

# GRID EMISSION FACTOR FOR ARMENIA

2014-2016

Version 01.0

26 June 2017

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## Steps of grid emission factor calculation

The grid emission factor for the electricity system of the Republic of Armenia (Armenia) for 2016 has been calculated in line with provisions and recommendations provided in the version 5.0 of the “Tool to calculate the emission factor for an electricity system” (Tool) and based on information and data obtained by DNA from public sources and respective state authorities of Armenia.

### *Step 1: Identify the relevant electricity systems*

The national power distribution grid of Armenia covers all the country and is identified as the project electricity system for the purpose of grid emission factor calculation. The Armenian power system maintains power exchange with the national electricity grid of Iran and Georgia. In such a way, Iranian and Georgian national grids are considered as the connected electricity systems. For the purpose of determining the operating margin emission factor the Tool proposes four options to determine the CO<sub>2</sub> emission factor(s) for net electricity imports from a connected electricity system. Within the scopes of this study option (a) i.e. 0 tones CO<sub>2</sub> per MWh is selected.

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

Option I of the Tool i.e. “Only grid power plants are included in the calculation” is selected; hence, off-grid power plants are not included in the project electricity system.

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

According to the definition used in the Tool, low-cost/must-run resources are defined as 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. In accordance with this definition, within the scope of this study, all power plants except for four large thermal power plants (Yerevan TPP, Hrazdan TPP, Hrazdan TPP Unit N5 and CCGT Unit at Yerevan TPP) are selected as low-cost / must-run power plants.

Based on the statistic information provided by the Ministry of Energy Infrastructures and Natural Resources of RA during the period of 2012-2016, low-cost/must-run (LCMR) resources constituted more than 50% of the total grid generation in average of the five most recent years. Additionally, based on information on hourly load data provided by the Ministry, it was identified that averages load by LCMR resources is higher than average lowest annual system load (LASL) over the three years. Hence, following the procedure for application of operational margin methods provided in the Tool, “Simple adjusted OM” was selected for calculation of the operating margin emission factor.

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

In order to evaluate Operational Margin, net quantity of electricity (mln kWh) generated and delivered to the grid by all power units serving the system need to be identified as well as CO<sub>2</sub> emission factor (tCO<sub>2</sub>/MWh) of power units operated on fossil fuels need to be calculated. Information on net generation of electricity by all power plants (both LCMR and no LCMR) the Armenia power system in 2014-2016 is presented in the table below. According to the Tool, electricity import is also considered in calculation of Simple adjusted OM.

POWER PLANT	Delivered electricity (mln kWh)			Type of fuel
	2014	2015	2016	
No LCMR				
Hrazdan Thermal Power Plant	905.23	507.85	409.26	natural gas
Unit 5 of Hrazdan Thermal Power Plant	827.59	615.73	668.63	natural gas
Yerevan Thermal Power Plant	-	-	-	natural gas
CCGT Unit at Yerevan TPP	1398.77	1541.26	1380.76	natural gas
LCMR				
Metzamor NPP	2265.64	2571.10	2194.85	nuclear
Sevan-Hrazdan CHPPs (IEC)	465.33	444.31	395.60	hydro
ContourGlobal Hydro Cascade	826.60	909.57	981.80	hydro
Small Hydro Power Plants	670.56	818.68	940.11	hydro
Lori-1 Wind Power Plant	3.70	3.38	1.61	wind
Wind Power Plant	-	0.01	0.05	wind
Energy Center at YSMU – CHP Unit	14.54	12.33	6.33	natural gas
ArmRoscogeneration CJSC – CHP Unit	11.47	9.03	11.59	natural gas
Import	204.85	172.82	263.53	
TOTAL with Import	7594.26	6876.50	7254.13	
LCMR Plants	4257.84	4768.41	4531.95	
Low-cost/must-run plants + import	4462.69	4941.24	4795.48	

In the table below results of calculation of emission factors for no LCMR power plants for 2014-2016 is presented.

POWER PLANT	Year	Fuel consumption $FC_{i,m,y}$	Net calorific value of fuel $NCV_{i,y}$	Emission factor $EF_{CO_2,i,y}$	Emission factor
		1000nm <sup>3</sup>	GJ/1000nm <sup>3</sup>	tCO <sub>2</sub> /GJ	tCO <sub>2</sub> /MWh
Hrazdan TPP	2014	275583	34.710	0.054	0.57
	2015	162509	34.773	0.054	0.6
	2016	129544	34.278	0.054	0.59
Unit N5 at Hrazdan TPP	2014	210883	34.759	0.054	0.48
	2015	148592	35.165	0.054	0.46
	2016	164951	34.503	0.054	0.46
CCGT at Yerevan TPP	2014	305644	34.583	0.054	0.41
	2015	336813	34.554	0.054	0.41
	2016	303887	34.378	0.054	0.41

In the table below results of calculation of emission factors for LCMR power plants for 2014-2016 is presented.

