Baseline Determination for the Electricity Grid in the Kingdom of Saudi Arabia – Grid emission factor (GEF) according to CDM regulations

Background

The "Tool to calculate the emission factor for an electricity system" (in the following referring to the Tool) determines the CO_2 emission factor for the displacement of electricity generated by power plants in an electricity system, by calculating the "combined margin" emission factor of the electricity system. The combined margin is the result of a weighted average of two emission factors of the electricity system: the "operating margin" and the "build margin". The operating margin is the emission factor of the thermal power plants and all plants serving the grid that cannot be characterized as "must run". The build margin is the emission factor of a group of recently built power plants. This tool is required whenever electricity consumption or generation is relevant in the baseline and/or project scenario or in terms of leakage. It is particularly relevant for grid-connected electricity generation methodologies, be it for projects related to electricity generation or reducing electricity consumption.

This memo presents the calculation of the grid emission factor (GEF) for the Kingdom of Saudi Arabia (KSA) according to the Tool version 2.2.0 (decided by EB 61).

Grid emission factor calculation procedure

The following six steps are applied:

- STEP 1. Identify the relevant electricity systems;
- STEP 2. Choose whether to include off-grid power plants in the project electricity system (optional);
- STEP 3. Select a method to determine the operating margin (OM);
- STEP 4. Calculate the operating margin emission factor according to the selected method;
- STEP 5. Calculate the build margin (BM) emission factor;
- STEP 6. Calculate the combined margin (CM) emissions factor.

Step 1: Identify the relevant electricity systems

Saudi Arabia has a power transmission network that spans around 46,000 circuit km of high voltage lines and cables and range from 110kV to 380kV. The national transmission grid is divided into 4 regions (East, Central, West and South). All 4 main regions are interconnected since mid of 2010.

The Transmission Business Unit (TBU) of Saudi Electricity Company (SEC), as the owner and operator of this huge transmission system, is legally mandated to ensure the highest level of reliability and quality of electricity supply to its customers. Peak load in various regions of the Kingdom in 2010 reached as high as 45,661 MW, representing a growth rate of 10.8% over 2009. Peak load contribution of the interconnected networks and isolated networks increased in 2010 by 10.8% and 11.4% in 2009 respectively. Maximum load of interconnected and isolated networks in 2010 reached as high as 43,173 MW and 2,488 MW respectively (SEC, Annual Report 2010).

The interconnected grid is identified as the relevant electricity system; isolated networks are thus not covered. For the purpose of determining the operating margin emission factor following the options of the Tool, the CO_2 emission factor(s) for net electricity imports from a connected electricity system is considered 0 t CO_2/MWh. The same applies for independent power plants and power production by large industrial customers (e.g. water desalination) that are connected to the grid, as power plant specific data (on fuel consumption and fuel mix) are currently not available. On-going data collection efforts by the Electricity & Co-Generation Regulatory Authority and other relevant organizations are likely to close this data gap in the near future.

Table 1: Power generation from SEC and other power producers in the Kingdom of Saudi Arabia

GWh	2006	2007	2008	2009	2010
SEC Gross Generation from Generation Plants	*156,119*	*165,342*	*178,429*	*186,725*	*189,415*
SEC Net Generation from Generation Plants	*151,636*	*160,278*	*173,038*	*181,081*	*183,721*
of which provided by off-grid systems	-	-	*2,399*	*3,224*	*3,392*
SEC Net Generation from Generation Plants feed into grid	**151,636**	**160,278**	**170,639**	**177,857**	**180,329**
Energy Imported from SWCC	*22,328*	*20,847*	*19,580*	*17,366*	*16,000*
Energy Imported from other producers	*2,987*	*4,346*	*6,190*	*12,991*	*34,476*
Total Electricity Imported	**25,315**	**25,193**	**25,770**	**30,357**	**50,476**
Electricity inject into Transmission system	**176,951**	**185,471**	**196,409**	**208,214**	**230,805**
Total Electricity Sold	*163,151*	*169,780*	*181,098*	*193,472*	*212,263*
Total electricity Loss in the system	*13,799*	*15,690*	*17,710*	*17,965*	*21,935*
% Loss in the entire System	*7.8%*	*8.5%*	*9.0%*	*8.6%*	*9.5%*

