38,68	MJ/l
	Light fuel oil (no.2)	38,68	MJ/l
	Heavy fuel oil (no.6)	41,73	MJ/l

Table 2: Conversion factors for energy

1 Gigajoule (GJ)	= 0,001	Terajoule (TJ)
	= 1000	Megajoules (MJ)
	= 1x10^9	Joules (J)
	= 277,8	kilowatt-hours (kWh)
	= 948170	BTU

Table 3: Miscellaneous conversion factors

1 pound (lb)	= 0,454	kilogram (kg)
1 tonne	= 1000	kilograms (kg)
1 m^3	= 1000	litres (l)
1 imperial gallon	= 4,547	litres (l)
1 US gallon	= 3,785	litres (l)
1 cubic foot (pi^3)	= 0,02832	m^3
1 tera	= 1x10^{12}	
1 giga	= 1x10^9	
1 mega	= 1x10^6	

Table 4: Emission factors for fuels

		CO_2 (t/TJ)	N_2O (kg/TJ)	CH_4 (kg/TJ)
Natural Gas	Commercial boiler	49,68	0,52	1,1
	Industrial boiler	49,68	0,52	1,3
		CO_2 (kg/m^3)	**N_2O (kg/m^3)**	**CH_4 (kg/m^3)**
Light Oil	Commercial boiler	2830	0,013	0,026
	Industrial boiler	2830	0,013	0,006
Heavy Oil	Commercial boiler	3090	0,013	0,06
	Industrial boiler	3090	0,013	0,12
Propane (LPG)	LPG	1530	0,23	0,03

Table 5: CO_2 equivalent emission factors for electricity, by province (reference year: 1998)

	(t/MWh)
Newfoundland and Labrador	0,034
Prince Edward Island	1,012
Nova Scotia	1,984
New Brunswick	1,012
Quebec	0,009
Ontario	0,236
Manitoba	0,030
Saskatchewan	0,844
Alberta	0,915
British Columbia	0,027
Territories	0,368
Average for Canada	**0,222**

Table 6: Global Warming Potential (GWP)

Gas	GWP
CO_2	1
N_2O	310
CH_4	21