European Bank
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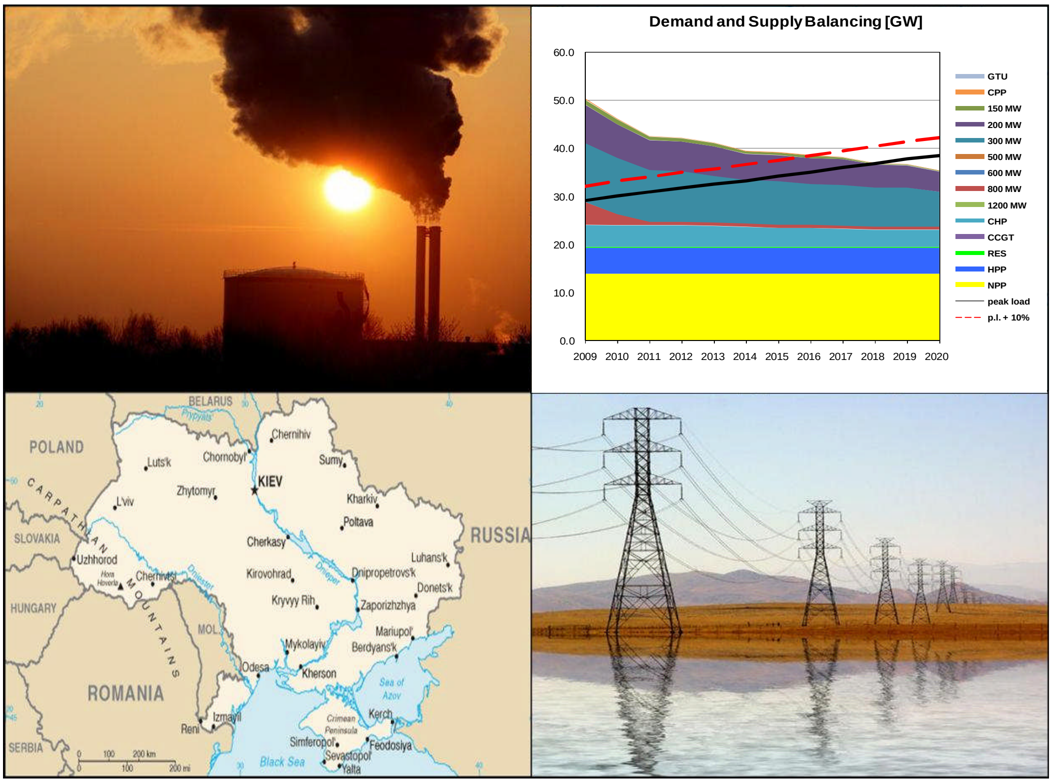
European Bank for Reconstruction and Development

Development of the electricity carbon emission factors for Ukraine



Baseline Study for Ukraine

- Final Report -

LAHMEYER INTERNATIONAL

perspectives climate change
a Point Carbon company

LI 260574

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ACRONYMS AND ABBREVIATIONS

CDM	Clean Development Mechanism
CHP	Combined heat and power
CM	Combined Margin
CO_2	Carbon dioxide
CPP	Condensing power plant
EBRD	European Bank for Reconstruction and Development
ENTSO-E	European Network of Transmission System Operators for Electricity
EUR	Euro (currency)
GHG	Greenhouse gas
GTU	Gas turbine unit
GW	Gigawatt
GWh	Gigawatt hour
HPP	Hydropower plant
IE	Independent Entity
JI	Joint Implementation
km	Kilometre
kV	Kilo volt
kVA	Kilo volt ampere
kWh	Kilowatt hour
LEC	Levelised Electricity Cost
LI	Lahmeyer International
MFE	Ministry of Fuel and Energy
MoM	Minutes of the Meeting
MS	Microsoft
MVA	Mega volt ampere
MVA	Mega volt ampere
MW	Megawatt
MWh	Megawatt hour
NEIA	National Environmental Investment Agency
NPP	Nuclear power plant
PSH	Pumped storage hydropower plant
RES	Renewable Energy Sources
SO-CDU	System Operator – Central Dispatching Unit
SRMC	Short Run Marginal Cost
t	Metric tonne
TPP	Thermal power plant
UAH	Hryvnia (currency in Ukraine)
UNFCCC	United Nations Framework Convention on Climate Change
UPS	United Power System

1 INTRODUCTION

The study project "Development of the electricity carbon emission factors for Ukraine" was assigned by the European Bank for Development and Reconstruction (EBRD) to the Consultant Lahmeyer International with Perspectives as subcontractor on 16 July 2009.

It is a Baseline Study with the overall goal to calculate reliable carbon emission factors for Ukraine for the period from 2009 to 2020. These electricity carbon emission factors for the Ukrainian electricity system shall facilitate to derive the baseline scenario of future Joint Implementation (JI) project activities since the EBRD considers financing a large number of investment projects that will lead to energy efficiency improvements in terms of greenhouse gas (GHG) emissions reductions.

As per the work schedule the project was divided into three major work packages:

Work Package I:	**Data Review & Analysis**
Work Package II:	**Development of Power System Simulation Model & Baseline Studies**
Work Package III:	**Validation by Accredited Independent Entity**

The study includes a thorough data review and analysis under a long term perspective. This was executed in order to reliably simulate the development of the Ukrainian electricity system. Official data has been made available with support by the National Environmental Investment Agency (NEIA), Kiev, Ukraine, which also acts as National Focal Point for Joint Implementation.

A detailed list of the utilised data sources including their origin is provided in the annex.

With regard to the structure of the present Baseline Study, the following approach according to Figure 1-1 was pursued.

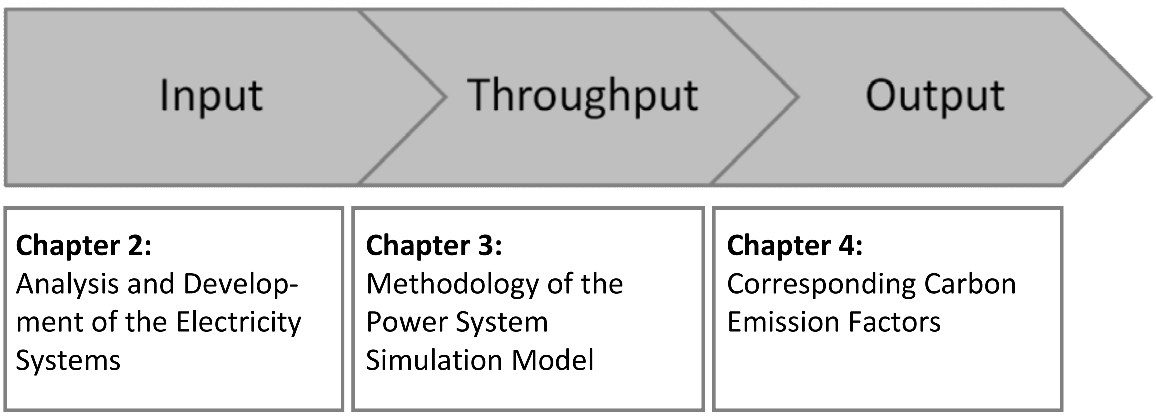


Figure 1-1: Structure of the Baseline Study

Accordingly, **Chapter 2** analyses and describes the present state of the electricity system in Ukraine, thus assessing the required input data for the calculation of the carbon emission factors.

Correspondingly, historic power generation and transmission capabilities in the respective system are outlined. Further on a demand analysis is conducted by assessing the overall load profiles vs. the expected electricity demand development for the period under consideration. Regarding the supply side the related subchapter deals with the analysis of the official investment program in order to facilitate a demand-supply-balancing. The envisaged electricity system's expansion plan is highlighted as well in this context.

Whereas the previous analysis forms the input data, **Chapter 3** describes in detail the underlying calculation method in terms of data throughput.

