Update Log for China's Electricity Database

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Background: With the development of technology in electricity generation and the changes to the ratio of different sources of electricity supply, the consumption of fossil fuels as well as the emission of greenhouse gases per kWh electricity supply has decreased evidently. Applying the outdated generic electricity data developed several years ago for LCA may lead to higher pollutant emission and environmental impact than reality. To calculate the environmental impact more accurately, Ecovane updated the consumption of fossil fuels and GHG emissions per kWh electricity supply for China national grid and provincial grid.

Update steps:

1. Obtain the provincial thermal power generation and fossil fuels consumption from the *Statistical Yearbook of China's Energy 2019*;
2. Obtain the net calorific values and the default carbon dioxide emission factors of different types of fossil fuels from *Statistical Yearbook of China's Energy 2019* and *National Guidelines for Provincial Greenhouse Gas Inventories (Pilot Edition)*;

Table 1 Carbon content, oxidation rate, and lower heating value of different kinds of fossil fuels

	Carbon Content	Oxidation rate	Lower heating value
	g carbon/MJ	%	MJ/t fuel or MJ/10,000 m^3 gas
Raw Coal	26.37	98	20,908
Cleaned Coal	25.41	98	26,344
Other Washed Coal	25.41	98	10,454
Briquette	33.56	98	17,584
Coke	29.42	93	28,435
Coke Oven Gas	13.58	99	173,535

Other Gas	12.20	99	202,218
Crude Oil	20.08	98	41,816
Gasoline	18.90	98	43,070
Diesel	20.20	98	42,652
Fuel Oil	21.10	98	41,816
Liquefied Petroleum Gas	17.20	99	50,179
Refinery Gas	18.20	99	45,998
Natural Gas	15.32	99	389,310
Other Petroleum Products	20.0	98	35,168
Other Coking Products	29.42	93	38,099
Gangue	25.8	98	8,363
Blast Furnace Gas	70.8	99	37,630
Converter Gas	46.9	99	79,450
Petroleum Coke	27.5	98	31,947
LNG	15.32	99	51,434

CO_2 emission factor can be calculated as follow:

$$Co_{CO2,k} = CC_k \times R_{C,k}/100 \times 44/12$$

Where, $Co_{CO2,k}$ denotes CO_2 emission factor (g CO_2/MJ) of fossil fuel type k, $R_{C,k}$ denotes oxidation rate (%), CC_k denotes carbon content (g carbon/MJ).

3. Obtain the default methane and nitrous oxide emission factors from *2006 IPCC Guidelines for National Greenhouse Gas Inventories*;
4. Calculate calorific value of different types of fossil fuels and the carbon dioxide, methane, nitrous oxide emission of different types of fossil fuels based on the methods proposed in *2006 IPCC Guidelines for National Greenhouse Gas Inventories*;

$$Cal_{i,k} = C_{i,k} \times H_k \times 10000$$

$$E_{CO2,i,k} = Cal_{i,k} \times Co_{CO2,k}/1000$$

$$E_{CH4,i,k} = Cal_{i,k} \times Co_{CH4,k}/1000$$

$$E_{N2O,i,k} = Cal_{i,k} \times Co_{N2O,k}/1000$$

Where, $Cal_{i,k}$ denotes calorific value of province i and fossil fuel type k

(MJ), $C_{i,k}$ denotes fossil fuel type k consumption in province i (10^4 t or 10^8 m^3); H_k denotes lower heating value of fossil fuel type k (MJ/t fuel or MJ/10,000 m^3 gas), $E_{CO2,i,k}$ denotes CO_2 emissions of fossil fuel type k in province i (kg CO_2), $E_{CH4,i,k}$ denotes CH_4 emissions of fossil fuel type k in province i (kg CH_4), $E_{N2O,i,k}$ denotes N_2O emissions of fossil fuel type k in province i (kg N_2O), $Co_{CH4,k}$ denotes CH_4 emission factor of fossil fuel type k(g CH_4/MJ), $Co_{N2O,k}$ denotes N_2O emissions of fossil fuel type k (g N_2O/MJ)。

5. Thermal power plants consist of coal-fired power plant, oil-fired power plant, gas-fired power plant. There are several kinds of fossil fuels used as inputs in the three kinds of thermal power plants, shown in the Table 2.