POWER PLANT	Year	Fuel consumption $FC_{i,m,y}$	Net calorific value of fuel $NCV_{i,y}$	Emission factor $EF_{CO_2,i,y}$	Emission factor
		1000nm <sup>3</sup>	GJ/1000nm <sup>3</sup>	tCO <sub>2</sub> /GJ	tCO <sub>2</sub> /MWh
Metzamor NPP, Large and Small HPPs, Lori-1 WPP	2014	0	0	0	0
	2015	0	0	0	0
	2016	0	0	0	0
Energy Center at YSMU – CHP Unit	2014	4309	34.790	0.054	0.56
	2015	3878	34.823	0.054	0.59
	2016	2116	34.272	0.054	0.62
ArmRosco generation CJSC – CHP Unit	2014	3125	34.869	0.054	0.52
	2015	2576	34.620	0.054	0.54
	2016	3227	34.290	0.054	0.52

Calculation of lambda factor is performed in accordance with the procedure set by the Tool and based on chronological (hourly) power generation data for each plant/unit provided by the Ministry.

In the table below results of calculation of lambda factor and respective Simple adjusted OM for 2014-2016 are presented.

The number of hours for which low-cost/must-run sources are on the margin (hours)	2014	2015	2016
	17	12	24
Lambda factor	0.0019406	0.0013699	0.0027322
Simple adjusted OM emission factor (tCO <sub>2</sub> /MWh)	<b>0.475</b>	<b>0.458</b>	<b>0.452</b>

#### *Step 5: Calculate the build margin emission factor*

Following the procedure for selection of power units  $m$  used to calculate the build margin described in the Tool, the set of five power units, excluding power units registered as CDM project activities, that started to supply electricity to the grid most recently (SET5-units) has been identified along with their annual electricity generation (AEGSET-5-units, in MWh).

In the table below information on installed capacities and cumulative share of power generation of these plants is given for 2014-2016.

The set of five power units (excluding power units registered as CDM project activities) that started to supply electricity to the grid most recently (SET5-units) for 2014-2016

Year	N	POWER PLANT	First year in service	Power generation in 2014, MWh	Cumulative share, %
2014	1	Yegheg SHPP	2014	746.5	0.01
	2	Spitak Jur SHPP	2014	13.6	0.00
	3	Mane SHPP	2014	896.4	0.01
	4	Khachaghbyur-2 SHPP (Megaenergy LLC)	2014	8056.7	0.11
	5	Khachi Qar SHPP	2014	3878.6	0.05
	<b>TOTAL</b>			<b>13591.9</b>	<b>0.18</b>
Year	N	POWER PLANT	First year in service	Power generation in 2015, MWh	Cumulative share, %
2015	1	Daranak SHPP	2015	955.7	0.014
	2	Arevis-1 SHPP	2015	477.6	0.007
	3	Nigava SHPP	2015	5351.3	0.080
	4	Gndevanq SHPP	2015	190.5	0.003
	5	Qajaran Wind Power Plant	2015	13.6	0.0002
	<b>TOTAL</b>			<b>6988.8</b>	<b>0.104</b>
Year	N	POWER PLANT	First year in service	Power generation in 2015, MWh	Cumulative share, %
2016	1	Seca SHPP	2016	1071.2	0.02
	2	Anapat-1 SHPP	2016	1573.1	0.02
	3	Amberd-3 SHPP	2016	11234.8	0.16
	4	Meghri-1 SHPP	2016	2512.7	0.04
	5	Her-Her SHPP	2016	1351.6	0.02
	<b>TOTAL</b>			<b>17743.3</b>	<b>0.25</b>

As it is seen from the above table the total power generation of the 5 recently commissioned power plants is much lower than 20% of total power generation of the system.

The next step requires determining the annual electricity generation of the project electricity system, excluding power units registered as CDM project activities (AEG<sub>total</sub>, in MWh), and to identify the set of power units, excluding power units registered as CDM project activities, that started to supply electricity to the grid most recently and that comprise 20% of AEG<sub>total</sub> (SET<sub>≥20%</sub>) and determine their annual electricity generation (AEG<sub>SET-≥20%</sub>, in MWh);

In the table below information on annual electricity generation as well as share of electricity generation of the plants included in SET<sub>≥20%</sub> is given.