Source: Electricity & Co-Generation Regulatory Authority (ECRA), 2011

Step 2: Choose whether to include off-grid power plants in the project electricity system (optional)

Option I "Only grid power plants are included in the calculation" is applied, as otherwise no valid grid emission factor can be calculated for KSA (see description in Step 3).

Step 3: Select a method to determine the operating margin (OM)

According to the Tool, the calculation of the operating margin emission factor ($EF_{grid,OM,y}$) shall be based on one of the following methods:

a) Simple OM – for all thermal power plants other than "low-cost/must-run"[1]; or
b) Simple adjusted OM (in case "low-cost/must-run" covers more than 50% of a country's generation); or
c) Dispatch data analysis OM (if hourly dispatch data are publicly available); or
d) Average OM – for all power plants serving the grid.

Options b and c cannot be used in the context of the Kingdom of Saudi Arabia as their eligibility criteria are not satisfied (Saudi Arabia has no hydro plants and thus option b) is not relevant; and the Electricity and Co-Generation Regulatory Agency does not publish hourly dispatch data that would allow to apply option c)), but a) and d) are principally available.

[1] Low-cost/must-run resources are defined as power plants with low marginal generation costs or power plants that are dispatched independently of the daily or seasonal load of the grid. They typically include hydro, geothermal, wind, low-cost biomass, nuclear and solar generation.

Option a), which applies to all plants other than "low-cost/must-run" ones, allows the following approaches:
(Sub-)Option A: Based on the net electricity generation and a CO_2 emission factor of each power unit; or, in case of these data not being available:
(Sub-)Option B: Based on the total net electricity generation of all power plants serving the system and the fuel types and total fuel consumption of the project electricity system.

Unfortunately, current data availability for Kingdom of Saudi Arabia does not allow the use of Option A, but ongoing efforts to collect power-plant specific data are likely to lead to availability of data to apply option A in the near future. Therefore, until those data can be made available, Option B would need to be used. But due to the fact that key data for calculation of the Build Margin are lacking until the power-plant specific data are available (see Step 5), for the time being, only option d) remains available for OM calculation. Under option d), the average OM emission factor ($EF_{grid,OM\text{-}ave,y}$) is calculated as the average emission rate of all power plants serving the grid, using the methodological guidance as described under option a) above for the simple OM, but including in all equations also low-cost/must-run power plants. Given that there are no real "low-cost/must-run" plants in the Kingdom of Saudi Arabia, de facto there is no difference to Option a).

To summarize, the determination of the OM for the Saudi grid is based on the average OM using ***total net electricity generation of all power plants serving the system and the fuel types and total fuel consumption of the project electricity system*** including approved CDM projects, if applicable, and imports.

The Tool allows use of either of the two following data vintages for calculation of the OM:

- Ex-ante option: the emission factor is determined once at the validation stage, and thus no monitoring and recalculation of the emissions factor during the crediting period is required. For grid power plants, a 3-year generation-weighted average is used.
- Ex-post option: the emission factor is determined for the year in which the project activity displaces grid electricity, requiring the emissions factor to be updated annually during monitoring.

The ***ex-ante*** option is applied at which the data vintage used to determine the emission factor is the last three years of available data, 2008 through 2010.