Since the resulting carbon emission factors shall facilitate to determine the baseline scenario for future JI project activities in Ukraine, their calculation has to be in full accordance with the official guidelines and calculation tools published by the United Nations Framework Convention on Climate Change (UNFCCC).

After having determined the applicable calculation method, the overall setup of the developed Power System Simulation Model is presented in detail in the following subchapter. Special emphasis is accordingly placed on the embedded dispatch analysis within the Model in order to facilitate the forecast of the most probable energy mix for the period between 2009 and 2020.

Chapter 4 presents the corresponding carbon emission factors for the Ukrainian electricity system after having simulated the power generation dispatch which was described previously.

The output of the Power System Simulation Model comprises:

- The forecasted load duration curves representing the future electricity demand;
- The forecasted energy mix representing the future electricity supply; and
- The resulting carbon emission factors.

The information is presented on an annual basis.

Finally, **Chapter 5** concludes the present study by summing up major project results and providing recommendations concerning the future application of the Power System Simulation Model with regard to continuous updating of the Model and its final utilisation by the users.

2 ANALYSIS AND DEVELOPMENT OF THE UNITED POWER SYSTEM OF UKRAINE

In the following a thorough analysis of the present state of Ukraine's electricity system is described. The analysis results serve as input parameters for the developed Power System Simulation Model in order to calculate the corresponding carbon emission factors as outlined in Chapter 3.

It is noted that in accordance with the already prepared Inception Report, which has been approved by the Client, Ukraine's United Power System (UPS) is taken into account as operated by the national power system operator, a subordinated body of the national power utility Ukrenergo.

Accordingly, the UPS in Ukraine was considered by the Consultant for all further calculations. Its geographical extent is provided in Figure 2-1 below.

Source: Ukrenergo

Figure 2-1: United Power System of Ukraine

In the following subchapters the current state and future development of the UPS is provided with regard to:

- Historic power generation and transmission;
- Demand analysis and forecast;
- Analysis of investment programs.

2.1 Historic Power Generation and Transmission

Being a member state of the former Soviet Union with a density of industrial agglomerations, the Ukrainian grid (see Figure 2-1) has significant overcapacity whereas a large number of power plants are either operating with a comparatively low capacity factor or have been moth-balled. Accordingly, overall capacity of all integrated power plants within the UPS, i.e. excluding plants which operate in isolated networks, amounted to roughly 50.2 GW in total in 2009.

Figure 2-2 provides a more detailed insight into the structure of the power plants operating in UPS Ukraine according to their power plant technology.

Accordingly, the share of conventional thermal power plants (TPP) amounts to almost 62% (30.9 GW) whereas nuclear power plants (NPP) amount to 27.5% (13.8 GW) of the installed capacity. Hydropower generation is ranked third with 5.5 GW of the installed capacity (11%).

Concerning overall power generation approximately 185,000 GWh were produced in Ukraine according to the most recent data. However the power output according to power plant technology differs considerably when compared to the installed capacity. Hence, nuclear power plants are clearly providing the base load of the electricity, adding up to an overall share of 48%. Thermal power plants supply the second largest share of power output, amounting to an almost equal share of 46% since a large overcapacity of fossil-fired power plants is still operating in the system. By contrast hydropower generation only contributes to around 6% of power output to the grid. It is thus only playing a marginal role within the country's electricity supply. Up to now other renewable energy sources (RES) did not make a considerable appearance.

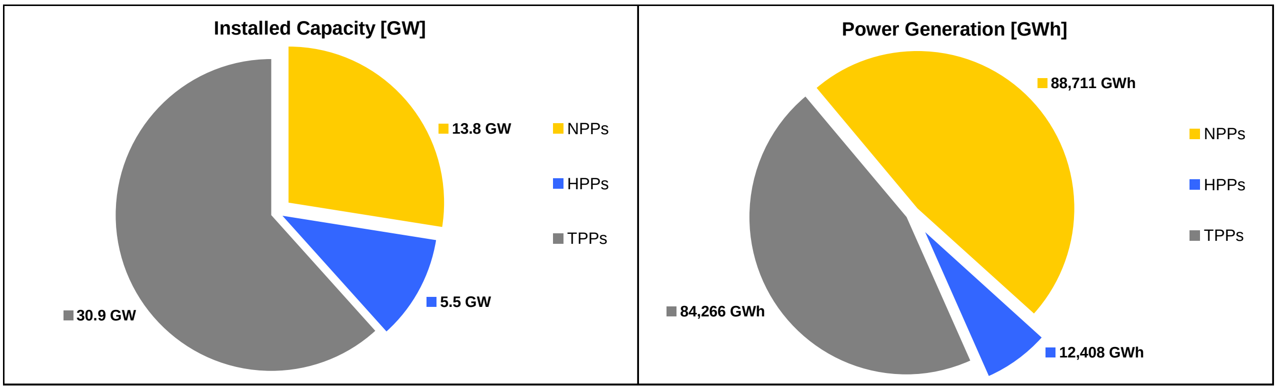


Figure 2-2: (a) Installed Capacity and (b) Power Generation in UPS Ukraine

Regarding the electricity transmission infrastructure in Ukraine, the grids are divided into different high-voltage classes in order to support the integral functioning of the underlying United Power System.

Hence, the high-voltage transmission grids in Ukraine are mainly formed by 110 to 750 kV transmission lines.

Due to its geographical location in Eastern Europe, Ukraine has constructed and is operating a large number of considerable high-power transmission lines of international importance which connect for instance the Western Ukraine with the European Network of Transmission System Operators for Electricity (ENTSO-E). Further connections of the Ukrainian UPS exist to the power systems of Russia, Moldova and Belarus for instance.

Bearing in mind above mentioned high-voltage classes, the transmission lines as presented in Table 2-1 are operated within the UPS of Ukraine amounting to an overall length of some 22,700 km.

Table 2-1: Length of Transmission Grids in UPS Ukraine

Length of transmissions grids [thousands km]

UPS	110 kV to 220 kV	330 kV	400 kV to 750 kV	TOTAL
Ukraine	4.6	13.2	4.9	**22.7**

With regard to historic electricity losses in the UPS of Ukraine, the most recent official figure was published in 2006 by the MFE and amounted to 13.1% of the overall electricity output in terms of technical losses.

However, due to the envisaged major investments in electricity infrastructure projects it is envisaged by the Ukrainian authorities to significantly decrease this value in the medium-term, see also the side note on Ukraine's Investment Program in Chapter 2.3.

2.2 Demand Analysis and Forecast

After having analysed the current state of power generation and transmission within the Ukrainian electricity system the following subchapter deals with most recent demand figures and forecasts in order to reliably estimate the future energy demand in the United Power System. Afterwards official investment programs are assessed in order to aim for an overall demand supply balancing.

Hence, a comprehensive electricity demand analysis was carried out which was based on official data being either publicly available by the national power utility Ukrenergo or that has been provided by Ukraine's Ministry of Fuel and Energy.

The analysis' results are summarised in the detailed fact sheet which is depicted in Figure 2-3 thereinafter.