The set of power units (excluding power units registered as CDM project activities) that started to supply electricity to the grid most recently and that comprise 20% of the system generation (SET<sub>≥20%</sub>) for 2014-2016

Year	POWER PLANT	First year in service	Fuel	Power generation, MWh	Share of AEG <sub>total</sub> (%)
2014	Hrazdan TPP Unit N5	2011	NG	857490	11.6
	85 small WPPs and HPPs	2010-2014	HY	301689	4.08
	CCGT Unit at YTPP	2010	NG	1447860	19.59
	<b>TOTAL</b>			<b>2607041.4</b>	<b>35.27</b>
2015	Hrazdan TPP Unit N5	2011	NG	638368	9.52
	94 small WPPs and HPPs	2010-2015	HY	415337	6.19
	CCGT Unit at YTPP	2010	NG	1594592	23.78
	<b>TOTAL</b>			<b>2634155.2</b>	<b>39.49</b>
2016	Hrazdan TPP Unit N5	2011	NG	694823	9.93
	105 small WPPs and HPPs	2010-2016	HY	490324	7.01
	CCGT Unit at YTPP	2010	NG	1427313	20.41
	<b>TOTAL</b>			<b>2612466.8</b>	<b>37.35</b>

As it is seen from the above two tables the group of power units included in SET<sub>≥20%</sub> comprises the larger annual electricity generation than power plants included in SET<sub>5-units</sub> in 2014-2016 period.

Since all power units included in the selected group (SET<sub>≥20%</sub>) started to supply electricity to the grid no more than 10 years ago, the set of power plants in the latter table is used for calculation of the Build Margin.

In the below emission factors for plants included in Build Margin as well as Build Margin emission factor for the system 2014-2016 are given.

Year	POWER PLANT	Emission factor of power plants included in BM (tCO <sub>2</sub> /MWh)	Build Margin emission factor (tCO <sub>2</sub> /MWh)
2014	Hrazdan TPP Unit N5	0.48	0.3854
	85 small HPPs	0	
	CCGT Unit at YTPP	0.41	
2015	Hrazdan TPP Unit N5	0.46	0.3591
	94 small HPPs	0	
	CCGT Unit at YTPP	0.41	
2016	Hrazdan TPP Unit N5	0.46	0.3456
	105 small HPPs	0	
	CCGT Unit at YTPP	0.41	

#### Step 6: Calculate the combined margin emissions factor

For the purpose of this study the weighted average Combined Margin (CM) method (Option a) has been used as the preferred option.

As the result of the performed calculations the following CM emission factors have been received for ex post approach for 2014-2016.

Year	EX POST (tCO <sub>2</sub> /MWh)	
2014	Simple Adjusted Operating Margin	0.4753
	Build Margin	0.3854
	CM for wind and solar	0.4528
	CM for all other projects	0.4303
2015	Simple Adjusted Operating Margin	0.4581
	Build Margin	0.3456
	CM for wind and solar	0.4333
	CM for all other projects	0.4086
2016	Simple Adjusted Operating Margin	0.4525
	Build Margin	0.3456
	CM for wind and solar	0.4258
	CM for all other projects	0.3991

#### Results of calculation: Combined Margin for 2016

As the result of the performed calculations the following CM emission factors have been received for ex ante approach for 2016.

Year	EX ANTE (tCO <sub>2</sub> /MWh)	
2016	Simple Adjusted Operating Margin	0.4620
	Build Margin	0.3456
	CM for wind and solar	0.4329
	CM for all other projects (1 <sup>st</sup> CP)	0.4038
	CM for all other projects (2 <sup>nd</sup> and 3 <sup>rd</sup> CP)	0.3748

## Annex I: Combine Margin Emission Factor for 2016 (ex-ante)

### The simple adjusted operating margin

	2014	2015	2016	Average	
<b>EF<sub>grid,OM-adj,y</sub></b> =	<b>0.4753183</b>	<b>0.458135</b>	<b>0.4525609</b>	<b>0.4620047</b>	<b>tCO2/MWh</b>