Table 2 Fossil fuels used in thermal power plants

Type of Thermal Power Plants	Type of Fossil Fuels
Coal-fired power plant	Raw coal, Refined coal, Other coal, Briquette, Coke, Other Coking Products, Gangue, Petroleum Coke
Oil-fired power plant	Crude oil, Gasoline, Diesel, Fuel oil, Other Petroleum Products
Gas-fired power plant	Natural gas, LNG, Coke Oven Gas, Other Gas, Blast Furnace Gas, Converter Gas, Refinery Gas

6. Obtain the auxiliary power ratio in different provinces from the *2018 Statistics of Electric Power Industry.* Assuming that different kinds of thermal power plants share the same auxiliary power ratio within each province. Assuming that the electricity generation of these three kinds of thermal power plants is proportional to the calorific values of the fossil fuels they each consumed (calculated by standard coal). Then we calculate the electricity supply from coal-fired, oil-fired and gas-fired power plants. The process is expressed as:

$$Q_{s,i,j} = Q_{p,i,j} \times (1 - \varphi_{i,j})$$

where , $Q_{s,i,j}$ and $Q_{p,i,j}$ denote the electricity supply and electricity generation respectively by different provinces and techniques (10^8 kWh), $\varphi_{i,j}$ denotes the auxiliary power consumption ratio of thermal power plants in different provinces (%).

Table 3. Electricity supply by thermal power plant types and provinces

Province	Total Electricity Supply	Electricity Supply by Coal-fired Power Plants	Electricity Supply By Gas-fired Power Plants	Electricity Supply By Oil-fired Power Plants
	10^8 kWh	10^8 kWh	10^8 kWh	10^8 kWh
Beijing	439.09	17.64	383.75	0.18
Tianjin	684.59	522.54	146.75	7.30
Hebei	3059.52	2449.71	607.98	1.47
Shanxi	2989.91	2738.32	214.43	0.44
Inner Mongolia	4642.84	4595.48	38.73	0.33
Liaoning	1869.00	1731.89	124.00	2.61
Jilin	820.29	782.97	6.30	0.76
Heilongjiang	987.91	821.06	26.39	0.40
Shanghai	809.18	648.01	135.71	1.56
Jiangsu	4927.93	4042.69	779.49	0.64
Zhejiang	3326.22	2980.88	209.32	0.66
Anhui	2616.07	2453.02	80.82	0.27
Fujian	2370.74	2121.58	172.79	1.90
Jiangxi	1233.39	1125.64	70.51	0.12
Shandong	5566.87	5241.35	187.09	0.89
Henan	2911.63	2703.64	99.77	1.71
Hubei	2749.36	2469.99	170.58	1.15
Hunan	1483.07	1276.66	116.78	2.79
Guangdong	4489.80	3666.47	619.57	2.60
Guangxi	1670.38	1426.54	136.58	0.42
Hainan	302.83	275.04	16.79	0.02
Chongqing	771.47	706.09	53.87	0.37
Sichuan	3668.71	2562.69	753.27	7.49
Guizhou	1922.39	1861.95	39.96	1.52
Yunnan	3209.13	2777.05	313.34	1.87
Shaanxi	1796.23	1642.86	143.41	0.35
Gansu	1492.17	1461.33	21.60	0.16
Qinghai	801.23	608.71	3.18	0.11
Ningxia	1557.72	1529.88	23.78	0.22

Xinjiang	3100.62	3065.91	31.20	0.20

7. Calculate the amount of hard coal/oil/gas consumption per kWh electricity supply by coal-fired/oil-fired/gas-fired power plants in different provinces. The process is expressed as:

$$P_{coal,i,k} = C_{i,k} \times 10000000/Q_{s,i,j}/100000000$$

$$P_{gas,i,k} = C_{i,k}/Q_{s,i,j}$$

$$P_{oil,i,k} = C_{i,k} \times 10000000/Q_{s,i,j}/100000000$$

Where , $P_{coal,i,k}$ and $P_{oil,i,k}$ denote the hard coal and oil consumption respectively per kWh electricity supply by coal-fired and oil-fired power plants in different provinces (kg/kWh), $P_{gas,i,k}$ denotes the gas consumption respectively per kWh electricity supply by gas-fired power plants in different provinces (m^3/kWh).