Step 4: Calculate the operating margin emission factor according to the selected method
As described in Step 3, the average OM emission factor is calculated based on the net electricity supplied to the grid by all power plants serving the system and based on the fuel type(s) and total fuel consumption of the project electricity system, as follows:

$$EF_{grid,OMaverage,y} = \frac{\sum_i (FC_{i,y} \cdot NCV_{i,y} \cdot EF_{CO2,i,y})}{EG_y}$$

Where:

$EF_{grid,OMaverage,y}$	=	Average operating margin CO_2 emission factor in year y (t CO_2/MWh)
$FC_{i,y}$	=	Amount of fossil fuel type i consumed in the project electricity system in year y (mass or volume unit)
$NCV_{i,y}$	=	Net calorific value (energy content) of fossil fuel type i in year y (GJ/mass or volume unit)
$EF_{CO2,i,y}$	=	CO_2 emission factor of fossil fuel type i in year y (t CO_2/GJ)
EG_y	=	Net electricity generated and delivered to the grid by all power sources serving the system, including low-cost/must-run power plants/units, in year y (MWh)
i	=	All fossil fuel types combusted in power sources in the project electricity system in year y
y	=	The relevant year as per the data vintage chosen in Step 3

The result of the OM for each relevant year 2008-2010 is summarized in Table 2. The generation weighted $EF_{OM,y1-y3}$ results in 0.654 t CO_2/MWh.

Table 2: Result for the OM 2008-2010

2008 $EF_{grid,OMaverage,y}$ (tCO_2/MWh)	**0.661**
2009 $EF_{grid,OMaverage,y}$ (tCO_2/MWh)	**0.682**
2010 $EF_{grid,OMaverage,y}$ (tCO_2/MWh)	**0.625**
Generation weighted $EF_{OM,y1-y3}$	**0.654 (tCO_2/MWh)**

Step 5: Calculate the build margin (BM) emission factor

To calculate the BM would require data on the commissioning date of all power units that are responsible for 20% of annual electricity generation in the last year, as well as power plant-specific annual electricity generation for that year. This data is not available in the Kingdom of Saudi Arabia for all power units until the on-going data collection efforts by the Electricity and Co-Generation Regulatory Agency are completed and thus the BM cannot yet be calculated. However, the BM is not required if a simplification according to the GEF tool is used. The simplification is available if data are unavailable and the project is located **in a country with less than 10 registered projects** at the starting date of validation. This condition is fulfilled in the Kingdom of Saudi Arabia as of August 2011 with zero registered projects. Hence, the combined margin is equal to the average OM calculated as per step 4. Once the data for the BM become available, the simplification will no longer be applied.

Step 6: Calculate the combined margin emissions factor

Since for the Kingdom of Saudi Arabia the conditions for applying option (b) are fulfilled, the simplified CM, only the $EF_{grid,OMaverage,y}$ is considered for calculating the combined margin (CM) emission factor ($EF_{grid,CM,y}$), and the result is identical to Table 2.

Data applied and data sources

Average Fuel Densities		
Specific gravity	[Mton/m^3]	
(Residual) Fuel oil	0	
Diesel Oil	0.0000	
Net Calorific Values	(Source: King Fahd University for Petroleum and Minerals and Saudi Aramco 2001	
Gas/ Diesel Oil	42.55	TJ/ 10^3 tonnes
Residual Fuel Oil	40.92	TJ/ 10^3 tonnes
Crude	45.07	TJ/ 10^3 tonnes
Gas	49.3	TJ/ 10^3 tonnes

Default CO_2 Emission Factors for Combustion (Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 2 Energy, Ch. 1; 1.23)

Fuel	**CEF** (t C/TJ)	**CEF (t CO2/TJ)**
Diesel	20.2 (t C/TJ)	72.6 (t CO2/TJ)
Residual Fuel Oil	21.1 (t C/TJ)	75.5 (t CO2/TJ)
Crude	20.0 (t C/TJ)	71.1 (t CO2/TJ)
Gas	15.3 (t C/TJ)	54.3 (t CO2/TJ)

Fuel Types

Residual Fuel Oil
Diesel
Crude
Gas

Determination of Average Fuel Densities

Natural gas:
Density at 15°C and 101.325 kPa — 0.678 kg/m3
0.678 tonne/1000 m3

Natural Gas — 37.40 GJ/ 10^3 m^3 gas
Source: IPCC, Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_6_Fugitive_Emissions_from_Oil_and_Natural_Gas.pdf

