Additional information on calculating the emission factors of Chile for the JCM

Summary

In order to secure net emission reductions in the methodology, the following reference emission factors will be applied depending on the grid to which a proposed project activity will connect in Chile:

- Table 1 summarises the applied reference emission factors for the PV system(s) in a proposed project activity, which is directly connected to a regional grid, or connected to a regional grid via an internal grid *not* connecting to a captive power generator (PV Case 1).
- Table 1 also summarises the applied reference emission factors for the PV system(s) in a proposed project activity, which is connected to an internal grid connecting to *both* a regional grid and a captive power generator (PV Case 2).

Table 1. **Reference emission factor PV Case 1 and Case 2**

Regional grid name	Emission factor for PV Case 1 (tCO_2/MWh)	Emission factor for PV Case 2 (tCO_2/MWh)
SEN (National System)	0.404	0.404
Aysén System	0.176	0.176
Magallanes System	0.361	0.361

- A reference emission factor of **0.533 t-CO_2/MWh** is applied, in the case that the PV system (s) in a proposed project activity is *only* connected to an internal grid connecting to a captive power generator (PV Case 3).

1. Current status of the electricity system in Chile

The Chilean electric power grid is organised into three independent systems [1] (Figure 1): the National Electricity System (SEN, *Sistema Eléctrico Nacional*), which is the interconnecting system of the Central System (SIC, *Sistema Interconectado Central*) and the Northern System (SING, *Sistema Interconectado Norte Grande*) since November 2017, serving the northern and central part of the country; and two small systems, Aysén and Magallanes serving the south. All electric power generation, transmission and distribution activities are implemented by the private sector under the supervision of the National Energy Commission (CNE, *Comisión Nacional de Energría*).

[1] National Energy Commission (2018) 2018 Energy Statistical Yearbook Chile

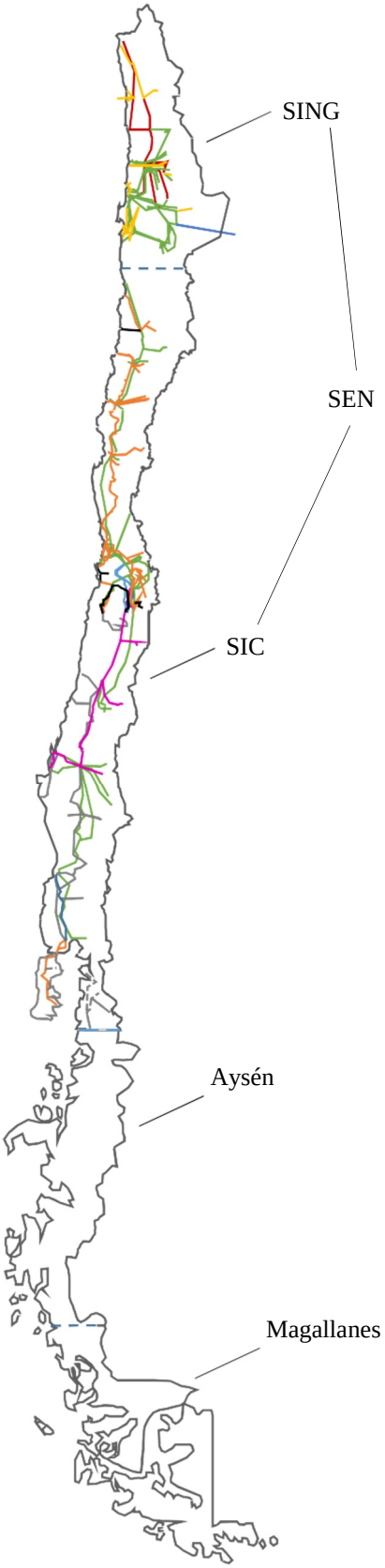


Figure 1. The three independent electricity systems in Chile

Throughout 2016-2018 (Table 2), the SIC and SING (hereafter referred to as SEN) was the main electricity system in Chile, covering more than 99% of the national electricity generation[2]. The rest of electricity is supplied by the Aysén and Magallanes.