8. Calculate the carbon dioxide, methane, nitrous oxide emissions per kWh electricity supply by coal-fired/oil-fired/gas-fired power plants in different provinces. The process is expressed as:

$$GH_{CO2,i,j} = \Sigma E_{CO2,i,k}/Q_{s,i,j}/100000000$$

$$GH_{CH4,i,j} = \Sigma E_{CH4,i,k}/Q_{s,i,j}/100000000$$

$$GH_{N2O,i,j} = \Sigma E_{N2O,i,k}/Q_{s,i,j}/100000000$$

Where , $GH_{CO2,i,j}$, $GH_{CH4,i,j}$, and $GH_{N2O,i,j}$ denote the carbon dioxide, methane, nitrous oxide emissions per kWh electricity supply respectively by coal-fired/oil-fired/gas-fired power plants in different provinces.

9. Derive the net electricity exchanged among China Six Grids (Northeast China, Northwest China, North China, Central China, East China, South China) based on *2018 Statistics of Electric Power Industry*. Figure 1 shows the electricity flows among grids.

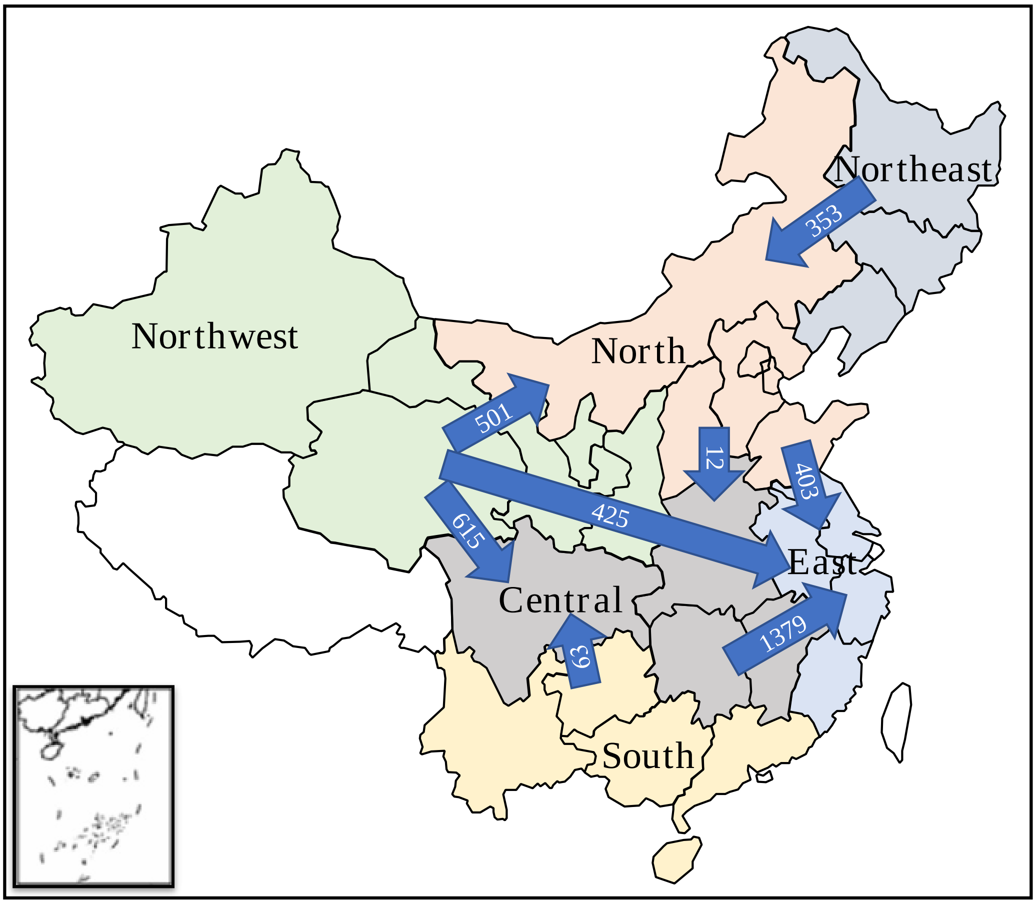

Fig1. Electricity Flows among China Six Grids (10^8 kWh)

10. Assume that each Grid first mix the electricity generated from the provinces, the mixed electricity also covers the net electricity it receives from other Grids, then the mixed electricity is exported to other Grids which are net electricity receiver. Based on the above statistical assumption, we derive the percentage of electricity contributed by each provincial in each Grid.