Default off-grid power plants efficiencies
(Source: Annex 1: Default efficiency factors for power plants, " Tool to calculate the emission factor for an electricity system" (Version 02.2.0)

Generation Technology	CAP≤10	10<CAP≤50	50<CAP≤100	100<CAP≤200	200<CAP≤400	400<CAP≤1000	CAP>1000
Reciprocant engine system (e.g. diesel-, fuel oil-, gasengines)	28%	33%	35%	37%	39%	42%	45%

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Total electricity Loss in the system	*13,799*	*15,690*	*17,710*	*17,965*	*21,935*
% Loss in the entire System	*7.8%*	*8.5%*	*9.0%*	*8.6%*	*9.5%*

Source: Electricity & Co-Generation Regulatory Authority (ECRA) (2009), Statistical Booklet, Riyadh. 2009 and 2010 provided by ECRA, 2011, Riyadh.

Fuel consumption SEC	**2008**				**2009**				**2010**			
	Gas	**Crude**	**HFO**	**Diesel**	**Gas**	**Crude**	**HFO**	**Diesel**	**Gas**	**Crude**	**HFO**	**Diesel**
	Million M^3	**Tonne**			**Million M^3**	**Tonne**			**Million M^3**	**Tonne**		
East	15,235	321,600	0	1,022,897	12,756	3,164,675	0	1,199,003	11,443	3,484,757	0	1,387,608
Central	8,906	4,234,739	0	1,497,886	9,340	4,558,431	0	1,349,330	8,483	5,172,275	0	1,807,976
West	0	3,165,718	6,949,185	3,665,976	0	7,173,020	3,880,873	4,109,658	0	9,562,130	2,482,811	4,076,487
South	0	1,233,487	0	3,901,700	0	1,507,309	0	4,129,802	0	1,462,733	0	3,711,081
Total	**24,141**	**8,955,544**	**6,949,185**	**10,088,459**	**22,095**	**16,403,436**	**3,880,873**	**10,787,794**	**19,926**	**19,681,895**	**2,482,811**	**10,983,152**
Estimation on diesel consumption for off-grid systems				208,609				280,348				294,957

Source: Provided by Electricity & Co-Generation Regulatory Authority (ECRA), 2011, Riyadh

Calculation

Result for the CM 2008-2010

Baseline Grid Emission Factor		
Year 1 (2008)		
EF_{OM} (tCO_2/MWh)	0.661	
Annual generation (MWh)	196,409,000	
Year 2 (2009)		
EF_{OM} (tCO_2/MWh)	0.682	
Annual generation (MWh)	208,214,000	
Year 3 (2010)		
EF_{OM} (tCO_2/MWh)	0.625	
Annual generation (MWh)	230,805,000	
Generation weighted $EF_{OM,y1\text{-}y3}$ (tCO2/MWh)	0.654	
Simplified CM method $\mathbf{EF_{grid,CM,y} = 1*EF_{OM,y1\text{-}y3} + 0*EF_{BM,y3} =}$	**0.654**	**(tCO_2/MWh)**

2008				Main fuel source							Calculation of average OM		
Plant *m*	**Fueltype** *i*	**Operation start**	**Annual Generation** $EG_{m,y}$ (MWh)	**Fuel Consumption** $FC_{i,m,y}$ (10^3t),(Mm^3)	**Net Calorific Value** $NCV_{i,y}$ (TJ/10^3t), (TJ/Mm^3)	**Fuel EF** $EF_{CO2,i,y}$ (tCO2/TJ)	**CO_2 Emissions** (tCO2) FC x NCV x EF_{CO2}	**Baseline** $EF_{grid,OMsimple,y}$ (tCO2/MWh)	**Low cost / must run**	**CDM registered**	**Generation** (accumulated MWh)	**CO2 Emissions** (accumulated tCO2)	**Emission Factor** (tCO2/MWh)
SEC	Diesel	n.a.		9,885	42.55	72.60	30,537,559	unavailable			0	30,537,559	**0.000**
	Gas	n.a.		24,141	37.40	54.30	49,026,026	unavailable			0	79,563,584	**0.000**
	Residual fuel oil	n.a.		6,949	40.92	75.50	21,469,229	unavailable			0	101,032,813	**0.000**
	Crude	n.a.		8,956	45.07	71.10	28,697,835	unavailable			0	129,730,648	**0.000**
Imports/other producers			25,770.00				0.000	0			25,770	0	**0.000**
Total			**196,409,000**				129,730,648				196,409,000	129,730,648	**0.661**
											2008 $EF_{grid,OMaverage,y}$ (tCO_2/MWh)		**0.661**