<b>EG</b>	7 594 275	7 606 084	7 254 127	(MWh) Net quantity of electricity generated and delivered to the grid
<b>EG<sub>m,y</sub></b>	3 131 588	2 664 847	2 458 651	(MWh) Net quantity of electricity generated and delivered to the grid by not low-cost/must-run power units
<b>EG<sub>k,y</sub></b>	4 462 687	4 941 237	4 795 475	(MWh) Net quantity of electricity generated and delivered to the grid by low-cost/must-run power units

<b>MWh (plot line)</b> =	<b>510.25632</b>	<b>565.55916</b>	<b>549.91134</b>
<b>y</b> =	<b>8743</b>	<b>8748</b>	<b>8760</b>
<b>X</b> =	<b>17</b>	<b>12</b>	<b>24</b>

<b>λ</b> =	<b>0.0019406</b>	<b>0.0013699</b>	<b>0.0027322</b>
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### The build margin 2016

<b>EF<sub>grid,BM,y</sub></b> =	<b>0.3456902</b>	<b>tCO2/MWh</b>
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### The combined margin 2016

<b>EF<sub>grid,CM,y</sub></b> =	<b>0.4329261</b>	<b>tCO2/MWh</b>	<b>For Wind and Solar projects</b>
<b>EF<sub>grid,CM,y</sub></b> =	<b>0.4038475</b>	<b>tCO2/MWh</b>	<b>For other projects</b>

	<b>W<sub>OM</sub></b>	<b>W<sub>BM</sub></b>
<b>For Wind and Solar projects</b>	<b>0.75</b>	<b>0.25</b>
<b>For other projects</b>	<b>0.5</b>	<b>0.5</b>

## Annex II: Combine Margin Emission Factor for 2016 (ex-post)

### The simple adjusted operating margin

$$EF_{\text{grid,OM-adj,y}} = 0.4525609 \text{ tCO}_2/\text{MWh}$$

<b>EG</b>	7 254 127	(MWh) Net quantity of electricity generated and delivered to the grid
<b>EG<sub>m,y</sub></b>	2 458 651	(MWh) Net quantity of electricity generated and delivered to the grid by not low-cost/must-run power units
<b>EG<sub>k,y</sub></b>	4 795 475	(MWh) Net quantity of electricity generated and delivered to the grid by low-cost/must-run power units

<b>MWh (plot line)</b>	<b>= 549.91134</b>
<b>y</b>	<b>= 8760</b>
<b>X</b>	<b>= 24</b>

$$\lambda = 0.0027322$$

### The build margin

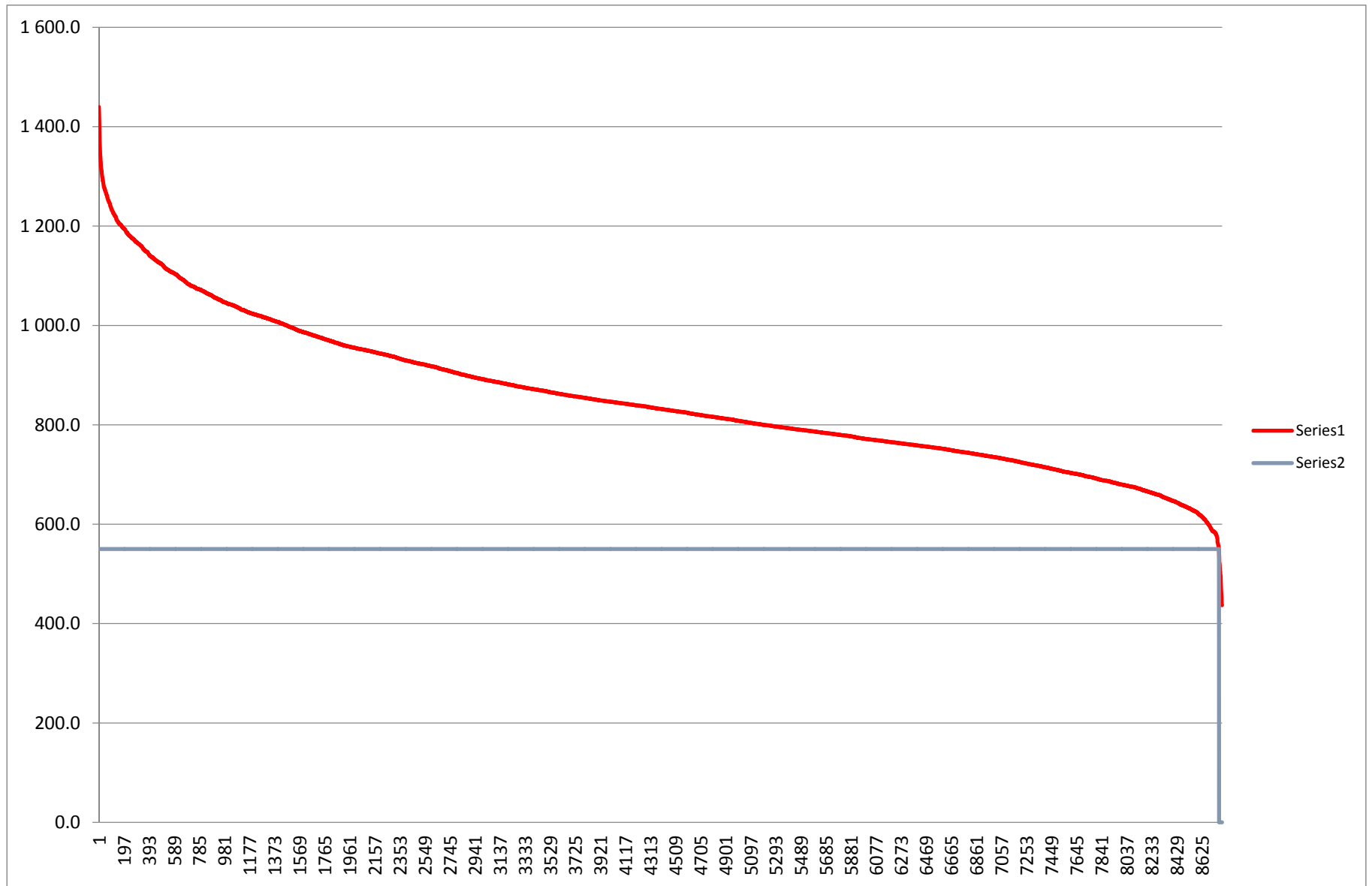
$$EF_{\text{grid,BM,y}} = 0.3456902 \text{ tCO}_2/\text{MWh}$$