11. The update of China's electricity data in Ecoinvent database (China regionalized dataset renamed as EI-CN-2020) is demonstrated in Figure 2.

i. Update the China's high voltage electricity data. First, update the amount of hard coal/oil/gas consumption and carbon dioxide, methane, nitrous oxide emissions per unit of electricity supply by coal-fired/oil-fired/gas-fired power plants in different provinces. Second, update the share of electricity supply from different electricity generation technologies, such as hydropower, wind power and nuclear, at province level. Third, update the share of electricity supply from different provinces at the Six regional electricity grid in China.

ii. Update the Six Grid's medium voltage electricity data by adopting the updated high voltage electricity data (2020) as input for the medium voltage electricity.

iii. Update the Six Grid's low voltage electricity data by adopting the updated medium voltage electricity data (2020) as input for the low voltage electricity.

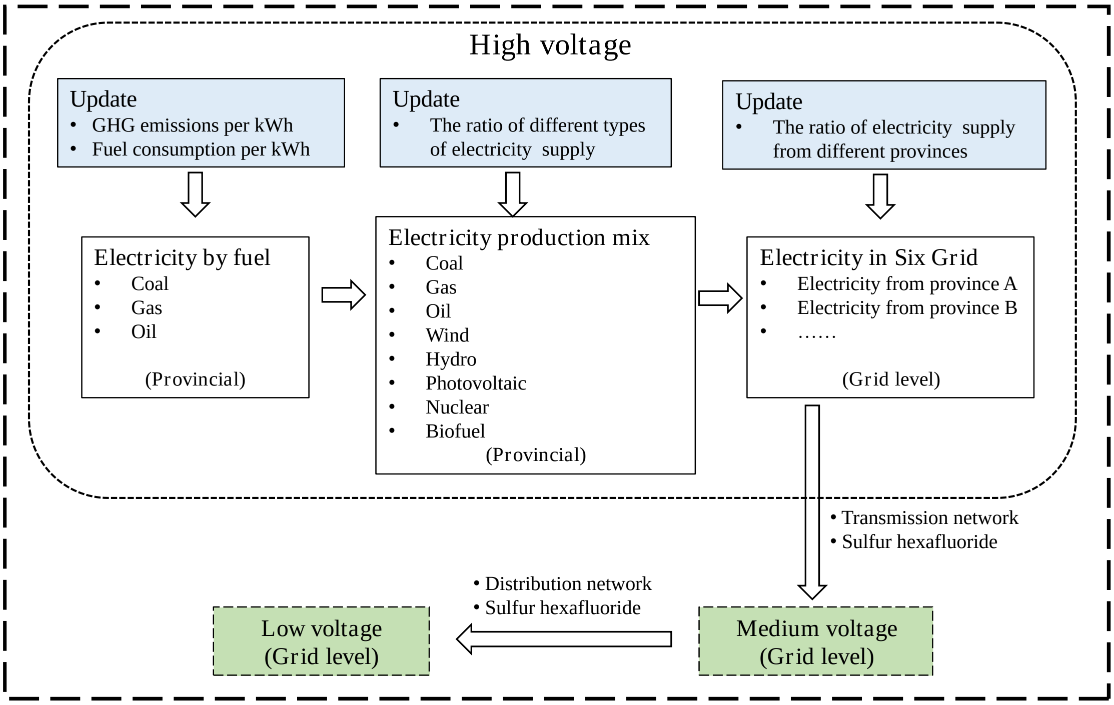

Fig 2. The steps of updating Six Grid's electricity data

12. Regionalization using updated electricity data: in SimaPro, replace all other country's high/medium/low voltage electricity data with China's high/medium/low voltage electricity data. (Motivation: Considering the lack of China's local LCI database, researchers usually use process data from the EU or US as substitutes to do life-cycle assessment on China's products. Most of these process data consumes electricity. And in some of them, the electricity consumption accounts for more than 90% of the environmental impacts of the process. To substitute other country's electricity data with China's electricity data is a considered a good way to obtain a better approximation of China's process and impact data).