2009				Main fuel source							Calculation of average OM		
Plant *m*	**Fueltype** *i*	**Operation start**	**Annual Generation** $EG_{m,y}$ (MWh)	**Fuel Consumption** $FC_{i,m,y}$ (10^3t),(Mm^3)	**Net Calorific Value** $NCV_{i,y}$ (TJ/10^3t), (TJ/Mm^3)	**Fuel EF** $EF_{CO2,i,y}$ (tCO2/TJ)	**CO_2 Emissions** (tCO2) FC x NCV x EF_{CO2}	**Baseline** $EF_{grid,OMsimple,y}$ (tCO2/MWh)	**Low cost / must run**	**CDM registered**	**Generation** (accumulated MWh)	**CO2 Emissions** (accumulated tCO2)	**Emission Factor** (tCO2/MWh)
SEC	Diesel	n.a.		10,515	42.55	72.60	32,482,273	unavailable			0	32,482,273	**0.000**
	Gas	n.a.		22,095	37.40	54.30	44,870,968	unavailable			0	77,353,241	**0.000**
	Residual fuel oil	n.a.		3,881	40.92	75.50	11,989,802	unavailable			0	89,343,043	**0.000**
	Crude	n.a.		16,403	45.07	71.10	52,564,433	unavailable			0	141,907,477	**0.000**
Imports/other producers			30,357.00				0.000	0			30,357	0	**0.000**
Total			**208,214,000**				141,907,477				208,214,000	141,907,477	**0.682**
											2009 $EF_{grid,OMaverage,y}$ (tCO_2/MWh)		**0.682**

2010				Main fuel source							Calculation of average OM		
Plant *m*	**Fueltype** *i*	**Operation start**	**Annual Generation** $EG_{m,y}$ (MWh)	**Fuel Consumption** $FC_{i,m,y}$ (10^3t),(Mm^3)	**Net Calorific Value** $NCV_{i,y}$ (TJ/10^3t), (TJ/Mm^3)	**Fuel EF** $EF_{CO2,i,y}$ (tCO2/TJ)	**CO_2 Emissions** (tCO2) FC x NCV x EF_{CO2}	**Baseline** $EF_{grid,Omsimple,y}$ (tCO2/MWh)	**Low cost / must run**	**CDM registered**	**Generation** (accumulated MWh)	**CO2 Emissions** (accumulated tCO2)	**Emission Factor** (tCO2/MWh)
SEC	Diesel	n.a.		10,696	42.55	72.60	33,041,851	unavailable			0	33,041,851	**0.000**
	Gas	n.a.		19,926	37.40	54.30	40,466,119	unavailable			0	73,507,971	**0.000**
	Residual fuel oil	n.a.		2,483	40.92	75.50	7,670,545	unavailable			0	81,178,516	**0.000**
	Crude	n.a.		19,682	45.07	71.10	63,070,180	unavailable			0	144,248,696	**0.000**
Imports/other producers			50,476.00				0.000	0			50,476	0	**0.000**
Total			**230,805,000**				144,248,696				230,805,000	144,248,696	**0.625**
											2010 $EF_{grid,OMaverage,y}$ (tCO_2/MWh)		**0.625**