Tool to calculate baseline emission factor for an electricity system (Grid Tool)

Training workshop- Grid emission factor 19-20 Aug 2015

UNFCCC

RCC, Kampala

Training Module

- **Module I**
  - ✓ Basic concepts and key features

- **Module II**
  - ✓ Most common issues in SB submissions

- **Module III**
  - ✓ Step by step procedure to determine grid emission factor (walk through demo/exercise)

Tool to calculate the emission factor for an electricity system

Module I

Basic concept and key features

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Opportunity to green the power system

Countries	Status	Electrification Rate	Share of Renewable
Eritrea	LDC	32.20%	1.28%
Kenya		20.00%	57.64%
Malawi	LDC	9.00%	99.34%
Sudan	LDC	35.00%	76.37%
United Republic of Tanzania	LDC	<50 ?	66.51%

REPRESENTATION OF LOAD IN A POWER SYSTEM

Modeling of power systems requires a model of the load, a model of the generating capacity, and a statement of the relationships between the two in the matter of immediate interest.

Representation of Loads

- Chronological

Interval model of load

Chronological Representation of Loads

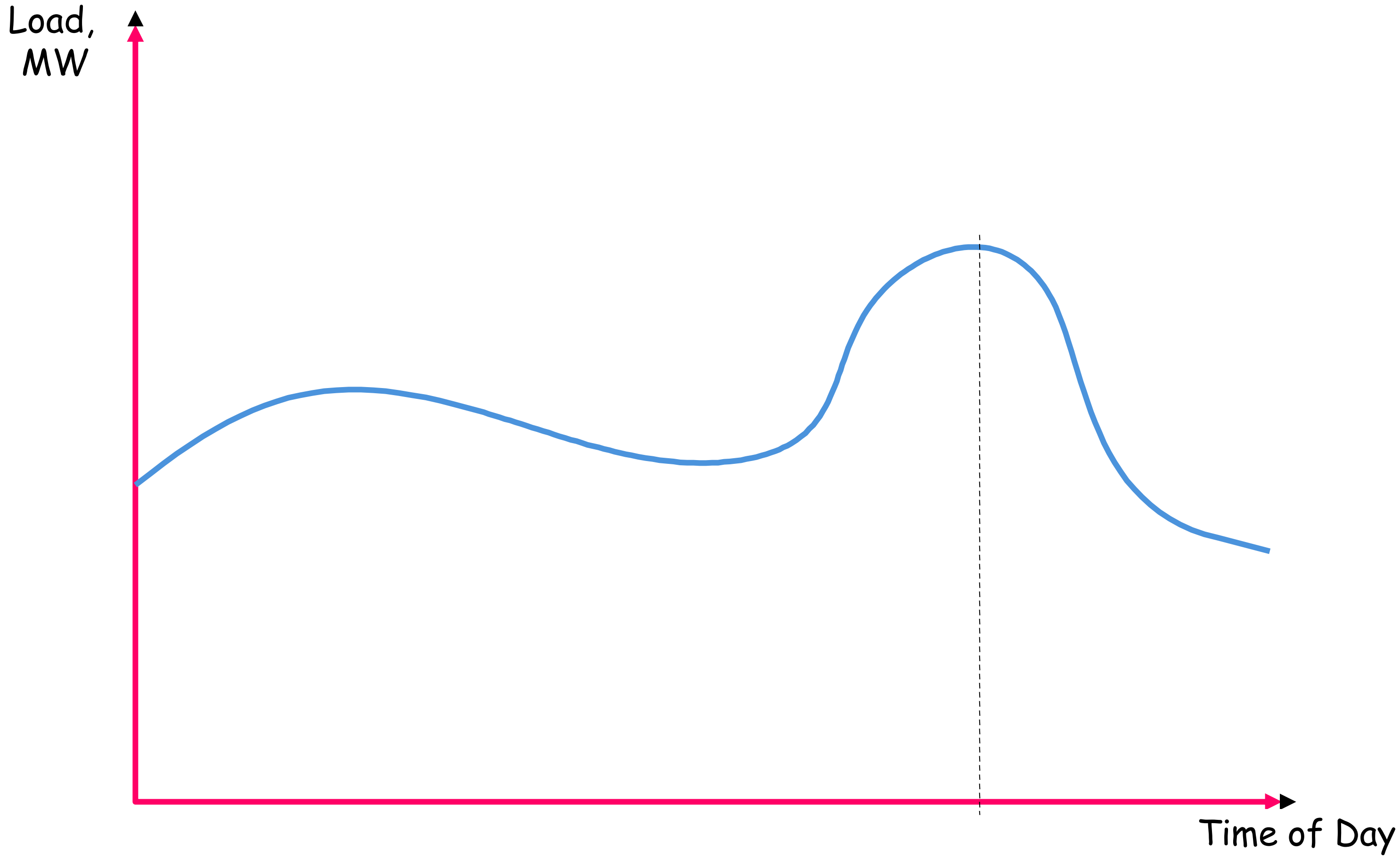


Figure 3.1

Interval Model of Load

- The Chronological load curve is not easy to use: it cannot be easily approximated by a mathematical function.
- Often loads in each time interval are rearranged in descending order of magnitude to obtain a curve usually known as the Load Duration Curve (LDC).
- LDC can be represented by mathematical functions.
- LDCs are monotonic decreasing (see e.g., Figure); they can be fitted to mathematical expressions a property that is sometimes useful.
- They can be guessed from a few parameters, e.g. maximum demand, minimum demand, load factor.

In figure, the horizontal axis of LDC represents the duration of Load (P) being in excess of or equal to x_t

- LDC can be constructed from any period, and are frequently used for daily, weekly, monthly, quarterly, and annual intervals.

Area under the LDC represent the level of electrical energy consumption during the interval.

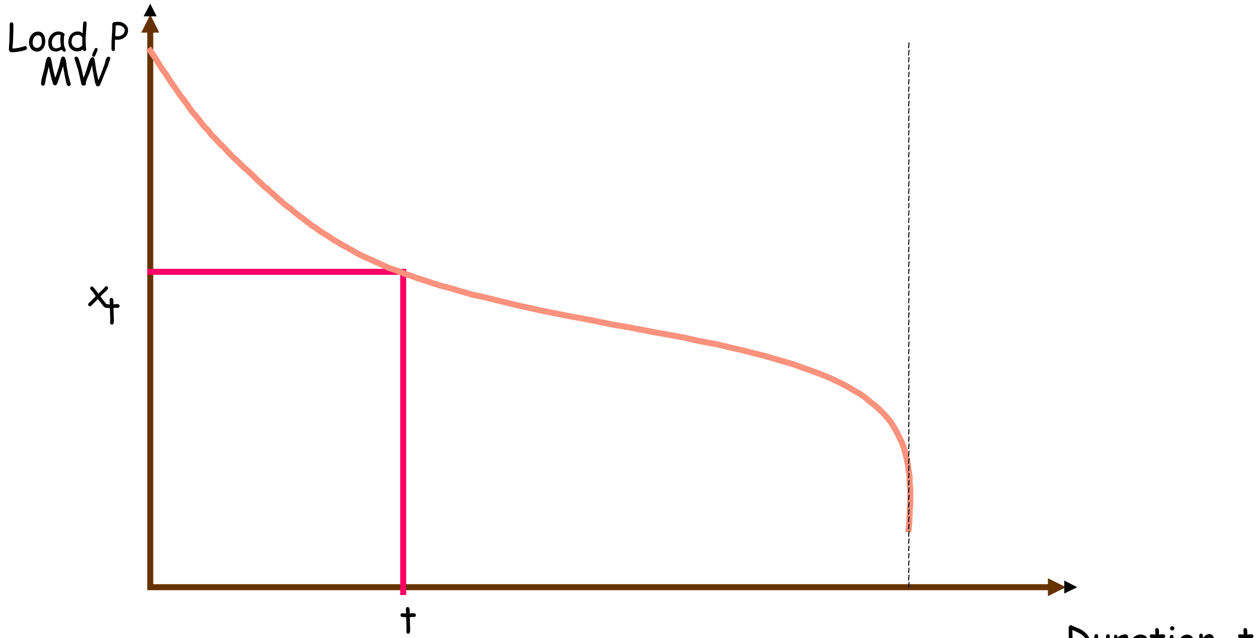


Figure 3.2

Back

Hours of the Day	Average Load, MW
1	1000
2	800
3	600
4	700
5	800
6	900
7	1000
8	1200
9	1500
10	1400
11	1300
12	1100
13	1300
14	1500
15	1600
16	1900
17	2100
18	2400
19	2700
20	3000
21	2800
22	2300
23	1900
24	1300