Table 2. Annual Power Generation per Electricity System*

Year	Gross Power Generation (TWh)			
	SEN[3]	Aysén[4]	Magallanes[5]	Total**
2016	73.35	0.16	0.32	73.85
2017	74.07	0.16	0.33	74.58
2018	75.43	0.17	0.34	75.96

* Power generation represents the amount of electricity generated by power plants connected in each grid that is transmitted and distributed for consumer use.

** The electricity generation of Los Lagos system is not included due to its limited amount of power generation.

Seven types of primary energy sources are used for electricity generation: coal, diesel and oil, natural gas, hydro, biomass, cogeneration, wind, and solar power. The share of electricity generated in 2016-2018 by each type of primary energy source is shown in Figure 2. The electricity generated from hydro, biomass, cogeneration, wind, solar power plants are deemed as low cost/must run (LCMR) power sources.

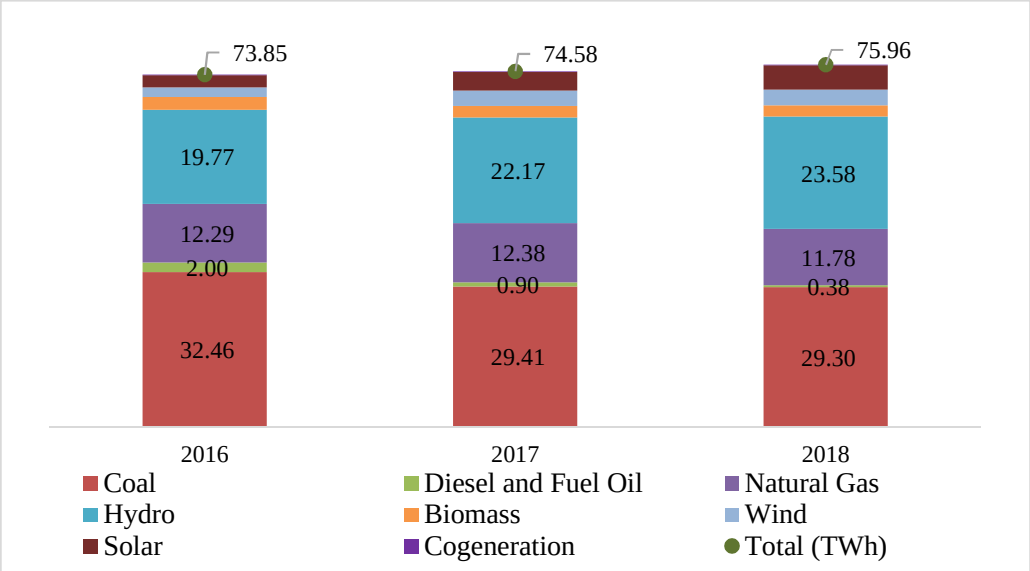


Figure 2. National Total Power Generation by Type of Fuel (TWh)
(Note: the figure is developed based on National Energy Commission (2020).)

[2] National Energy Commission (2018) 2018 Energy Statistical Yearbook Chile

[3] National Energy Commission (2020) Gross Generation of SEN. (accessed on March 2020) https://www.cne.cl/wp-content/uploads/2020/03/Generacion_Bruta.xlsx

[4] National Energy Commission (2020) Gross Generation of Aysén. (accessed on March 2020) https://www.cne.cl/wp-content/uploads/2019/06/generacion_bruta_Aysxn.xlsx

[5] National Energy Commission (2020) Gross Generation of Aysén. (accessed on March 2020) https://www.cne.cl/wp-content/uploads/2019/06/generacion_bruta_Magallanes.xlsx

2. Calculation of reference emission factor of electricity systems

Since the four electricity (grid) systems are independent from each other, reference emission factors are calculated for each system. In order to identify the reference emission factor of each grid in a conservative and simple manner to secure net emission reductions, the emission factors in this methodology are established by an operating margin that is calculated using emission factors of power plants including LCMR resources.