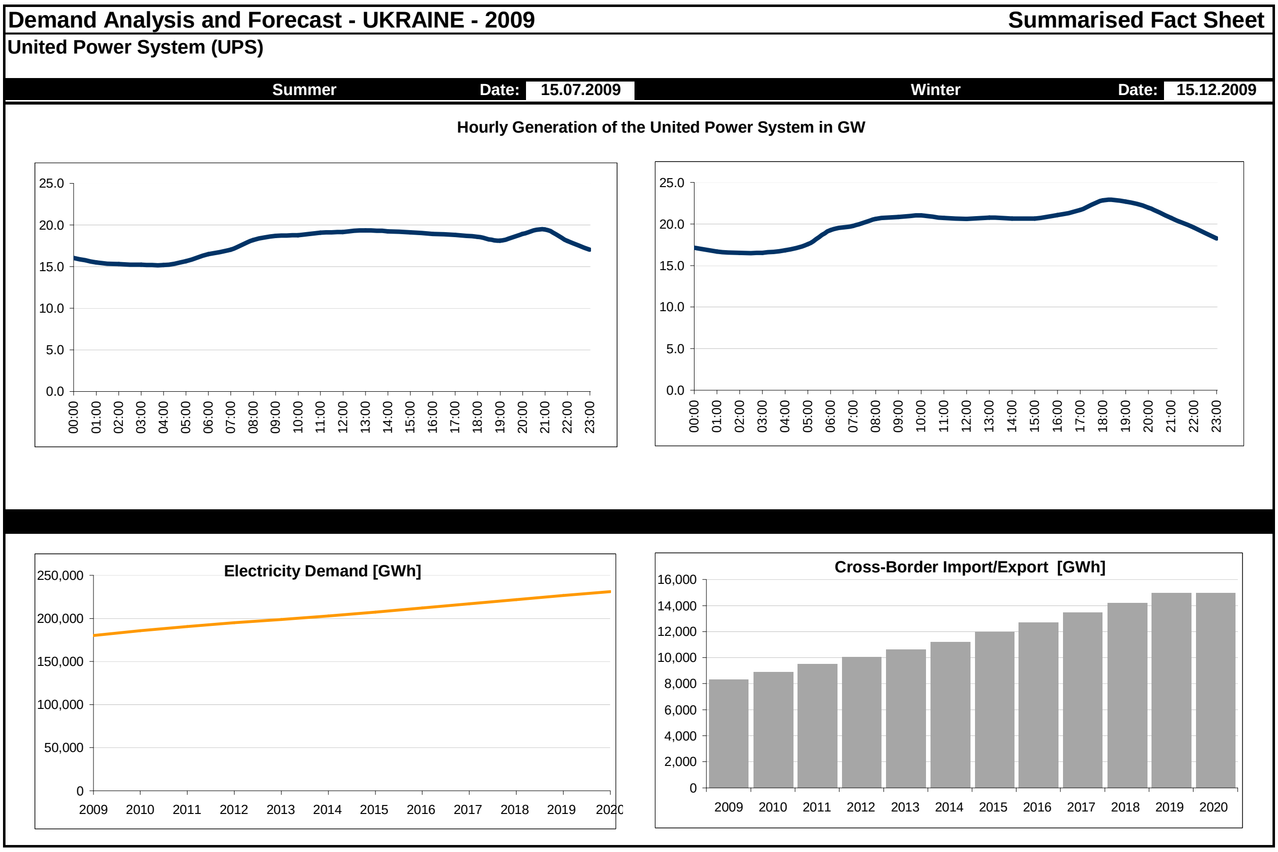


Figure 2-3: Demand Analysis and Forecast of UPS Ukraine

Figure 2-3 presents hourly generation curves which occurred in Ukraine during an exemplary working day in Summer and Winter 2009.

It is obvious that overall generation in summer tends to be lower than in winter when for instance the use of additional heating appliances increases the overall electricity demand. Moreover, a generation peak may be observed throughout the daily pattern in winter in the evening at around 6 p.m.

Further on, special emphasis is placed on both charts at the bottom of Figure 2-3.

The development of the overall electricity demand in Ukraine is provided therein which is based on official data. Accordingly, an average annual growth rate of 2.3% was projected for the period from 2009 until 2020. This value hence serves as important input parameter for the simulation of the future electricity demand and is therefore incorporated into the developed Power System Simulation Model, see Chapter 3.2. Moreover, cross-border imports and exports are also provided in the bottom charts implying that the UPS Ukraine remains a considerable net exporting grid throughout the period under consideration. It is moreover expected that the UPS of Ukraine exports an increasing amount of electricity into neighbouring electricity systems in the future.

Having thoroughly analysed the current and future electricity demand hitherto, the following subchapter accordingly deals with the electricity supply side in order to adequately cover the forecasted demand.

2.3 Analysis of Investment Programs

Despite the previously outlined overcapacities within the Ukrainian UPS new generation capacities are expected to come online in particular to replace inefficient power plants.

Hence, the expected increase of the peak load representing the future electricity demand and the retirement schedule of already operating power plants are considered in the following. Figure 2-4 (a) presents both developments for the Ukraine for the period from 2009 until 2020. The figure has been derived by analysing official investment plans which have been provided by the Ministry of Fuel and Energy. It can be seen that the currently installed and operating generation capacities cannot cover the forecasted peak demand beyond the year 2018.

With regard to Figure 2-4 (a) the aforementioned overcapacities become obvious in particular when compared to the expected peak demand curve. Nevertheless, a continuous decrease of such overcapacities is projected throughout the period under consideration. It is furthermore noted that the dashed line above the peak demand curve in Figure 2-4 (a) includes an additional 10% security margin in order to account for potential uncertainties. With reference to the expected peak demand including the security margin, new generation capacities would be required by 2016 according to the power plant retirement schedule.

In order to replace the inefficient and technically outdated power plants in the Ukrainian electricity system, additional investments in new constructions of state-of-the-art generation facilities are described subsequently.

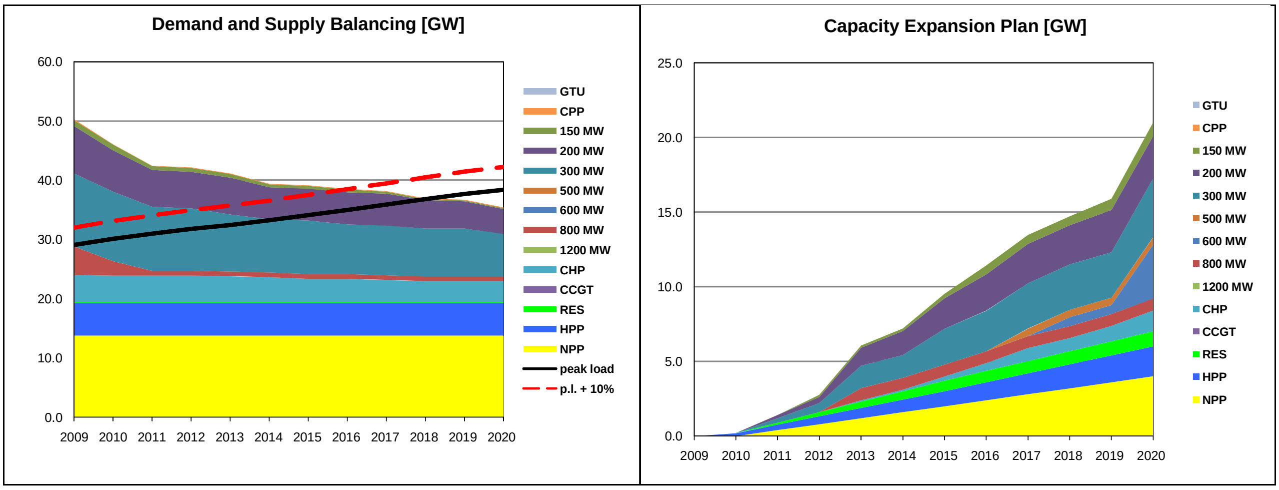


Figure 2-4: (a) Demand Supply Balancing and (b) Capacity Expansion Plan for UPS Ukraine

Accordingly, Figure 2-4 (b) summarises the capacity expansion plan for Ukraine.

Correspondingly, the implementation of above mentioned investments results in an overall capacity increase of 21 GW until 2020 in Ukraine in order to replace inefficient power plants. Furthermore, a variety of new power plant types are foreseen whereas capacity additions of CHP plants (12 GW of installed capacity in total) and nuclear plants (4 GW of installed capacity) contribute the largest share until 2020.