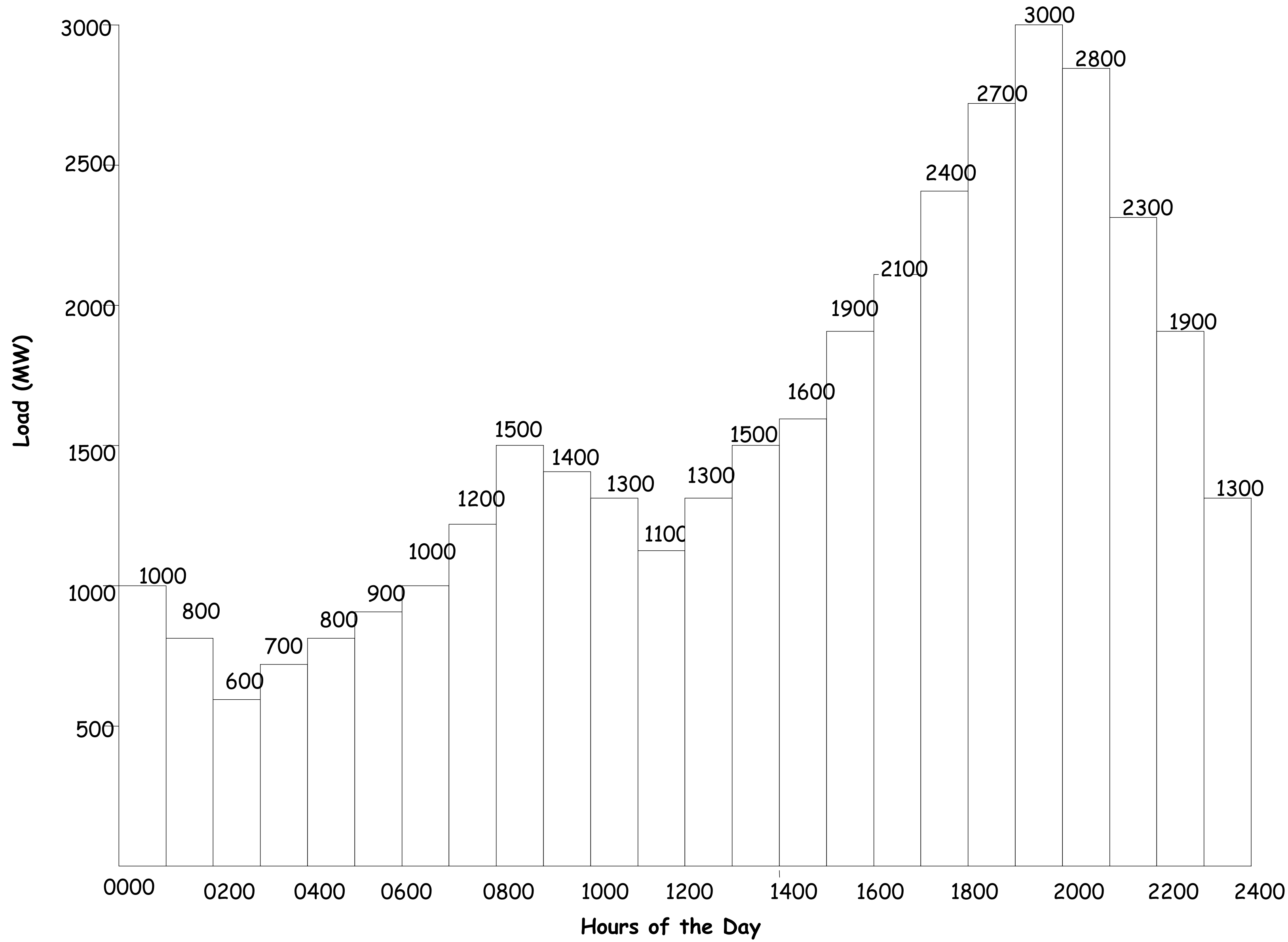
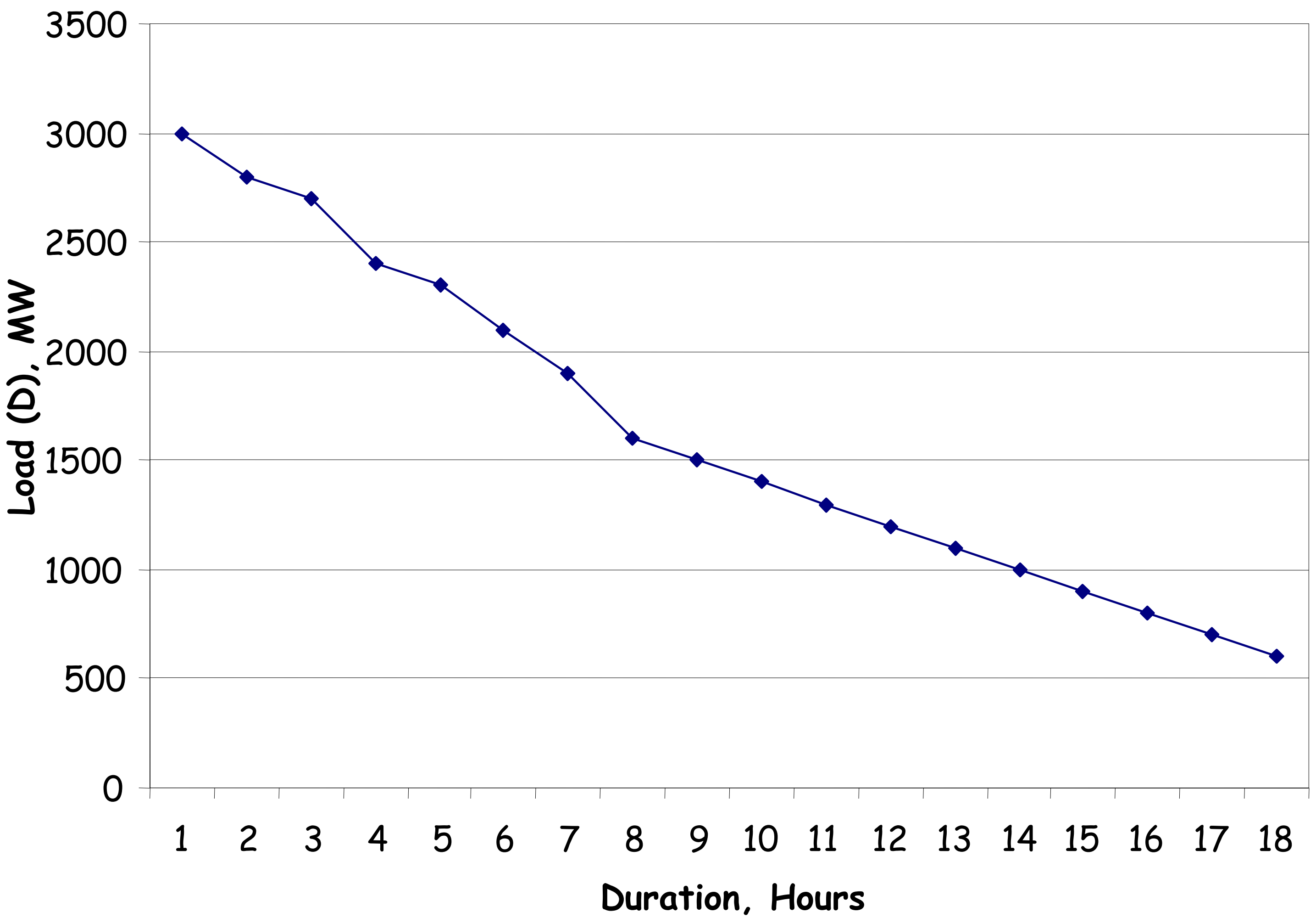