13. Update of provincial level electricity grid: based on the updated electricity supply and consumption data in each province, the net electricity inflow from the regional grid can be derived; the provincial electricity grid can be then calculated by mixing electricity supply from the provincial (self-supply) and regional grid (inflow) with respective ratio. For the province that does not need supply from the regional grid, the provincial grid electricity will be mainly represented by the province itself.

14. Global Warming Results Comparison using updated electricity

IMPACT 2002+ method was applied to evaluate global warming results comparison of 1kWh electricity supply in Six Grids between the year 2015 and 2018 (Fig.3).

Global warming results of Six Grids in 2015 show that Northeast China Grid has the highest impact (1.20 kg CO_2 eq), followed by North China Grid (1.09 kg CO_2 eq), East China Grid (0.84 kg CO_2 eq), and Northwest China Grid (0.79 kg CO_2 eq). Central China Grid (0.58 kg CO_2 eq) and South China Grid (0.51 kg CO_2 eq) have the least global warming impacts, only emit about half of the CO_2 equivalent per kWh than Northeast China Grid.

Global warming results of Six Grids in 2018 show that North China Grid has the highest impact (1.04 kg CO_2 eq), followed by Northeast China Grid (0.87 kg CO_2 eq), East China Grid (0.72 kg CO_2 eq), and Northwest China Grid (0.67 kg CO_2 eq). Central China Grid (0.44 kg CO_2 eq) and South China Grid (0.35 kg CO_2 eq) have the least global warming impacts, only emit about one third of the CO_2 equivalent per kWh than Northeast China Grid.

The global warming results of Six Grids in 2018 is lower than that in 2015. Specially, South China Grid reduces 30.14%, North China Grid reduces 27.94%, Central China Grid reduces 24.49%, Northwest China Grid reduces 15.33%, East China Grid reduces 14.4%, while North China Grid reduces only 4.74%.

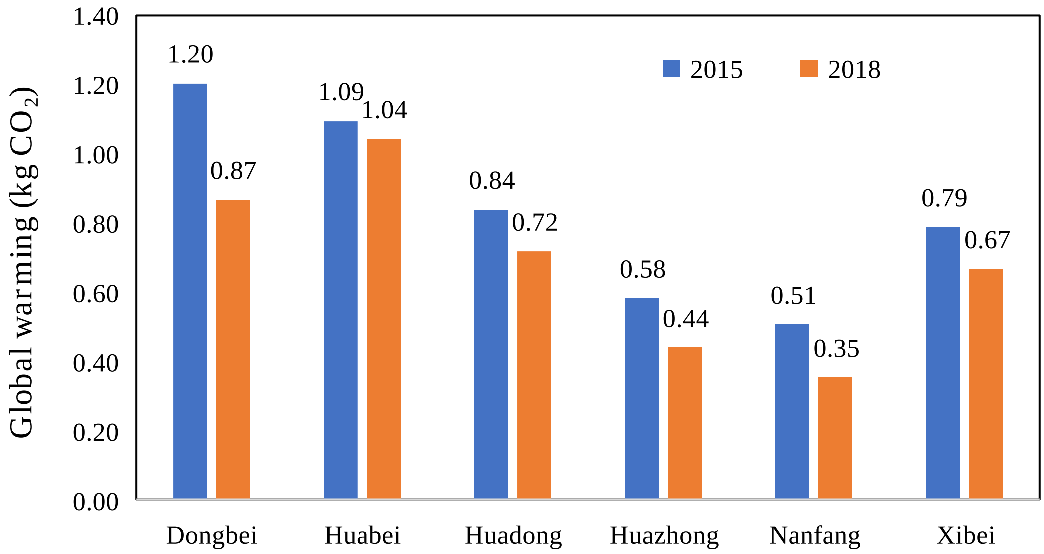

Fig 3. Global warming results comparison of 1kWh electricity supply in Six Grids between the year 2015 and 2018.

Notes:

1. In this update. We use the assumption that the auxiliary power ratio for internal usage is identical for coal, gas and oil fueled electricity in each province by adopting the ratio of thermal power plant in the provinces as default. In reality the ratio is different for the three types of electricity. When detailed data is available, more accurate estimation can be done.
2. The auxiliary power ratio of fossil fuel-based electricity, solar electricity, wind electricity, hydro-electricity, and nuclear based electricity in different provinces are sourced from the book of *2018 Statistics of Electric Power Industry*.