Conservative emission factor of LCMR power plant is set as zero, and conservative emission factors of fossil fuel power plants are calculated using the following equation:

Emission factor of fossil fuel power plant [tCO_2/MWh]

= (Emission factor of fuel source [$kgCO_2$/TJ]*10^{-3}*0.0036[TJ/MWh] /
(Heat efficiency (LHV) [%]/100)

Emission factors of coal, gas and diesel combustion are derived from the "IPCC guideline 2006, Volume 2, Chapter 2, stationary combustion" as 89,500 $kgCO_2$/TJ, 54,300 $kgCO_2$/TJ and 72,600 $kgCO_2$/TJ (Table 3). The heat efficiencies of coal-fired power plants and gas-fired power plants are applied as 39% and 53.7% respectively, taking into consideration the technologies being used in currently operational power plants in Chile (Table 3). With regard to diesel-fired power plants, a heat efficiency of 49%, an efficiency level which has not yet been achieved by the world's leading diesel generator, is applied.

Table 3. Constants for calculation of reference emission factor

Item	Values	Reference
Best heat efficiency of natural gas power plant (Candelaria, 2005)	53.7% (combined cycle)	o Colbún S.A. website[6], o General Electric catalogue[7]
Best heat efficiency of coal power plant (Cochrane and Angamos, 2015)	39% (sub-critical)	o Environmental Evaluation Services (SEA) Chile[8] o UNFCCC, 2015
Best heat efficiency of diesel power plant	49%	JCM Approved Methodologies: PW_AM001, MN_AM003, etc.
CO_2 emission factor of other bituminous coal	89,500 $kgCO_2$/TJ	IPCC guideline for National Greenhouse Gas Inventories 2006, Volume 2, Chapter 2, stationary combustion[9]
CO_2 emission factor of natural gas	54,300 $kgCO_2$/TJ	
CO_2 emission factor of diesel	72,600 $kgCO_2$/TJ	

[6] Colbún S.A. website. (accessed on March 2020) https://www.colbun.cl/centrales/candelaria/

[7] General Electric website. https://www.ge.com/content/dam/gepower-pgdp/global/en_US/documents/product/gas%20turbines/Fact%20Sheet/2017-prod-specs/GEA32931A%209E-GT13E2_Power_Plants_R2.pdf

[8] According to Environmental Impact Assessment of Cochrane Thermoelectric Plant reported to the SEA Chile (accessed March 2020) https://seia.sea.gob.cl/archivos/RCA_COCHRANE.pdf, the steam generated is 160 bar and 565°C and is expanded in a steam turbine of the condensation type. According to IEA (2011) Power Generation from Coal, this specification can be classified as sub-critical. The default efficiency factor for sub-critical technology is 39% according to UNFCCC CDM EB (2015) Tool to calculate the emission factor for an electricity system.

[9] IPCC default values at the lower limit of the uncertainty at a 95 per cent confidence interval.

Applying the emission factors and plant efficiencies (Table 3), the conservative emission factors are calculated to be **0.826** tCO_2/MWh for coal-fired power plants, **0.364** tCO_2/MWh for gas-fired power plants and **0.533** tCO_2/MWh for diesel-fired power plants. The conservative emission factors are applied for calculating the reference emission factor of each grid in Chile.

Using the conservative emission factors for each power source data and electricity generation including LCMR resources, operating margins of each grid are obtained using the following equation:

$$EF_{RE,j} = \frac{\sum_i EG_{i,j} \times EF_i}{\sum_i EG_{i,j}} \qquad \text{… Equation 1}$$

Where:

$EF_{RE,j}$ = The reference emission factor of regional grid *j* [tCO_2/MWh]

EF_i = Conservative emission factor of power plant type *i* [tCO_2/MWh]

$EG_{i,j}$ = Average electricity generated and delivered to each grid from power plant type *i* including LCMR resources in grid *j* during 2016-2018 [MWh]

There are three possible cases of solar PV installation in a project activity in terms of its connectivity to the grid and captive power generator:

- PV case 1: the PV system(s) is directly connected to a regional grid, or connected to a regional grid via an internal grid not connecting to a captive power generator.
- PV Case 2: the PV system(s) is connected to an internal grid connecting to both a regional grid and a captive power generator.
- PV Case 3: the PV system(s) is only connected to an internal grid connecting to a captive power generator.

a. Reference emission factor of National System (SEN, *Sistema Eléctrico Nacional*)

The SEN system is mainly powered by coal (41%), followed by hydro (29%), then natural gas (16%). Biomass, diesel and fuel oil, wind, solar, and cogeneration power supply the rest of the power generation.