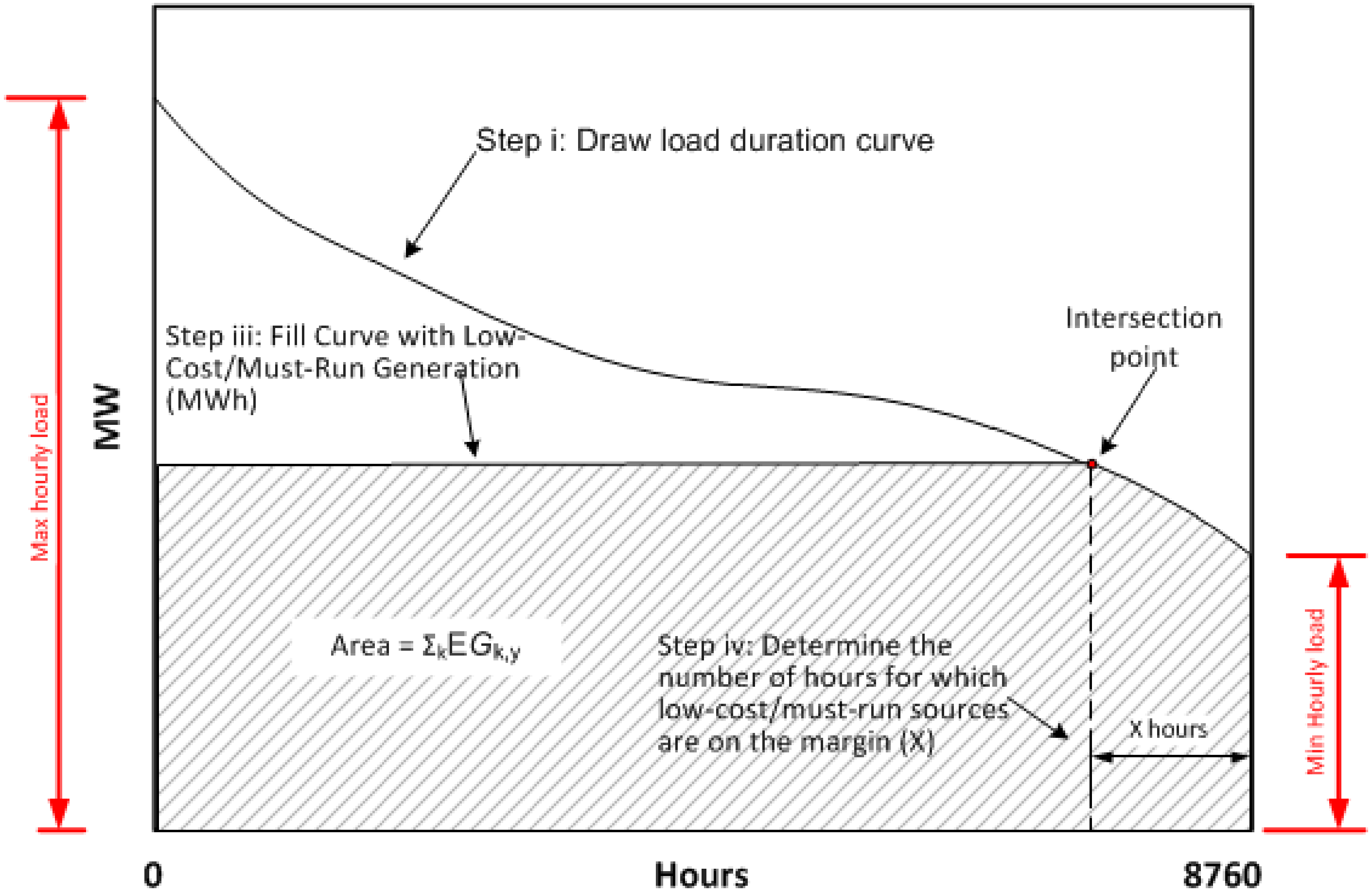
Figure 3 Average Hourly Loads

Load (D), MW (1)	Frequency (2)	Frequency of Load >= D (3)	% of Duration $= \frac{\text{Freq (L >=D)}}{24} \times 100$ (4)
3000	1	1	4
2800	1	2	8
2700	1	3	13
2400	1	4	17
2300	1	5	21
2100	1	6	25
1900	2	8	33
1600	1	9	38
1500	2	11	46
1400	1	12	50
1300	3	15	63
1200	1	16	67
1100	1	17	71
1000	2	19	79
900	1	20	83
800	2	22	92
700	1	23	96
600	1	24	100



3500
3000
2500
2000
1500
1000
500
0
Load (D), MW
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Duration, Hours

LDC- in the context of the grid tool



What is Grid emission factor (GEF) ?

- Represents baseline emission intensity (tCO_2/MWh) of a grid system (benchmark / predefined factor)
- GEF is used to determine baseline emissions of a project:
  - that supplies electricity to a grid (renewable energy) and/or
  - results in savings of grid electricity (energy efficiency)

Concept of the Grid Tool

CDM project displaces or avoid :

- ❑ electricity generation from existing power plants-

  Operating Margin

- ❑ Construction/operation of prospective power plants -

  Build Margin

Concept of the Grid Tool

Operating Margin EF

Build Margin EF

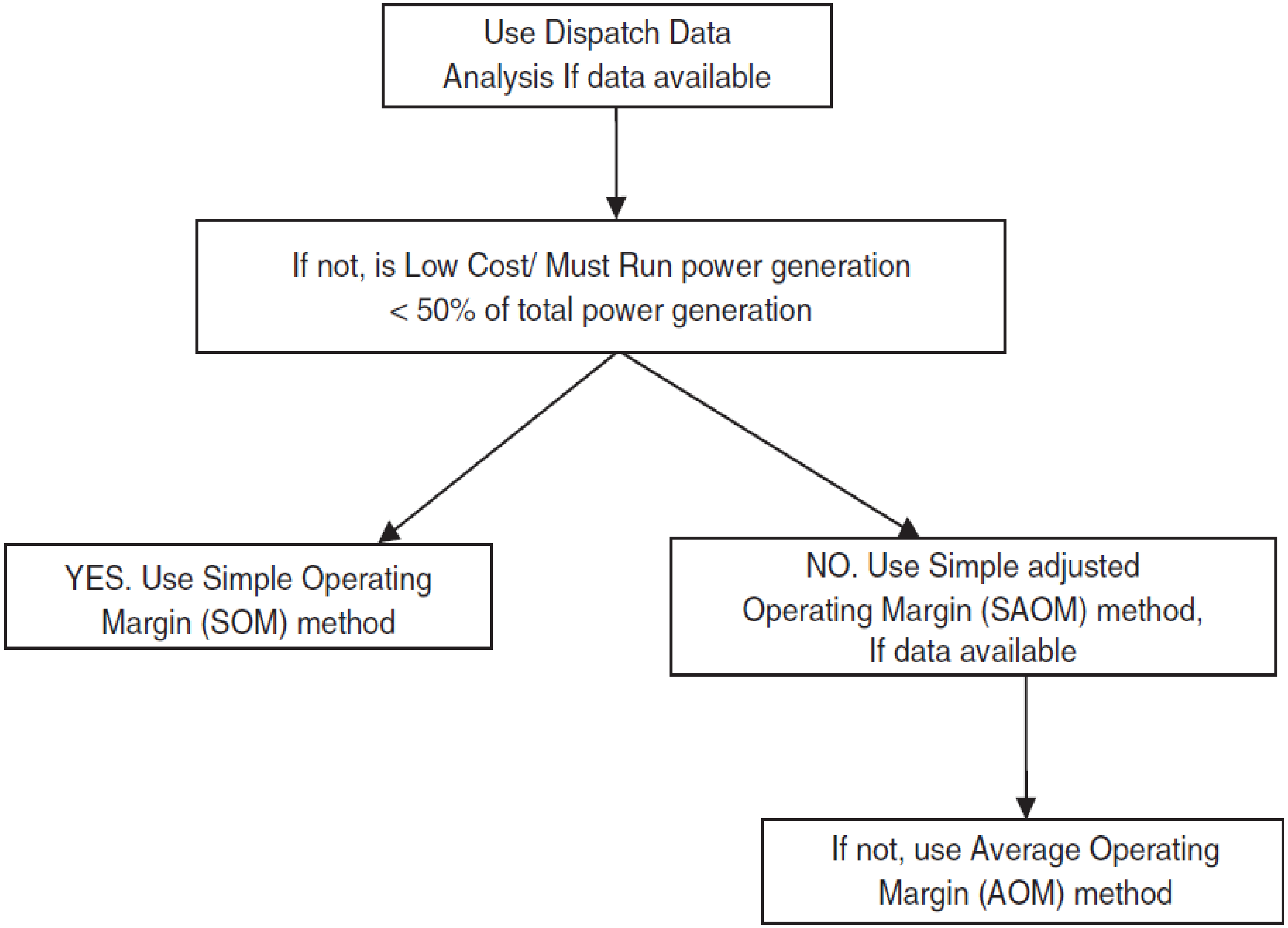
Combined Margin EF

CM = w x OM + y x BM (w +y < =100%)

w = 75% and y= 25% (intermittent non-dispatchable/renewables)