Side Note on Ukraine's Investment Program:

According to official investment plans published by the MFE in its "Energy Strategy of Ukraine for the Period until 2030" major investments in the power industry are outlined below.

However, it is noted that the subsequent list is not exhaustive:

- Modernisation, rehabilitation, improvement of operating nuclear power plants' safety and management;
- Extending operational lifetime of nuclear power plants;
- Commissioning new nuclear power units, hydro pumped storage power units and decommissioning of technically outdated units;
- Maintaining thermal power plant facilities by means of extending their operational lifetime, completion of pilot projects for the rehabilitation of TPP units, commissioning of new thermal facilities;
- Overall rehabilitation of TPP units, including the commissioning of new TPP units and mothballing of TPP units being inexpedient;
- Modernisation and development of power networks in view of expected interconnections to the United Power System of Ukraine.

The overall expected investments which have been announced for the Ukrainian power sector amount to approximately 500.6 billion UAH (~ 46 billion EUR) in total for the period from 2006 until 2030 based on the reference year 2006.

Summing up, the herein presented capacity expansion plan forms the basis for the simulation of the foreseen energy mix in Ukraine between 2009 and 2020. Accordingly, the corresponding carbon emission factors will be calculated by applying the data analysed in this present chapter as input.

In this context it is further noted that the underlying methodology for the simulation of the future energy supply scenario and its corresponding carbon emission factors are described in detail in the subsequent Chapter 3.

3 CALCULATION METHODOLOGY

Having thoroughly analysed the required input data for the calculation of the annual carbon emission factors in the previous chapter, the calculation methodology of the developed Power System Simulation Model is presented hereinafter.

Since the calculated carbon emission factors should facilitate the determination of baseline scenarios for the future development of Joint Implementation project activities in Ukraine, their calculation has to comply with official UNFCCC requirements, i.e. in particular a publicly available calculation tool.

Consequently, the structure of this present chapter first outlines the applicable UNFCCC "Tool to calculate the emission factor for an electricity system"[1] in its most recent version 02 dated 16 October 2009 and the applicable calculation method chosen by the Consultant.

Secondly, the setup and underlying calculation principles of the developed Power System Simulation Model, which was programmed in MS EXCEL, are explained in detail to provide a comprehensive insight into the assumptions and especially the processing of the analysed data.

It is noted that the subsequently described calculation methodology was presented to and approved by the assigned Accredited Independent Entity (AIE), TÜV SÜD[2].

In this regard the calculation methodology was also presented to and confirmed by NEIA during the intermediate meeting in Kiev.[3]

3.1 UNFCCC Calculation Method

The UNFCCC "Tool to calculate the emission factor for an electricity system, version 02" (in the following referred to as the UNFCCC Tool) was basically developed in the context of project activities under the Clean Development Mechanism (CDM). However, since the official UNFCCC CDM Baseline & Monitoring Methodologies and their related Methodological Tools are also applicable under the JI scheme, said UNFCCC Tool is applied in the following as official calculation method for the derivation of eligible carbon emission factors.

3.1.1 General Calculation Methodology

The general methodology for the calculation of carbon emission factors consists of a combination of the "Operating Margin" emission factor (OM) and the "Build Margin" emission factor (BM) in order to adequately estimate emissions in absence of a CDM or JI project activity.

For the calculation of the OM four different approaches can be used accordingly. Based on the data available and as mutually agreed with NEIA and TÜV SÜD in its role as Accredited Independent Entity, the **simple adjusted OM** is selected to calculate the carbon emission factors for Ukraine. This calculation method accordingly allows for a separate consideration of low-cost/must-run power plants in the electricity systems, which are defined as:

- Power plants with low marginal generation costs; and/or
- Power plants that are dispatched independently of the daily or seasonal load.

[1] Refer to UNFCCC (http://cdm.unfccc.int/index.html)
[2] An initial meeting was held on 12 January 2010 followed by conference calls.
[3] Minutes of Meeting (MoM) were prepared dated 12 March 2010.

Typically low-cost/must-run power plants include nuclear power plants, hydropower plants and other renewable power generation facilities. However, in the case of the Ukrainian electricity system, a major share of conventional thermal power plants is operated as must-run power plants as well since they supply heat in combined heat and power (CHP) operation mode for district heating purposes during the winter period.

Within the simple adjusted OM such low-cost/must-run power plants are considered separately, implying that their contribution to total grid generation is equal or higher than 50%.

Accordingly, the simple adjusted OM is calculated using the following equation:

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

Where:

$EF_{grid,OM-adj,y}$	Simple adjusted operating margin CO_2 emission factor in year *y* [tCO_2/MWh];
λ_y	Factor expressing the percentage of time when low-cost/must-run power plants are on the margin in year y [%];
$EG_{m,y}$	Net quantity of electricity generated and delivered to the grid by power unit *m* in year *y* [MWh];
$EG_{k,y}$	Net quantity of electricity generated and delivered to the grid by low-cost/must-run power unit *k* in year *y* [MWh];
$EF_{EL,m,y}$	CO_2 emission factor of power unit *m* in year *y* [tCO_2/MWh];
$EF_{EL,k,y}$	CO_2 emission factor of power unit *k* in year *y* [tCO_2/MWh].

The crucial parameter λ_y, which allows for a differentiation between low-cost/must-run power units and other dispatchable power units, is obtained as follows:

$$\lambda_y = \frac{Number\ of\ hours\ low-cost/must-run\ sources\ are\ on\ the\ margin\ in\ year\ y}{8760\ hours\ per\ year}$$

Further on, the BM has been calculated. It assumes that recently built power plants are indicative for future capacity additions to a respective electricity system. It shall thus represent recent developments within the electricity system, especially in which the installed generation capacity is increasing.

In accordance with UNFCCC requirements the sample group of power plants comprising the build margin consists of either:

(i) The set of five power units that have been built most recently; or

(ii) The set of power capacity additions in the electricity system that comprise 20% of the system generation and that have been built most recently,

whichever comprises the larger annual power generation.

The BM is accordingly calculated as follows:

$$EG_{grid,BM,y} = \frac{\sum_{m} EG_{m,y} \times EF_{EL,m,y}}{\sum_{m} EG_{m,y}}$$

Where:

$EF_{grid,BM,y}$	Build Margin CO_2 emission factor in year *y* [tCO_2/MWh];
$EG_{m,y}$	Net quantity of electricity generated and delivered to the grid by power plant *m* in year *y* [MWh];
$EF_{EL,m,y}$	CO_2 emission factor of power unit *m* in year *y* [tCO_2/MWh].

After having calculated the OM and BM carbon emission factor, the overall carbon emission factor which constitutes the applicable baseline scenario in a respective electricity system is defined as the Combined Margin (CM) and calculated as per the following equation:

$$EG_{grid,CM,y} = EF_{grid,OM,y} \times w_{OM} + EF_{grid,BM,y} \times w_{BM}$$

Accordingly, the CM carbon emission factor is derived by combining the OM and BM under consideration of respective weighting factors. In accordance with the UNFCCC Tool the weighting factors w_{OM} and w_{BM} are determined to be equal by default where $w_{OM} = 0.5$ and $w_{BM} = 0.5$. However, other weighing factors can be applied within the Model (e.g. for wind and solar power projects).

As outlined above the UNFCCC calculation guideline forms the backbone for the setup and, moreover, the calculation mode of the developed Power System Simulation Model. The Model's structure is presented in the following subchapter, whereas special emphasis is placed on the required dispatch analysis in order to forecast the most realistic power supply scenario for the period under consideration.