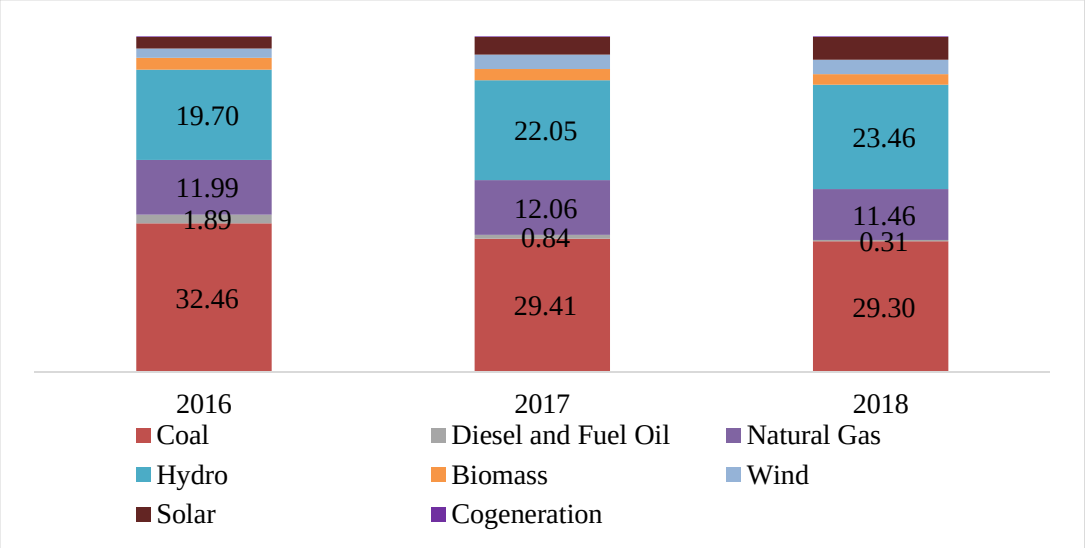


Figure 3. Electric power generated by power plants in SEN grid by fuel type (TWh, 2016-2018) (Note: the figure is developed based on National Energy Commission (2020).)

Applying the conservative emission factors and power generation (Figure 3) to Equation 1, the reference emission factor to be applied for solar PV in a proposed project activity which is directly connected, or connected via an internal grid not connecting to a captive power generator (PV Case 1), to the **SEN grid is 0.404 tCO_2/MWh,** as shown in Table 1.

b. Reference emission factor of Aysén system

The Aysén system is mainly powered by hydropower (62%). Diesel and fuel (33%) and wind power (5%) supply the rest of the power generation.