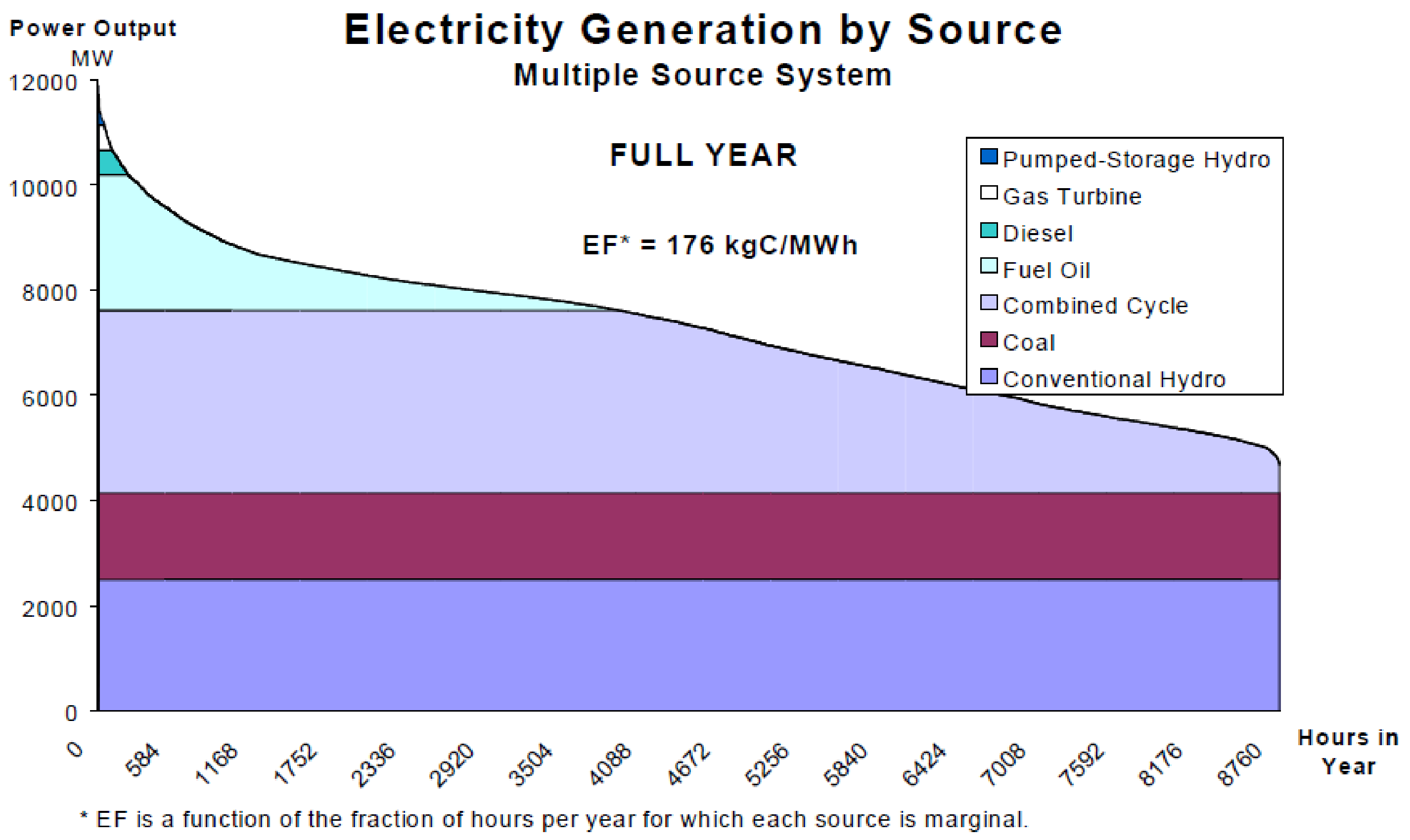
w = 50% and y= 50% (other projects such as geothermal,energy efficiency)

Decision tree: Four alternative methods for identifying the generation sources in the OM



Operating Margin: Dispatch data analysis OM

- Emission factor is determined based on the grid power units that are actually dispatched <u>at the margin</u> during each hour



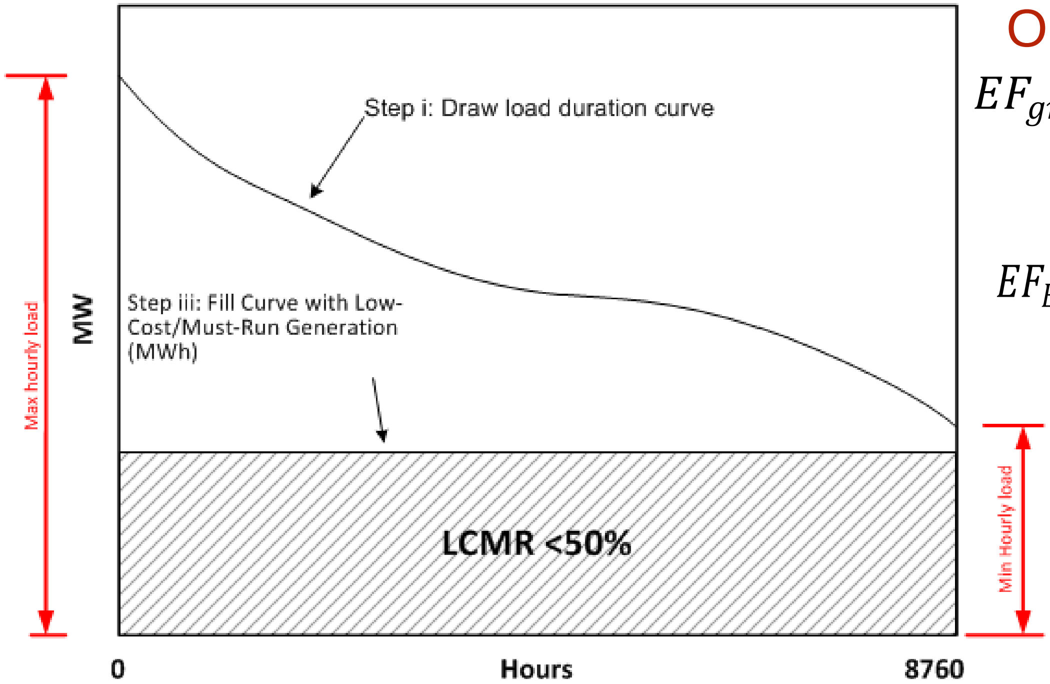
Operating Margin: Dispatch data analysis OM

Marginal Power Source Displacement

	Hours of Source being marginal hours	Share of Marginal Hours %	Emissions Factor kgC/MWh	Weighted Emissions Factor kgC/MWh
Conv. Hydro	0	0%	0	0
Coal Thermal	0	0%	260	0
Combined Cycle	4889	56%	137	76
Fuel Oil Thermal	3650	42%	225	94
Diesel Generation	117	1%	288	4
Gas Turbine	58	1%	257	2
Pump Stor. Hydro	46	1%	0	0
Sum	8760	100%		176

-Applicable to countries with merit order dispatch system
-Focus of the training will be on the other simplified methods to determine OM >>

Operating Margin: Simple OM



Option 1

$$EF_{grid,OMsimple,y} = \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}}$$

$$EF_{EL,m,y} = \frac{\sum_i FC_{i,m,y} \times NCV_{i,y} \times EF_{CO2,i,y}}{EG_{m,y}}$$

or

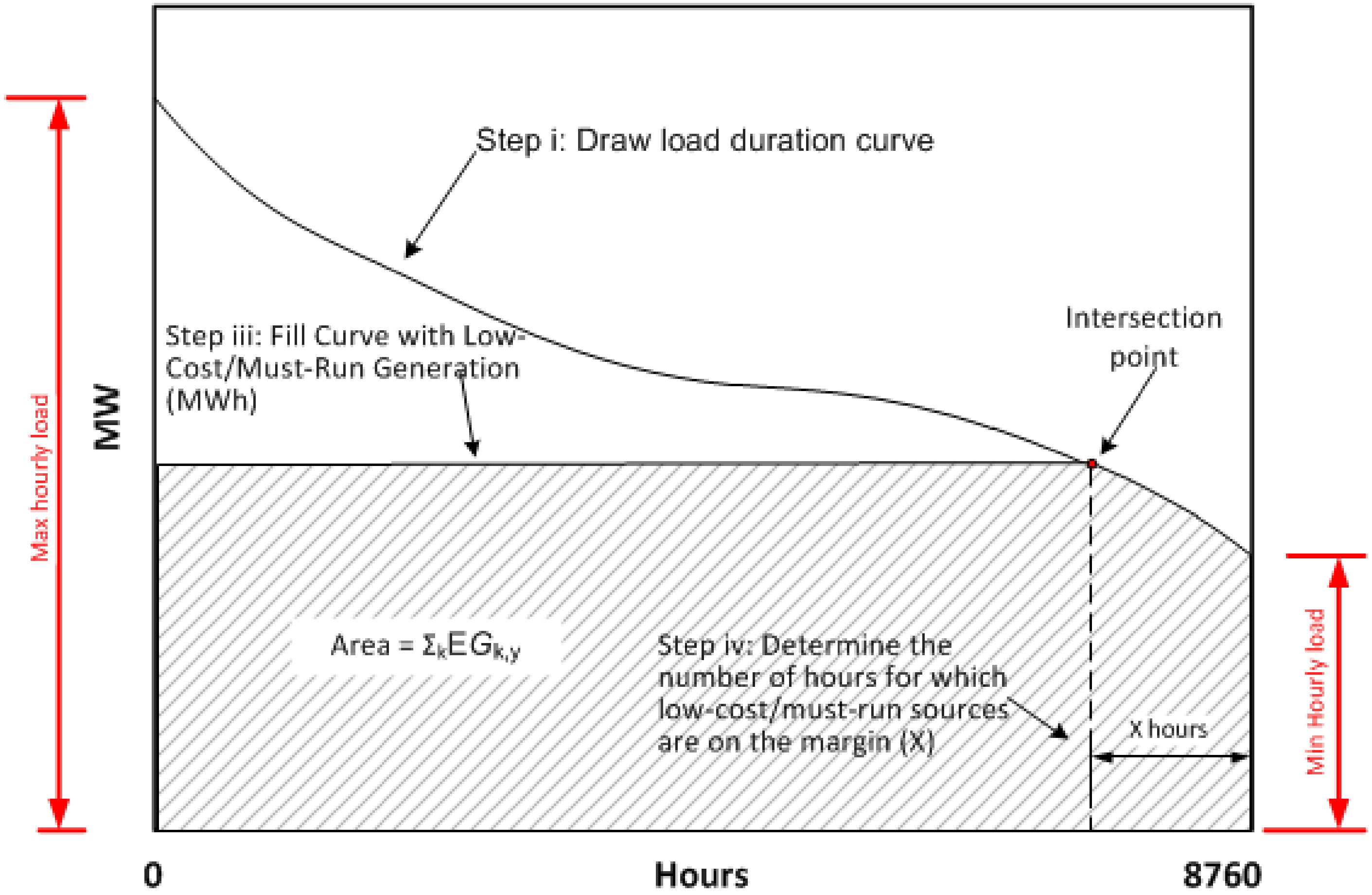
$$EF_{EL,m,y} = \frac{EF_{co2,m,i,y} \times 3.6}{\eta_{m,y}}$$

Option 2

$$EF_{grid,OMsimple,y} = \frac{\sum_i FC_{i,y} \times NCV_{i,y} \times EF_{CO2,i,y}}{EG_y}$$

Demonstrate calculations using IPCC values

Operating Margin: Simple Adjusted OM



$$EF_{grid,OM-adj,y} = \left(1-\lambda_y\right) \times \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}} + \lambda_y \times \frac{\sum_k EG_{k,y} \times EF_{EL,k,y}}{\sum_k EG_{k,y}}$$

Lambda =0 → simple OM

Operating Margin: Average OM

- ❑ Emission factor is determined as the average emission rate of all power plants including LCMR serving the grid
- ❑ Results into conservative GEF
- ❑ Apply as a last resort

Build Margin

Build Margin EF is determined for the cohort of power plants.