3.1.2 Statements regarding Specific Issues defined in the UNFCCC Tool

Regarding some specific detailed issues for the calculation of the emission factors, the UNFCCC Tool provides options or encourages the user to provide an own approach. In the following, statements are made regarding the different issues:

<u>Retrofits:</u>

In case of a retrofit, the user may replace an existing power generation unit by adding the retrofitted power generation unit again into the list of power plants (including improved efficiency/capacity). However, to avoid double counting of capacity additions resulting from retrofits within the BM, the original commissioning date of the specific power generation unit remains unchanged.

Reference: UNFCCC Tool, p. 14: *"As a general guidance, a power unit is considered to have been built at the date when it started to supply electricity to the grid.*"

Reference: UNFCCC Tool, p. 15: *"Capacity additions from retrofits of power plants should not be included in the calculation of the build margin emission factor.*"

<u>JI (CDM) projects:</u>

The Model offers the option to mark TPP, HPP and RES power plants as JI projects. These marked power generation units are considered specifically within the identification of the units for the theoretically calculated BM (see Chapter 3.2).

Reference: UNFCCC Tool, p. 14 and p. 15: "*Power plant registered as CDM project activities should be excluded from the sample group m. However, if the group of power units, not registered as CDM project activity, identified for estimating the build margin emission factor includes power unit(s) that is(are) built more than 10 years ago then: (i) Exclude power unit(s) that is (are) built more than 10 years ago from the group; and (ii) Include grid connected power projects registered as CDM project activities, which are dispatched by dispatching authority to the electricity system.*"

<u>BM calculation for Ukraine:</u>

With regard to the calculated ex-ante Carbon Emission Factors for Ukraine, only the calculated Operating Margin shall be considered as applicable baseline scenario.

The Ukrainian electricity system is characterized by a large overcapacity. Therefore, the share of the recently built units for the last 5 years is significantly less than 20 % of the system generation (in MWh). Furthermore, the time period that corresponds to the construction of the most recent 20% of total system generation is of about more than 25 years and has limited representativeness of the expected technology and fuel mix of the Build Margin power plants.

The UNFCCC Tool assumes that a JI project activity will substitute existing power production (OM) and/or will avoid the construction of new plants (BM). However, in Ukraine the BM is mainly based on new nuclear power plants which are part of the low-cost/must-run plants. It is unrealistic to assume that a JI project will avoid the construction of these power plants or having them produce less electricity. Hence, from a methodological point of view the BM shall be excluded since the representativeness of the Build Margin units in the total installed capacity in Ukraine is very limited or none.

Reference: UNFCCC Tool, p. 14, footnote 6: "*If this approach does not reasonably reflect the power plants that would likely be built in the absence of the project activity, project participants are encouraged to submit alternative proposals for consideration by the CDM Executive Board.*"

<u>Consideration of imports:</u>

The Model is based on the principle that all emissions are counted for one electricity system which are actually emitted within this very electricity system. This means, that electricity exports are added to the load and their respective emissions are counted within the considered electricity system. Following this principle electricity imports are counted with zero emissions.

Reference:

UNFCCC Tool, p. 4: "*[…] determine the CO_2 emission factor(s) for net electricity imports […] [with] 0 tCO_2/MWh*" (option (a)).

This rule is applied for intra-national (if applicable) as well as cross-border imports.

Aggregation and distinction of power plants:

In order to reduce complexity due to the large amount of power generation units installed in the Ukrainian electricity system, similar power generation units at one site are clustered as one power plant according to their technology, capacity, fuel and efficiency. Since this clustering is based on the rules stipulated in the UNFCCC Tool the so derived power plants are called "UNFCCC power plants" within this Baseline Study.

Reference:

UNFCCC Tool, p. 1: *"A power plant/unit is a facility that generates electric power. Several power units at one site comprise one power plant […] ."*

Consideration of offgrid power plants:

In order to forecast the grid emission factor of Ukraine's unified electricity system, IPS Ukraine, offgrid power plants are not considered.

Reference:

UNFCCC Tool, p. 4: *"Project participants may choose between the following two options to calculate the operating margin and build margin emission factor: Option 1: Only grid power plants are included in the calculation."*

Fuels:

For the net calorific values as well as the fuel emission factors the corresponding IPCC default values are used.

In case a power unit utilises more than one fuel, only the fuel type with the lowest CO_2 emission factor is considered.

Reference:

UNFCCC Tool, p. 20 + p. 21: "*IPCC default values at the lower limit of the uncertainty at a 95% confidence interval as provided in table 1.2 [and table 1.4] of Chapter 1 of Vol. 2 (Energy) of the 2006 IPCC Guidelines on National GHG Inventories.*"

UNFCCC Tool, p. 8: *"Where several fuel types are used in the power unit, use the fuel type with the lowest CO_2 emission factor […]."*

Hydropower plants:

Since pumped storage hydropower plants in Ukraine represent only marginal installed capacity, they are considered in this particular case amongst the general category of hydropower plants. This approach follows the official approach of the Ukrainian National Energy Strategy 2006 in Section III p. 26.

Utilisation of sources:

Generally, only official and/or publicly available data has been used for the calculation of the emission factors. However, in order to evaluate the quality of the data, these data have been cross-checked with Lahmeyer International's internal information.

3.2 Setup of the Power System Simulation Model

After having described the theoretical fundamentals of the carbon emission factor calculation defined by the UNFCCC Tool the present chapter focuses on the structure as well as on the principles of the Power System Simulation Model. Whereas the UNFCCC Tool provides guidance for the calculation of the carbon emission factor ex post (i.e. based on historic data), the purpose of the present study consists in applying such guidance by elaborating a forecast of the most probable development of the carbon emission factor of the Ukrainian power system.

Subchapter 3.2.1 gives a detailed overview on the general structure of the Power System Simulation Model whereas in the subsequent subchapters underlying principles of the calculation mode are explained.

3.2.1 General Structure

The UNFCCC Tool stipulated a guideline on how to calculate historic carbon emission factors of electricity grids actually realised. The UNFCCC Tool thus defines rules for the calculation of those grid emission factors ex post, i.e. all values concerning historic grid loads, power plant operation data (e.g. annual generation, total amount of CO_2 emissions), commissioning and retirement of power units are already existent and serve as input parameters for the calculation.

However, the objective of the present study is to provide a forecast on the most probable development of the grid emission factor of the Ukrainian power system. This forecast is further on referred to as “ex ante” calculation in order to distinguish it from the ex post calculation as described above.

The result of this study shall furthermore not only be limited to the forecast of the grid emission factor, but also focuses on the Model which enables the user to recalculate the emission factor on an ongoing basis. As already described the guidelines of the UNFCCC Tool refer to past years and do not aim for forecasted values. Nevertheless, the Power System Simulation Model shall also enable the calculation of binding grid emission factors. Due to this fact, the Consultant decided in accordance with the Client and the assigned Independent Entity to integrate the ex post calculation into the Model, which enables the exact calculation of historic grid emission factors in accordance with the UNFCCC rules. This basic structure of the Model is shown in Figure 3-1.