### The combined margin

$$EF_{\text{grid,CM,y}} = 0.3991256 \text{ tCO}_2/\text{MWh}$$

<b>W<sub>OM</sub></b>	<b>=</b>	<b>0.5</b>
<b>W<sub>BM</sub></b>	<b>=</b>	<b>0.5</b>

Annex III: Load duration curve for 2016



## Annex IV: Combine Margin Emission Factor for 2015 (ex-post)

### The simple adjusted operating margin

$EF_{\text{grid,OM-adj,y}}$	=	<b>0.45813499</b>	tCO <sub>2</sub> /MWh
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<b>EG</b>	7 606 084	(MWh) Net quantity of electricity generated and delivered to the grid
<b>EG<sub>m,y</sub></b>	2 664 847	(MWh) Net quantity of electricity generated and delivered to the grid by not low-cost/must-run power units
<b>EG<sub>k,y</sub></b>	4 941 237	(MWh) Net quantity of electricity generated and delivered to the grid by low-cost/must-run power units

<b>MWh (plot line)</b>	=	<b>565.559157</b>
<b>y</b>	=	<b>8748</b>
<b>X</b>	=	<b>12</b>

$\lambda$	=	<b>0.00136986</b>
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### The build margin

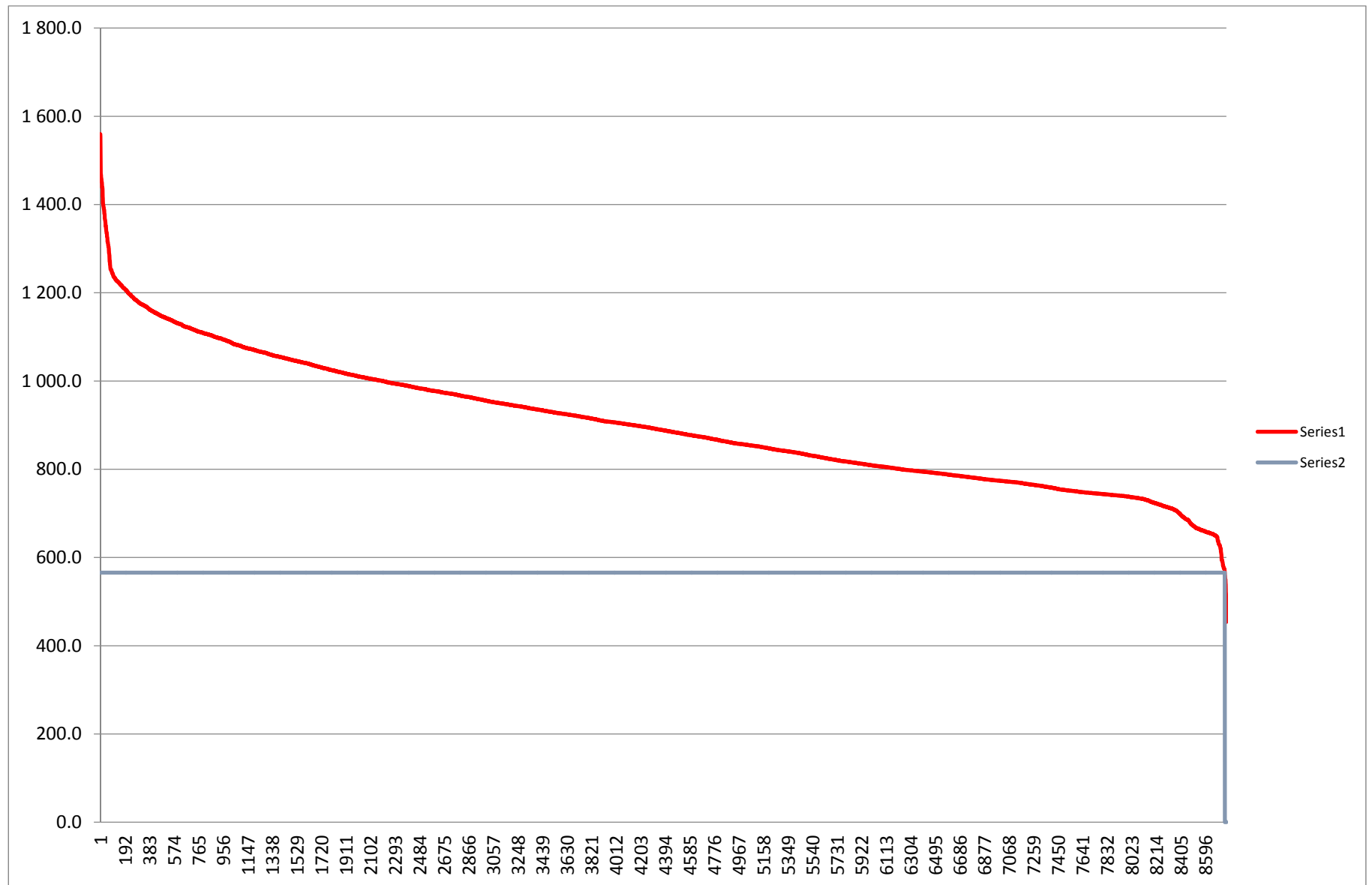
$EF_{\text{grid,BM,y}}$	=	<b>0.35909381</b>	tCO <sub>2</sub> /MWh
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### The combined margin

$EF_{\text{grid,CM,y}}$	=	<b>0.4086144</b>	tCO <sub>2</sub> /MWh