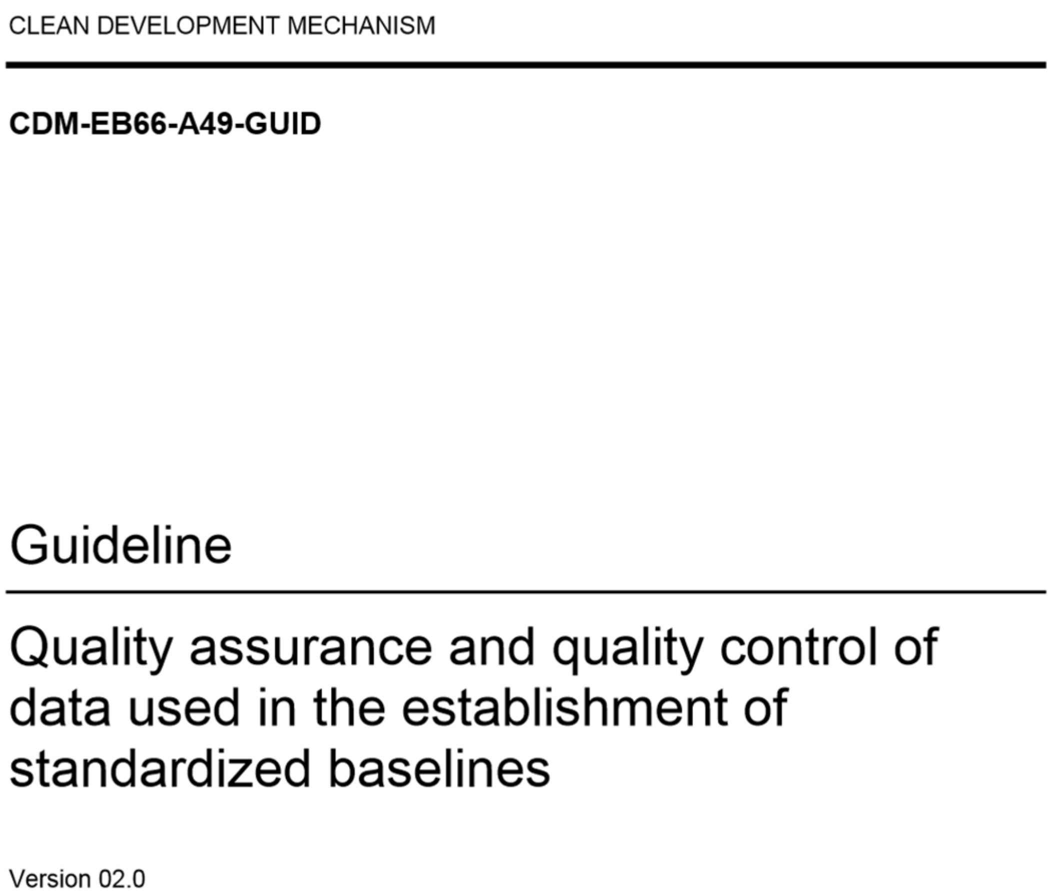
Cohort consists of:

- ❑ Five recently built power plants or
- ❑ Recently built power plants that supplied 20 per cent of generation in the last year

KEY DATA REQUIREMENTS to DETERMINE GEF

	Dispatch data OM	Simple adjusted OM	Simple OM	Average OM	Build margin
Power generation per plant		✓	✓		✓
Power generation aggregated			(✓)	✓	
Fuel consumption per plant		✓	✓		✓
Fuel type and technology		✓	(✓)		(✓)
Fuel consumption aggregated			(✓)	✓	
Hourly power generation and fuel consumption per plant	✓				
Hourly load of the grid		✓			
Date of commissioning					✓

Discuss QA/QC aspects



CLEAN DEVELOPMENT MECHANISM

CDM-EB66-A49-GUID

Guideline

Quality assurance and quality control of data used in the establishment of standardized baselines

Version 02.0

Tool to calculate the emission factor for an electricity system

Module II

Step by step procedure to determine GEF

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Features/Concepts of Grid tool

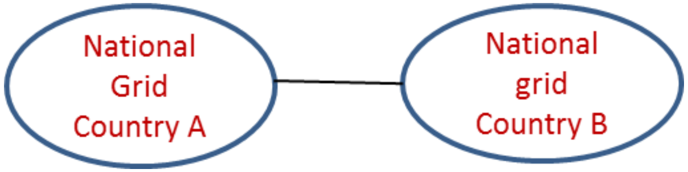
Steps:

- Step 1: Identifying the relevant electricity systems;
- Step 2: Choose whether to include off-grid power plants in the project electricity system;
- 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: Calculating the combined margin (CM) emission factor.
- Data delivery protocal and QA/QC Aspects

Step 1: Identifying the relevant electricity systems (Case study): Delineation of Project electricity system and connected electricity system

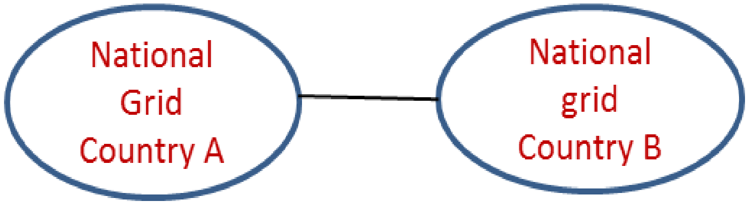
- Interconnecting line has significant transmission constraint .

- CDM project is being implemented in country A. In this case the impact of CDM project in country A is assumed to have negligible displacement effect (OM, BM) in country B's grid due to transmission constraints between the two electricity systems. Here.
  a) Country B-grid is defined as "connected electricity system" and Country A-grid is defined as "project/grid electricity system";
  b) The power flow between the tie-line is considered either **export or import;**



Step 1: Identifying the relevant electricity systems (Case study): Delineation of Project electricity system and connected electricity system

- No transmission constraints i.e., an implementation of CDM project in country A or in Country B can have similar displacement effects in country A-grid
- OM and BM needs to be evaluated considering both electricity systems as a single grid system. Here:
- (a) Country-A grid and country-B grid together constitute a single grid system (project electricity system) and hence a single grid emission factor;
- (b) A common grid emission factor is developed with consents from both the countries. (e.g., SAPP, WAPP)



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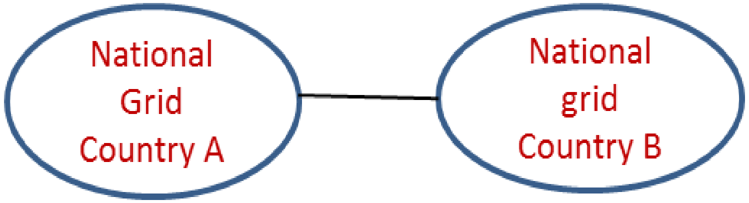
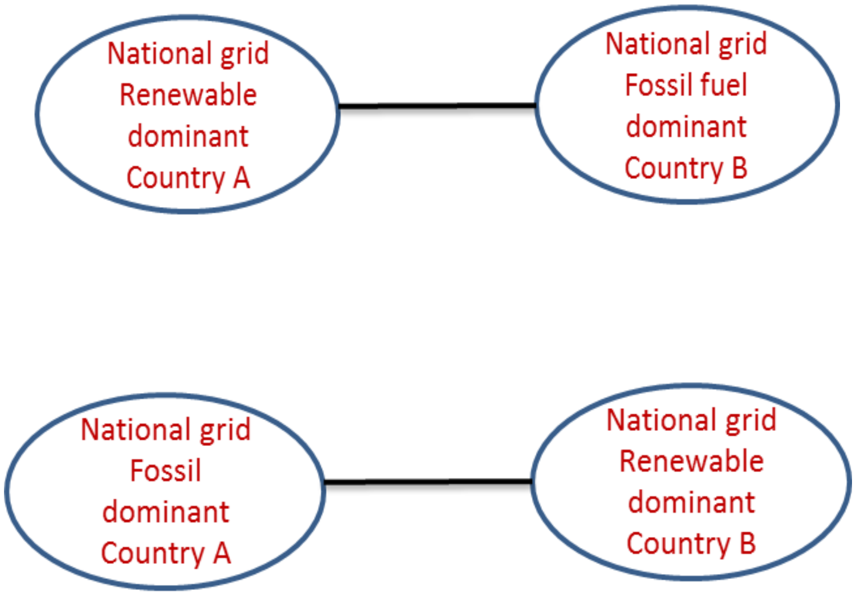