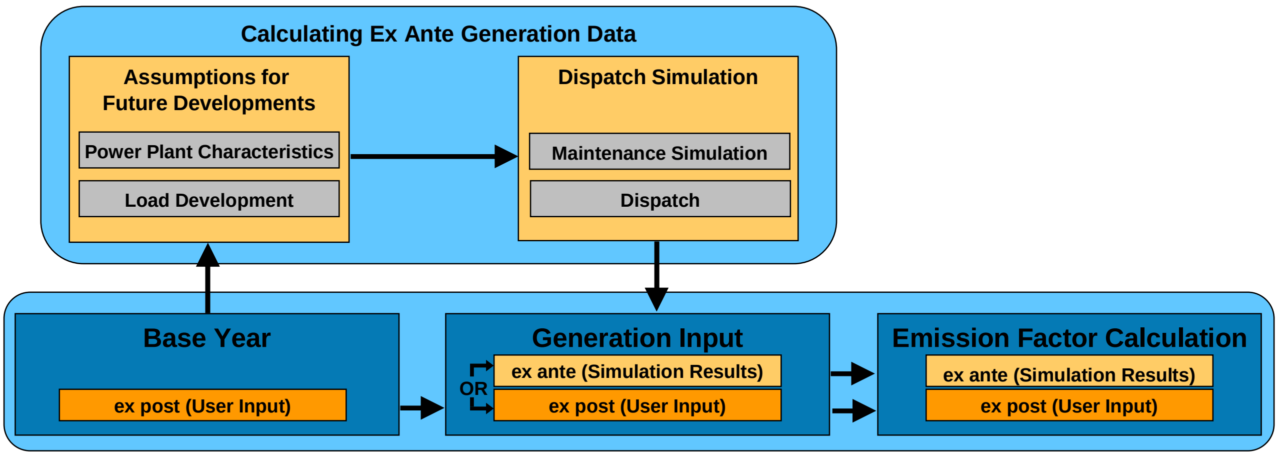


Figure 3-1: Basic Structure of the Power System Simulation Model

Accordingly, the Model disposes of a dynamic carbon emission factor calculation which is used for ex post calculation and ex ante (in terms of a forecast) calculation. The difference thus relies in the nature of the implemented parameters. Since for historic years all input parameters already exist, they have to be input into the Model and the Model computes the exact carbon emission factor based on the input values. For the forecast (ex ante) the required input parameter are not realised yet by contrast.

For this reason, the Power System Simulation Model takes into account official forecasts of the development of the power system, such as installed capacity, technologies, efficiencies, fuels, dispatch behaviour, commissioning and retirement of power units, forecasts for domestic electricity demand as well as imports and exports. As a function of these parameters the Power System Simulation Model simulates the operation of the power system with all its units. The results of this simulation represent the input parameters for the consecutive calculation of the carbon emission factor following the approach provided by the UNFCCC Tool as described above. In other words: The Power System Simulation Model generates input parameters for the future which are required to calculate the carbon emission factor. The calculation of the ex ante carbon emission factor is then conducted based on the same principles with the same equations and structure as the Model utilises for the ex-post calculation (compare Chapter 3.1.2).

The principal structure of the Power System Simulation Model's data processing is shown in Figure 3-2:

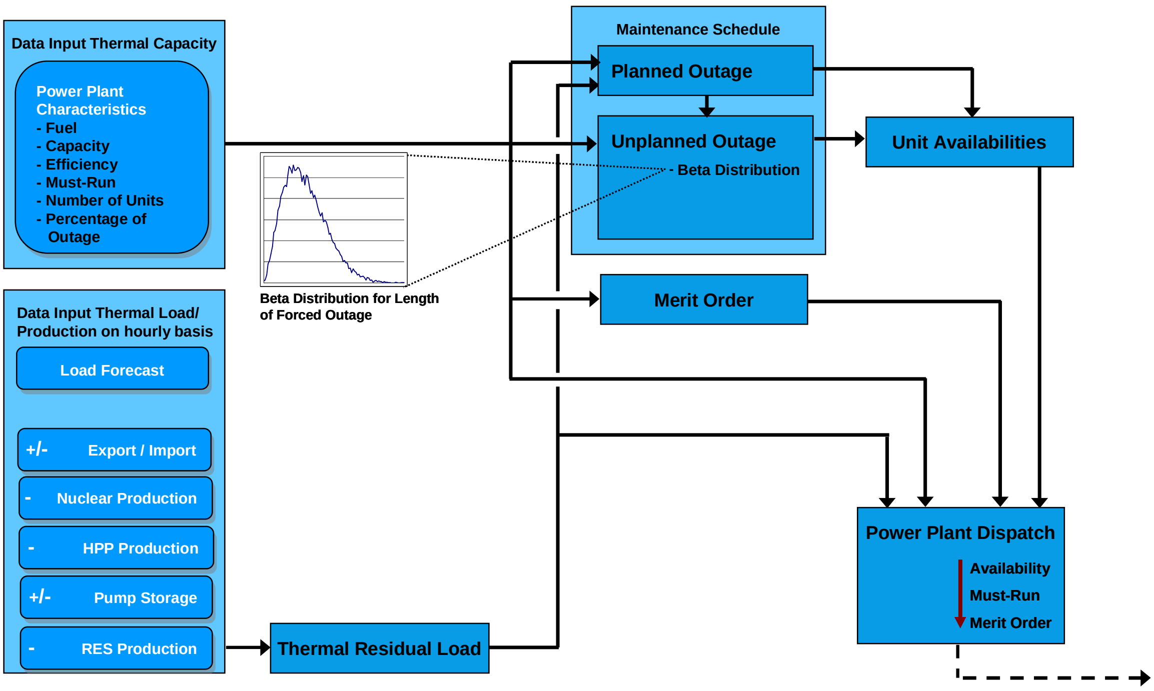


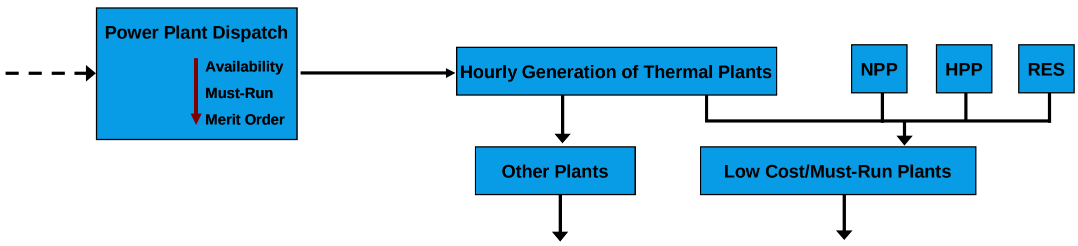
Figure 3-2: Data Processing Structure of the Power System Simulation Model

As described earlier, the Model requires several input parameters concerning the characteristics of existing as well as to be commissioned power units until 2020. Additionally, information regarding the electricity demand (e.g. hourly load curve, annual electricity demand) as well as the import/export profile is needed in order to forecast the entire load of the power system for each hour of the forecasted year. This electric load has to be supplied by the means of all generating units available. In doing so, the generation of nuclear power plants (NPP), hydropower plants (HPP), pumped-storage hydropower plants (PSH) and renewable energy plants (RES) is deducted from the entire load. The resulting residual load has to be covered by the conventional thermal power plants (TPP), resulting in the “Thermal residual load”. A detailed description of this process and the generation profiles of each type of power plant technology is given in the next subchapter.

By utilising information about planned maintenance and forced outage rates of each power unit, the maintenance schedule is computed. In parallel, the Model defines the merit order of the thermal power plants according to their generation costs on a qualitative basis (for a detailed description see next subchapter).

As a function of all these information, the dispatch of the thermal power plants is performed while respecting operation restrictions, such as must-run, spinning reserve operation as well as technical minima of the power units.

As a result of the dispatching the annual generation and the herewith associated emissions are calculated. According to the rules of the Simple Adjusted OM calculation (see Chapter 3.1), thermal power plants are distinguished between low-cost/must-run plants and other plants. Since the generation of nuclear as well as hydropower plants represents a low-cost source of energy, their generation is considered as low-cost/must-run generation. The same approach is applied for renewable energy plants. As their power output cannot be dispatched, they represent must-run generation. The emissions of the low-cost/must-run power plants are thus divided by the sum of the entire low-cost/must-run generation in order to calculate the second term of the carbon emission factor equation according to the Simple Adjusted OM method. This process is depicted schematically in Figure 3-3.



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

Figure 3-3: Data Processing Structure for the Carbon Emission Factor Calculation within the Power System Simulation Model

The following section theoretically describes the calculation of the Build Margin. However, it is noted that the calculated Build Margin is not considered in Ukraine as defined in Chapter 3.1.2.