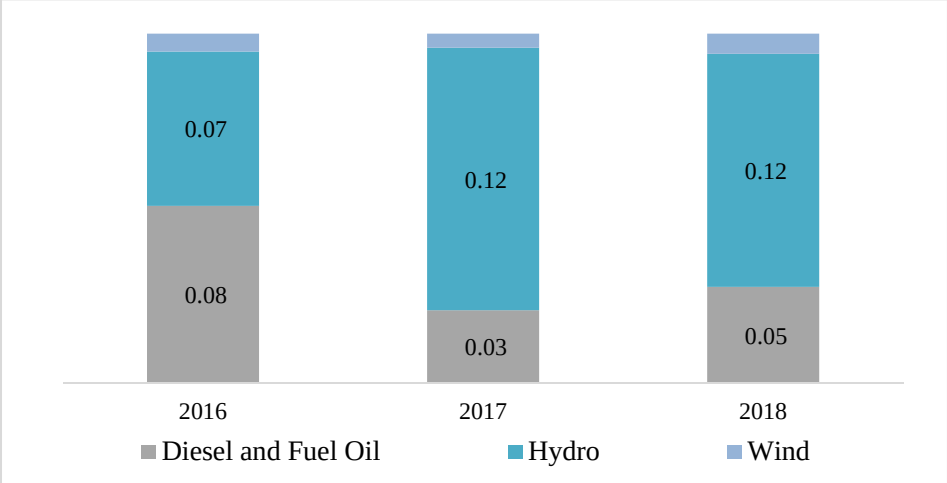


Figure 5. Electric power generated by power plants in Aysén grid by fuel type (TWh, 2016-2018) (Note: the figure is developed based on National Energy Commission (2020).)

Applying the conservative emission factors and power generation (Figure 5) to Equation 1, the reference emission factor to be applied for solar PV in a proposed project activity which is directly connected, or connected via an internal grid not connecting to a captive power generator (PV Case 1), to the **Aysén grid is 0.176tCO_2/MWh,** as shown in Table 1.

c. Reference emission factor of Magallanes system

The Magallanes system is powered by natural gas (94%), diesel and fuel oil (3%), and wind power (2%).

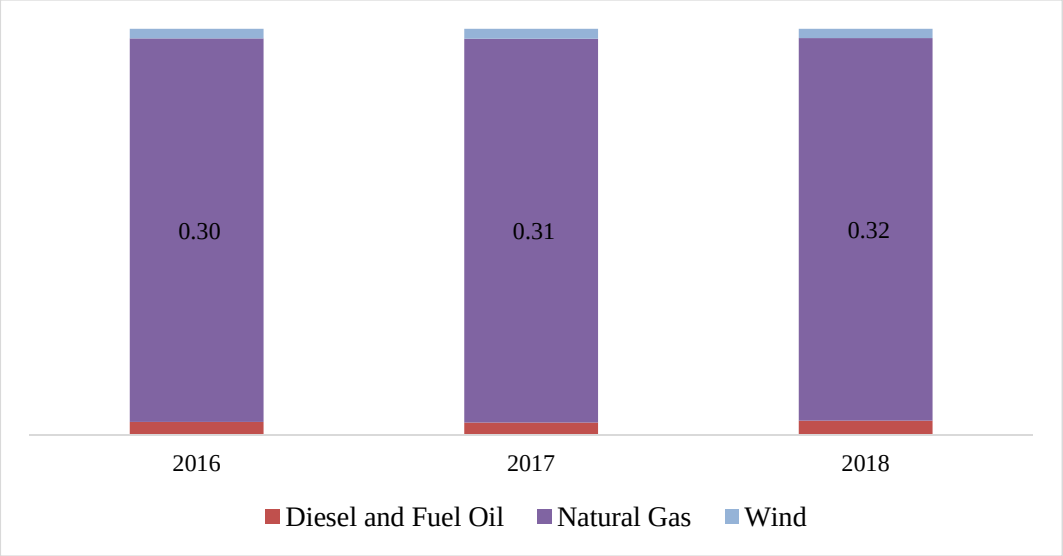


Figure 6. Electric power generated by power plants in Magallanes grid by fuel type (TWh, 2016-2018) (Note: the figure is developed based on National Energy Commission (2020).)

Applying the conservative emission factors and power generation (Figure 6) to Equation 1, the reference emission factor to be applied for solar PV in a proposed project activity which is directly connected, or connected via an internal grid not connecting to a captive power generator (PV Case 1), to the **Magallanes grid is 0.361 tCO_2/MWh,** as shown in Table 1.

3. Calculation of reference emission factor of a captive power generator (PV Case 3)

To determine the emission factor of a captive power generator which normally uses a diesel generator in a conservative and simple manner, a heat efficiency of 49%, an efficiency level which has not yet been achieved by the world's leading diesel generator, is applied.