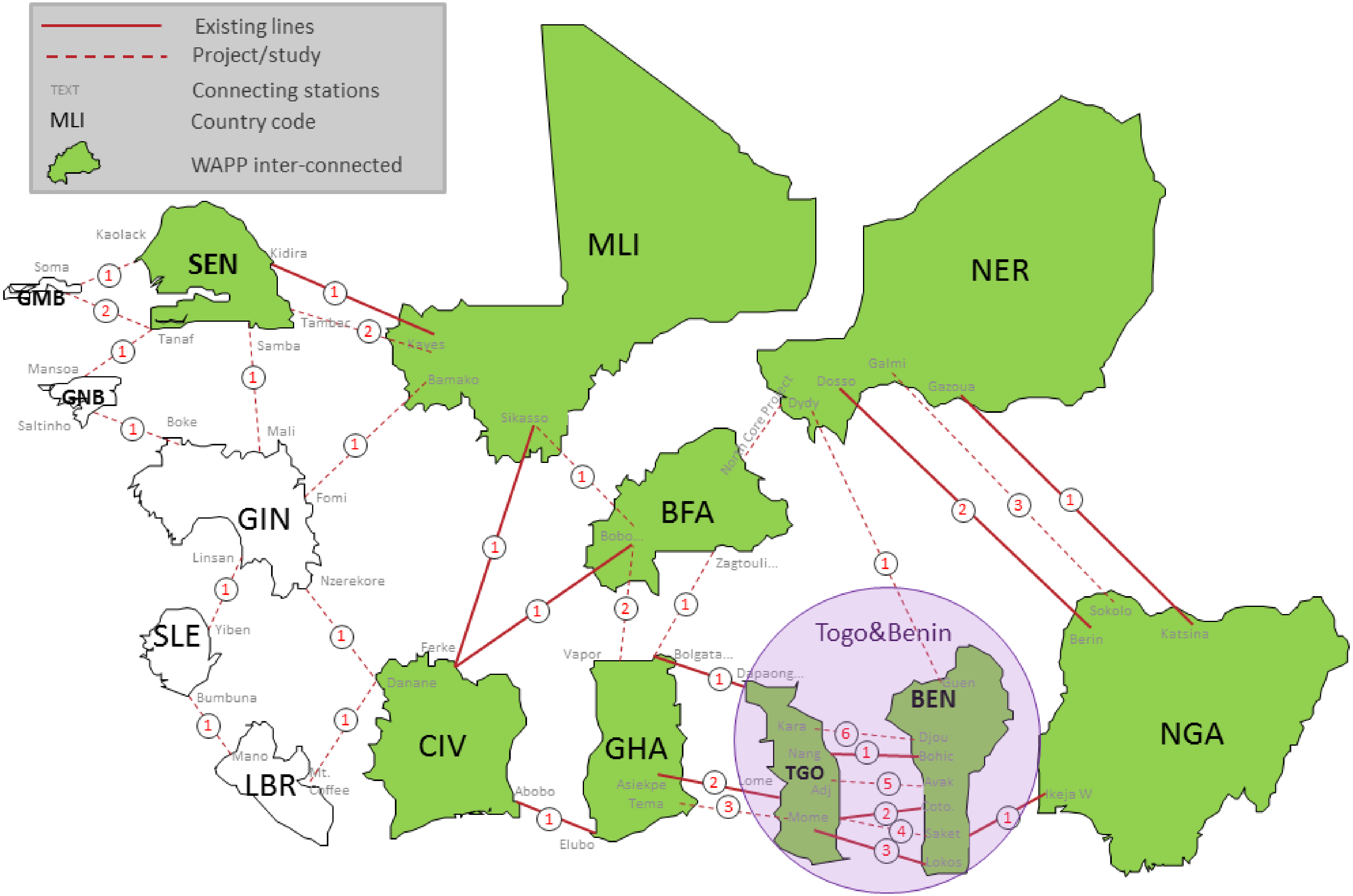
Step 1: Identifying the relevant electricity systems (Case study)



- One is fossil fuel dominant and another country is renewable rich.
- There is no transmission constraint.

- Discuss pros/cons of on delineation of grid system in the two ases

Step 1: Identify the relevant electricity systems (Question/Exercise)



Step 1 (continued) - Transmission constraints check

Export From	Line No.	Import To	Line Voltage (kV)	Maximum load capacity (MW)	Power transmission (MWh)		Operational Load Factor		Transmission constraint check (<90%)	
					2012	2013	2012	2013	2012	2013
NGA	1	NER	132	40	151,963	160,953	43%	46%	OK	OK

Discuss alternative method (10% of installed capacity)

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

- Is off-grid users (but connected to grid) significant (>10% of total installed capacity in grid system ?
- In operation due to unreliable/unstable operation ?

- Default emission factor (0.8 tCO_2/MWh) and default energy generation (10% of total energy production in grid) for
  - LDCs/SIDS or CDM underrepresented countries
  - Demonstrably load shedding program

- Different approach for mini/micro grid fed by a single generator (example of The Gambia and Eritrea)

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

- **Is share of low cost/must run (LCMR) generation < 50% ?**

- LCMR resources –

  a) power plants with low marginal generation costs or dispatched independently of the daily or seasonal load of the grid. They include:
     - hydro, geothermal, wind, low-cost biomass, nuclear and solar generation.
     - If a fossil fuel plant is dispatched independently of the daily or seasonal load of the grid (e.g., CHP plant)

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

Sample:

Years	2009	2010	2011	2012	2013	AVG
Total Generation (MWh)	31,246,756	36,338,337	38,501,818	42,256,048	14,347,665	32,538,125
Low cost/must run (MWh)	9,930,618	9,323,535	8,742,084	8,498,497	1,774,859	7,653,919
Share of Low cost/must run (%)	31.78%	25.66%	22.71%	20.11%	12.37%	23.52%
5yr average Low cost / must run:	23.52%	Simple OM Possible?		YES		

LCMR generate 23,5% of total electricity

Step 3 (continued) – data collection requirements

- Information to clearly identify the plant;
- Date of commissioning;
- Capacity (MW);
- **Net electricity generation in the relevant year(s)**
- Fuel type(s) used ;
- Fuel consumption of each fuel type in the relevant year(s)
- Load curves (if available)
- Fuel specifications (NCV & EF, or IPCC default)
- **Imports/exports records**

CLEAN DEVELOPMENT MECHANISM

TOOL07

SDMDocType

Methodological tool

Tool to calculate the emission factor for an electricity system

Version 04.0

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Quality assurance and quality control of data used in the establishment of standardized baselines

Version 02.0

Step 3 (continued) - Possible data vintages:

- Ex-ante: 3-year generation-weighted average by using the most recent data available at the time of validation; no need for monitoring and recalculating the emission factor during the crediting period.
- Ex-post: updated for the year in which the power plant displaces grid electricity; emission factor should be recalculated annually

→ Discuss pros and cons of ex ante vs ex post approach

Step 4: Calculate the operating margin emission factor according to the selected method

Generation-weighted average CO_2 emissions per unit of net electricity generation (tCO_2/MWh), excluding LCMR

Where

$$EF_{grid,OMsimple,y} = \frac{\sum_m EG_{m,y} \times EF_{EL,m,y}}{\sum_m EG_{m,y}}$$

$EF_{grid,OM\ simple,y}$	**= Simple operating margin CO_2 emission factor in year y (tCO_2/MWh)**
$EG_{m,y}$	= Net quantity of electricity generated & delivered to the grid by power unit m in year y (MWh)
$EF_{EL,m,y}$	= CO_2 emission factor of power unit m in year y (tCO_2/MWh)
m	= All power units serving the grid in year y except low-cost/must-run power units
y	= The relevant year as per the data vintage chosen in Step 3

Step 4 (continued) – Determination of $FE_{EL,m,y}$

Option A1: If data on fuel consumption and electricity generation is available, the emission factor is determined as

Where

$$EF_{EL,m,y} = \frac{\sum_i FC_{i,m,y} \times NCV_{i,y} \times EF_{CO2,i,y}}{EG_{m,y}}$$

$FC_{i,m,y}$	= Amount of fuel type i consumed by power unit m in year y (Mass or volume unit)
$NCV_{i,y}$	= Net calorific value (energy content) of fuel type i in year y (GJ/mass or volume unit)
$EF_{CO2,I,y}$	= CO2 emission factor of fuel type i in yea y (tCO2/GJ)
$EG_{m,y}$	= Net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh)
i	= All fuel types combusted in power unit m in year y