Regarding the Build Margin calculation in theory, the Model looks back into the history of the recently commissioned power units based on the commissioning years of the respective power units. In line with the UNFCCC Tool, the most recent power units which in sum generate more than 20% of the annual entire generation of the power system are identified. The emissions and the generation of these power plants are taken into account when calculating the BM emission factor according to the principles described in Chapter 3.1.

Consequently, the Combined Margin emission factor is calculated as the weighted average (see Chapter 3.1) of the Operating Margin and the Build Margin emission factor.

The approach stipulated above considers the supply-side carbon emission factors. Furthermore, the Model offers the option to compute the demand-side carbon emission factors in accordance with the CDM "Tool to calculate baseline, project and/or leakage emissions from electricity consumption, version 01". Supply-side carbon emission factors are converted by applying technical loss figures of the electricity system.

3.2.2 Forecast of Residual Load supplied by Thermal Power Plants

In order to forecast the electric load for a future year, the Model requires two input parameters: Firstly, the hourly load profile for one year ("base year") is needed. Secondly, the forecast of the entire annual generation is needed. The respective forecasts are on the basis of consumption at "sent-out" level. "Sent-out" refers to the respective busbars of the power plants. This means, that actual losses consumed in the electrical grid ("technical losses") as well as non-technical losses, e.g. theft of energy, are already incorporated i.e. deducted in these forecasts. The hourly load curve of the base year is scaled with the annual consumptions at sent-out level in order to get a forecast of the load curve for the corresponding year. With this approach, not only the targeted annual energy demand is met but also the characteristic consumption patterns are transcribed to the future years, in particular the time and the height of peak load.

For Ukraine the hourly load curve (sent-out level) is given for domestic load. Exports are given as annual amount of energy. This annual amount was divided by the sum of annual hours as it is considered as base load. This approach is in line with representative monthly figures given by Ukrenergo.

For the purpose of this study, 2009 is regarded as base year because this year represents the last historic year, for which most of the data is available as exact realised values or at least as exact values for the first half year with prognostic continuation for the entire year. Nonetheless, the Model is designed in that way, that users can change the base year to a year for the period under consideration, e.g. to 2012. This ensures that the now calculated emission factor forecast based on official forecast data of the power system from 2009 can be continuously updated with later official data, which will be more precise since the actually forecasted year will be closer and less uncertainty will prevail in these official forecasts.

As the final objective of this study is the evaluation of grid emission factors, non-emitting power plants are looked at on an aggregate basis. This approach is plausible due to several aspects: Since nuclear power plants (NPP) can hardly be ramped up and down, their generation represents base load generation. By this reason, their officially forecasted power generation for future years is modelled so as to provide constant base load power during the entire year. For this reason, they can be aggregated as a "single big" virtual nuclear power plant. The same can be applied for renewable energy sources: Since their share in installed capacity is very low (< 0.1%) the shape of their generation has only a marginal influence on the generation of the other power plants.

The objective of pumped-storage hydro power plants is to perform peak-shaving in order to allow for a more economical operation of thermal power plants. Since the levelised electricity costs of peaking power plants are always rather expensive, PSH plants can thus enable economies by flattening the residual load for the thermal plants. By reason of the diurnal seasonality of peak and off-peak times (diurnal load pattern), PSH plants are typically operated to provide for a day-night shifting. Within this context, PSH plants are thus modelled in that way, to reduce the annual load during peak times. Based on officially forecasted annual generation and charging values, these values are broken down to their respective daily values and then put into the diurnal load curve whenever peak times (and off-peak times respectively) occur while respecting their maximum rated capacity. Figure 3-4 shows an exemplary operation of a PSH plant for one day.

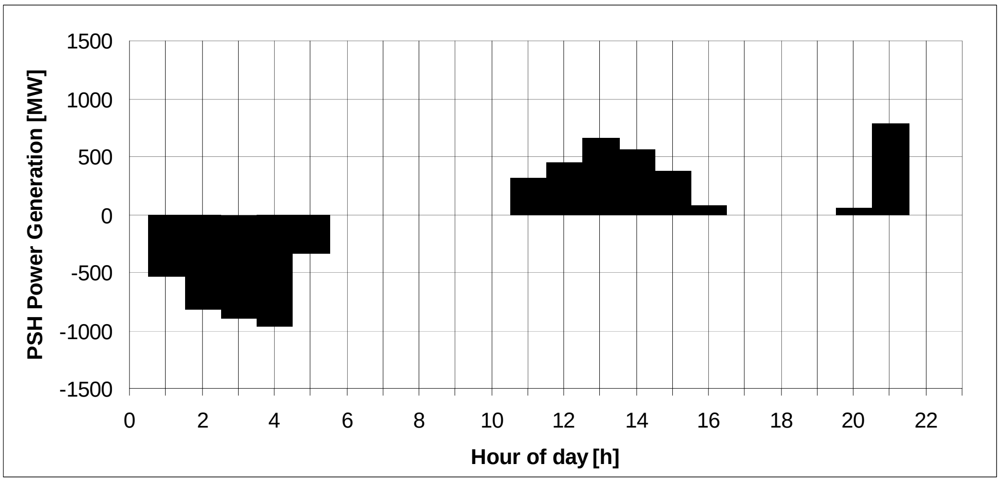


Figure 3-4: Pumped-storage hydro power plant production and charge for a sample day

The operation of hydro power plants is similar to the one of pumped-storage hydro power plants. Since their primary energy is there anyways (renewable character) and its accession can be controlled very easily, hydro power plants represent optimal peaking power plants. Hence, hydro power plants are dispatched so as to flatten the load curve in order to reduce peaks. Besides river barrage HPPs there are also run-of-the-river HPPs (mostly smaller) without storages capabilities. These plants provide base load generation throughout the day. Based on publicly available information the base component accounts for 65%, the peaking component for 35% in terms of daily generation. Figure 3-5 shows the daily operation of hydro power plants on a sample day.

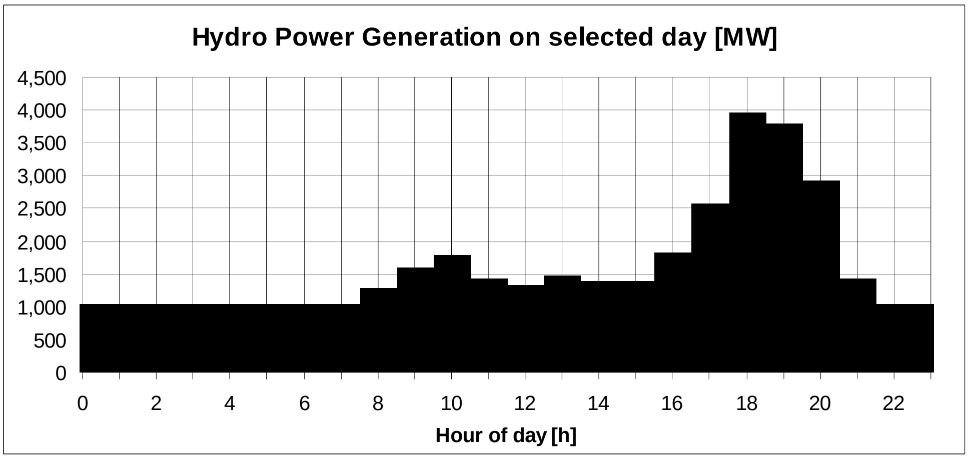


Figure 3-5: Hydro power plant production for a sample day

Due to seasonal variations in the hydrology of the water intakes of the HPPs, intra-annual distribution of hydro power production has been evaluated based on Lahmeyer's country expertise. The seasonal hydroelectric generation pattern is assumed 20%-30%-20%-30%. These values were verified by interviews with local experts. In addition, the effect on the annual total emissions of the entire system is only marginal.