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<b>W<sub>OM</sub></b>	=	<b>0.5</b>
<b>W<sub>BM</sub></b>	=	<b>0.5</b>

Annex V: Load duration curve for 2015



## Annex VI: Combine Margin Emission Factor for 2014 (ex-post)

### The simple adjusted operating margin

$EF_{\text{grid,OM-adj,y}}$	=	<b>0.4753183</b>	tCO <sub>2</sub> /MWh
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<b>EG</b>	7 594 275	(MWh) Net quantity of electricity generated and delivered to the grid
<b>EG<sub>m,y</sub></b>	3 131 588	(MWh) Net quantity of electricity generated and delivered to the grid by not low-cost/must-run power units
<b>EG<sub>k,y</sub></b>	4 462 687	(MWh) Net quantity of electricity generated and delivered to the grid by low-cost/must-run power units

<b>MWh (plot line)</b>	=	<b>510.25632</b>
<b>y</b>	=	<b>8743</b>
<b>X</b>	=	<b>17</b>

$\lambda$	=	<b>0.0019406</b>
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### The build margin

$EF_{\text{grid,BM,y}}$	=	<b>0.3854739</b>	tCO <sub>2</sub> /MWh
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### The combined margin

$EF_{\text{grid,CM,y}}$	=	<b>0.4303961</b>	tCO <sub>2</sub> /MWh
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<b>W<sub>OM</sub></b>	=	<b>0.5</b>
<b>W<sub>BM</sub></b>	=	<b>0.5</b>

Annex VII: Load duration curve for 2014