Step 4 (continued) – Determination of $FE_{EL,m,y}$

Option A2: If only data on electricity generation and the fuel types used is available, determination based on the CO2 emission factor of the fuel type used and the efficiency of the power unit, as

$$EF_{EL,m,y} = \frac{EF_{CO2,m,i,y} \times 3.6}{\eta_{m,y}}$$

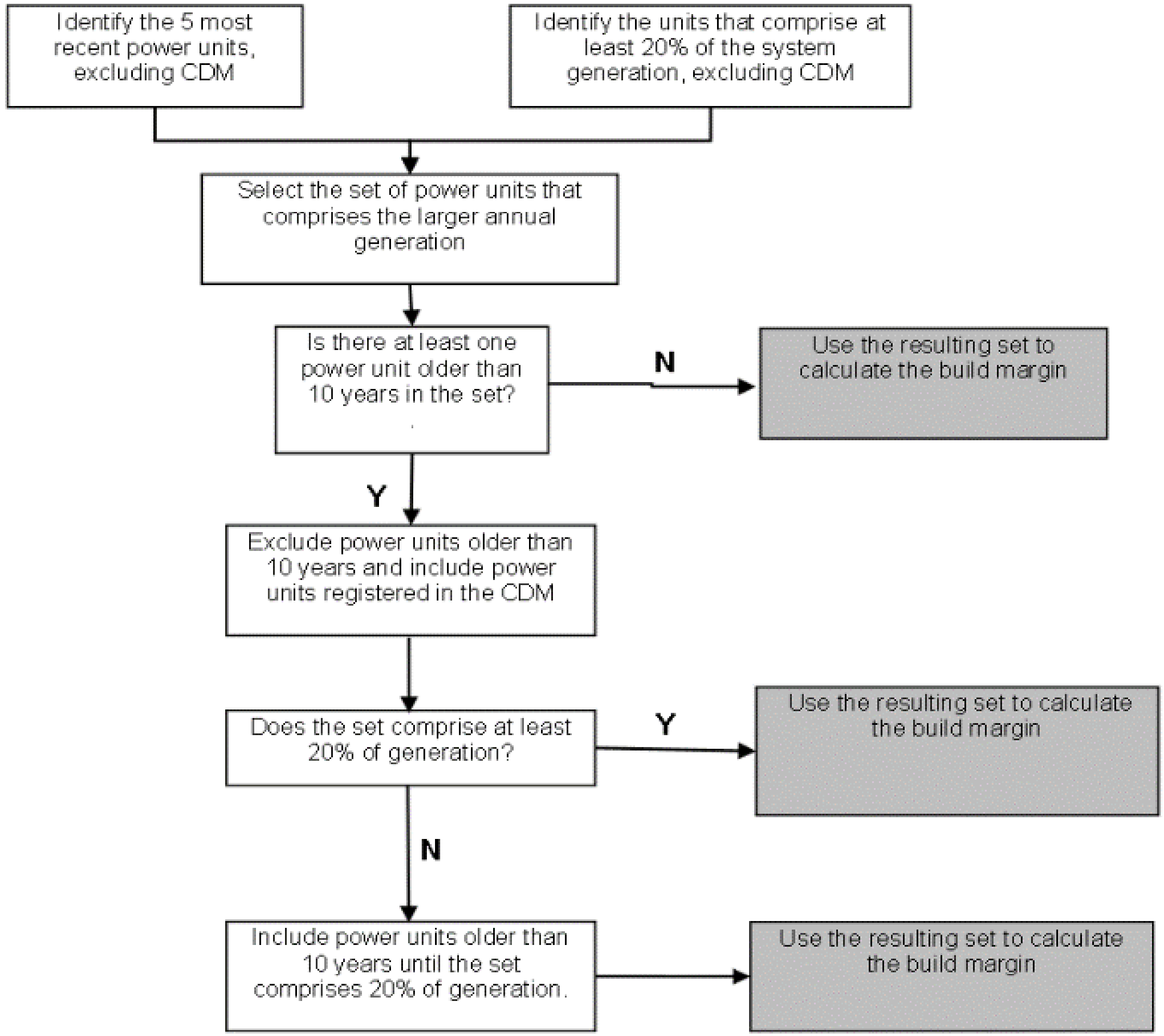
Where

$EF_{CO2,m,I,y}$	= Average CO_2 emission factor of fuel type i used in power unit m in year y (tCO_2/GJ)
$\eta_{m,y}$	= Average net energy conversion efficiency of power unit m in year y (ratio)
i	= All fuel types combusted in power unit m in year y

Consideration of import/export in OM calculation

- For the purpose of determining the operating margin emission factor, use one of the following options to determine the CO_2 emission factor(s) for net electricity imports from a connected electricity system:
  a) 0 t CO_2/MWh; or
  b) The simple operating margin emission rate of the exporting grid, determined using Step 3 apply to the exporting grid; or
  c) The simple adjusted operating margin emission rate of the exporting grid, determined as described in Step 4
  d) The weighted average operating margin (OM) emission rate of the exporting grid, determined as described in Step 4
- For imports from connected electricity systems located in Annex I country(ies), the emission factor is 0 tons CO_2 per MWh.
- Electricity exports should not be subtracted from electricity generation data used for calculating and monitoring the electricity emission factors

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



Step 5 (continued) - WAPP BM calculation results

Total ∑EG without CDM (MWh)	**13,069,865**	
Criteria	SET 5 units	SET 20%
Total Power generation for BM (MWh)	808,710	3,140,867
Emissions for BM (tCO2)	518,530	1,996,599
Build Margin excl. off-grid	0.6412	0.6357
Selected BM for the grid system (tCO_2/MWh)	**0.6357**	

- 5 most recent units as of 2012
- 20% of power generation encompasses more (16 units)

Step 6: Calculate the combined margin (CM) emission factor

$$EF_{grid,CM,y} = w_{OM} . EF_{grid,OM,y} + w_{BM} . EF_{grid,BM,y}$$

- For wind and solar power generation projects, $w_{OM} = 0.75$, $w_{BM} = 0.25$ for all crediting periods
- For all other projects, $w_{OM} = 0.5$, $w_{BM} = 0.5$ for the first crediting period, and $w_{OM} = 0.25$, $w_{BM} = 0.75$ for second and third crediting period

Step 6 (continued) – SAMPLE GEF results

Project types	1st crediting period					2nd or 3rd crediting period				
	OM	BM	CM	W_{om}	W_{bm}	OM	BM	CM	W_{om}	W_{bm}
Solar and Wind power project	0.5715	0.6357	**0.588**	0.75	0.25	0.5715	0.6357	**0.588**	0.75	0.25
Other renewables	0.5715	0.6357	**0.604**	0.5	0.5	0.5715	0.6357	**0.62**	0.25	0.75
Other projects	0.5715	0.6357	**0.604**	0.5	0.5	0.5715	0.6357	**0.62**	0.25	0.75

Discuss recurring issues and QA/QC aspects

CLEAN DEVELOPMENT MECHANISM

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Module III

Hands on Exercises (General)

Feedback /exercise on country specific issues

Training workshop- Grid emission factor 19-20 Aug 2015

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RECAP of DAY1 - Determination of GEF (Step by step procedure)

- Step 1: Identifying the relevant electricity systems;
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Demo/hands-on exercise to determine OM, BM and CM

Electricity systems	Power plant	Commissioning Year	Percentage of Total Generation	2012				Is plant registered as CDM ?	Is plant comissioned more than 10 yrs ago ?	CHECK !! recent 5 units or 20%	
				Net Electricity Generation (MWh)	Fuel Consumption (litres)	Fuel Consumption (kt)	Emission Factor (tCO2/MWh)				
Central Grid	Kotu Power Plant	1981	43.00%	102,009.00	26.69	22.93	0.68	no	yes		
	Brikama Power Plant (GEG)	2006	35.63%	84,533.00	23.22	19.95	0.71	no	no	35.63%	57.00%
	Batokunku	2009	0.04%	95.65				no	no	0.04%	21.36%
	Brikama Power Plant (Wartsila)	2011	21.24%	50,391.00	10.87	9.34	0.56	no	np	21.24%	21.32%
	Tanji Power Plant	2012	0.08%	191.68				no	no	0.08%	0.08%
	Total Annual Generation			237,220.33							
	EF(BM)	**0.651**									

Source for electricity generation data: NAWEC and CONREPP Data Delivery protocols

Diesel densit 0.859 kg/l

	Emission Factor	NCV
	tCO2/TJ	TJ/kt
HFO	75.5	39.8

Source: Lower end value in the IPCC 2006 Guidelines, Volume 2, Table 1.2. (NCV), Table 1.4 (EF)

Application of CM

Operating Margin	0.713
Build Margin	0.651

First crediting period

	Solar/Wind	Others
Weight OM	0.75	0.5
Weight BM	0.25	0.5
Combined Margin	**0.697**	**0.682**

2nd Creiditng period

	Solar/Wind	Others
Weight OM	0.75	0.25
Weight BM	0.25	0.5
Combined Margin		

	Annual generation (MWh)	Baseline emissions (tCO2)	Project emissions/year (tC)2)	Emission reduction/year	
Solar	33000	23016.54098	0	23016.54098	15.06849315
Wind					
Hydro					