The emission factor of diesel power generation is calculated from the heat efficiency using the following equation:

Emission factor of diesel power plant [tCO_2/MWh]

= (CO_2 emission factor of diesel oil [$kgCO_2$/TJ]*10^{-3}*0.0036[TJ/MWh] / (Heat efficiency (LHV) [%]/100)

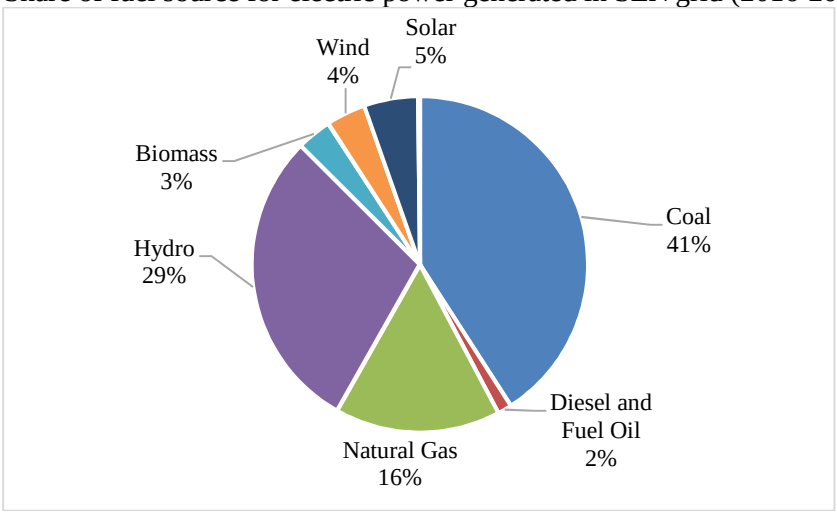
Applying the default value of the emission factor of diesel combustion which is 72,600 $kgCO_2$/TJ derived from "IPCC guideline 2006, Volume 2, Chapter 2, stationary combustion", together with the heat efficiency of 49%, the emission factor of a captive power generator and the reference emission factor to be applied for solar PV system(s) which is directly connected, or connected via an internal grid connecting to *only* a captive power generator (PV Case 3), is calculated to be **0.533 tCO_2/MWh**.

4. Selection of the reference emission factors in the case a solar PV system is connected to both grid and captive power generator (PV Case 2)

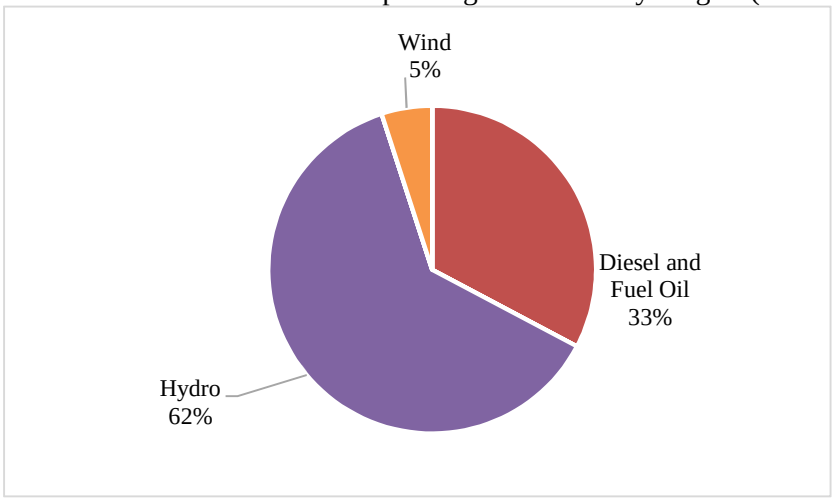
In the case the PV system(s) in a proposed project activity is connected to an internal grid connecting to *both* a regional grid and a captive power generator (PV Case 2), a comparison was made for each regional grid, between the emission factor for PV Case 1 (as shown in Table 1) and the emission factor for PV Case 3 (conservative emission factor of diesel-fired power plants of 0.533 tCO_2/MWh). The lower value resulting from this comparison was then applied as PV Case 2, as shown in Table 1.

Annex

a. Share of fuel source for electric power generated in SEN grid (2016-2018)



b. Share of fuel source for electric power generated in Aysén grid (2016-2018)



c. Share of fuel source for electric power generated in Magallanes grid (2016-2018)