Carbon credi 11508.27049

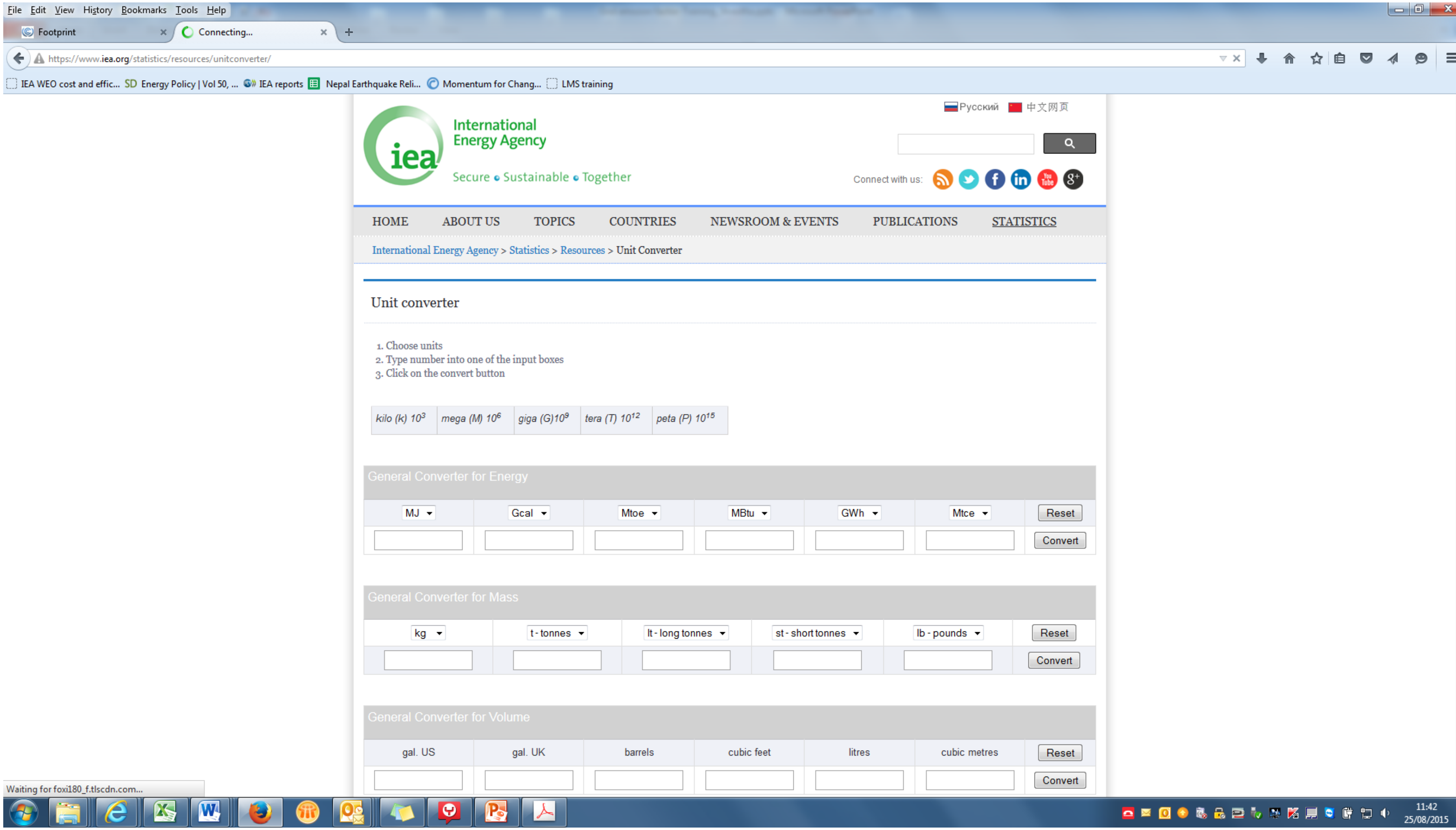
ver / Installed Capacity / Operating Margin Data / Build Margin / Combined Margin

IPCC default values (NCV and EF)

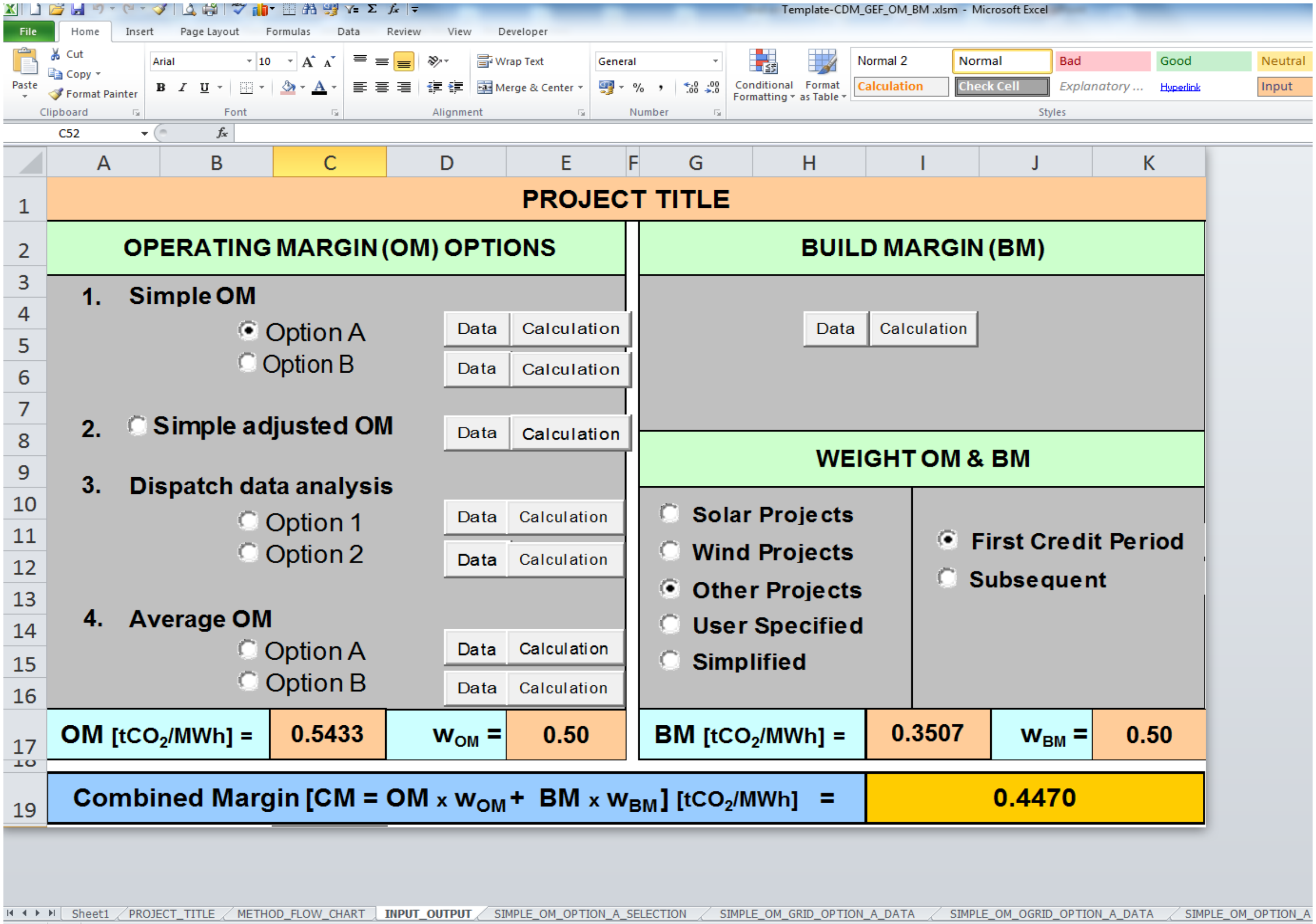
TABLE 1.2
DEFAULT NET CALORIFIC VALUES (NCVS) AND LOWER AND UPPER LIMITS OF THE 95% CONFIDENCE INTERVALS [1]

Fuel type English description		Net calorific value (TJ/Gg)	Lower	Upper
Crude Oil		42.3	40.1	44.8
Orimulsion		27.5	27.5	28.3
Natural Gas Liquids		44.2	40.9	46.9
Gasoline	Motor Gasoline	44.3	42.5	44.8
	Aviation Gasoline	44.3	42.5	44.8
	Jet Gasoline	44.3	42.5	44.8
Jet Kerosene		44.1	42.0	45.0
Other Kerosene		43.8	42.4	45.2
Shale Oil		38.1	32.1	45.2
Gas/Diesel Oil		43.0	41.4	43.3
Residual Fuel Oil		40.4	39.8	41.7
Liquefied Petroleum Gases		47.3	44.8	52.2
Ethane		46.4	44.9	48.8

IEA unit converter



Demo –Grid Tool Template



Tool to calculate the emission factor for an electricity system

Module III

Feedback /exercise on country specific issues

Training workshop- Grid emission factor 19-20 Aug 2015

UNFCCC

RCC, Kampala