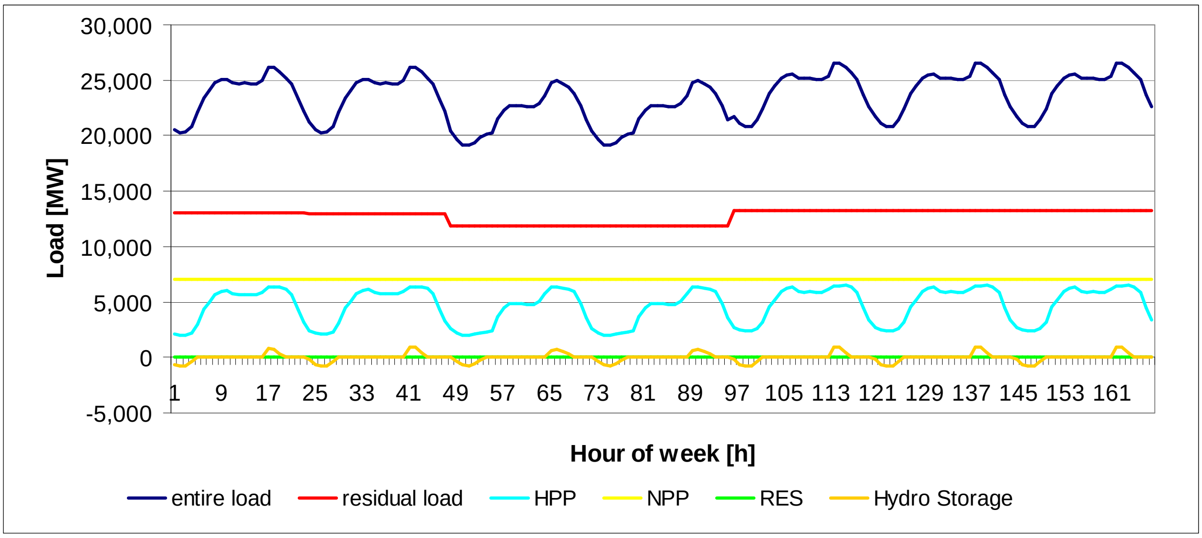


Figure 3-6: Relation of load curves for one sample week

Following the approach described in the previous subchapter, the generation of NPPs, RES, HPPs and PSHs is deducted from the entire grid load. The so formed load curve is called "residual load curve". The residual load curve in conjunction with the entire load curve and the curves which are considered for the transfer from the entire to residual load are demonstrated in Figure 3-6. This resting load has then to be supplied by thermal power plants. Their operational behaviour is described in the following two subchapters.

3.2.3 Maintenance Scheduling

In general, power unit unavailability consists of two different kinds of outages: Planned outage and forced outage. Planned outage is the annual maintenance period in which general repair and general overhauls are made. Forced outage is the uncertain, not schedulable unavailability of power units. In order to simulate the carbon emission factor with the dispatch calculation, the consideration of future power unit availability is strictly necessary.

The rules for the forecast of planned outages in this study are defined as follows:

30% of the units, beginning at the largest capacity, are planned to be serviced during low electricity demand months. In order to identify a low electricity demand period, a moving average over the hourly electricity consumption for the next three months is calculated and the minimum consumption hour identified. In this hour the intensive service period will start. In that period the above mentioned largest units are served. All other units will be serviced throughout the year. The duration of the planned maintenance will be 10% of the year, namely 876 hours.

In order to simulate the uncertain forced outage the following assumptions are made:

The longer one specific power unit is available, the larger is the possibility that a forced outage will occur. Once the unit is unavailable this will be the case at least for the next 4 days. Afterwards the possibility rises that the unit will become available again the longer the unit is unavailable.

Within the Model, first the planned maintenance schedule is set and afterwards the simulation of random outages is run, based on the already set planned maintenance periods. The result is an assembly of power unit availabilities on an hourly solution.

3.2.4 Merit Order & Power Plant Dispatching

The operation of the power plants is determined by economic as well as technical criteria. Whereas the generation hierarchy is determined mainly by economic parameters, the actual operation of so ordered power units follow technical rules.

The economic criterion consists in always supplying the instantaneous electricity demand with economically optimal combination of the available power plants. This objective is realised in the so-called “merit order” principle which orders the power plants according to their incremental cost of power generation. For calculating the emission factor by simulating the operation of the power system the Short Run Marginal Costs (SRMC) are considered on a qualitative basis. The merit order curve first considers the type of fuel, since the fuel expenditures make up for the largest cost component in SRMC. Secondly, the sizes of the power units are taken into account. Since large-scale power units are able to allow for economies of scale, their incremental cost of power generation or Levelised Electricity Cost (LEC) is lower than a similar power unit with a smaller installed capacity.

Hence, the installed capacity constitutes the second criterion within the setup of the merit order curve. The third criterion takes into account the average efficiency of the power units, which determines how efficient the fuel is used in order to generate electricity.

For the calculation of the emissions in an hour h of specific power plant j two separate plant efficiencies are taken into account. The ambient conditions determine essentially the efficiency of the combustion process as well as the turbine operation. However, the main driver of the efficiency is constituted by the temperature. Bearing in mind the large temperature differences in Ukraine due to the continental climate, the Model reflects these circumstances by the application of a specific efficiency during summer as well as a specific efficiency during winter. Moreover, combined heat and power plants have to extract a specific amount of steam for supplying district heating. Since a lower amount of hot steam can be used for electricity generation, the efficiency increases. The efficiencies of each power unit are either taken from technical data sheets or have been provided by authorities.

The technical criteria consist in a set of different restrictions which influence the operation of the power units:

Firstly, must-run restrictions force the power unit to always generate its rated power output because of combined heat and power mode for instance. Depending on the type of turbine they have either a fixed ratio of heat generation towards electricity generation (i.e. backpressure turbine) or they are condensing power plants with a flexible point of extraction (i.e. extraction condensing turbine). Since backpressure turbines either produce heat and electricity in fixed operation mode, they are obliged to also generate their rated electricity output. Extraction condensing turbines are more flexible because the point of steam extraction out of the turbine may be altered. Hence, they are not forced to always run at their electrical rated power. Nevertheless, since the heat demand in Ukraine is high during winter, both types of turbines have to produce their maximum heat output and thus run electrically at 100% of their rated power. During summer, heat demand is lower but still existing. By this reason, the backpressure turbines still have to run at 100% of their rated electric power whereas the condensing extraction turbines are not forced any more to produce their maximum heat output. They can keep the steam inside the turbine and use it for electricity production which enables a higher electric efficiency. During summer their electric must-run capacity counts for 40%.

The second technical restriction is composed by the technical minimum of each power unit. No thermal power unit can reduce its electric output to ranges around zero. The respective technically minimal output depends on the fuel. Coal units can reduce their power down to 50% of their rated capacity, gas units down to 30% of their rated capacity.

The third technical criterion consists in the spinning reserve. Power systems require balancing power. Hydropower plants and pumped storage hydropower plants can supply secondary and tertiary reserve power, depending on the delay in which power is needed. However, for a stable operation of a power system primary reserve power is needed within seconds or even smaller intervals. In this context the spinning masses of conventional thermal power turbines represent good means in order to balance electric power. By regulating the amount of steam that is flowing from the boiler into the turbine, the electrical power can be equilibrated. Thermal power plants represent thus the backbone of the power systems' frequency control. Due to this fact, the Model considers an operation of all thermal power units at maximum 90% of their rated electric power. Only in case the load increases the thermal power plants are operated up to their rated capacity.

3.2.5 Monte Carlo Simulation

Since the simulation of the forced outage of each power unit is described by stochastic processes, the actual availability of a specific power unit *j* in a specific hour *h* of the year is not deterministic. In other words: In each simulation run the availability of the unit *j* in the hour *h* can change as a function of the defined stochastic processes. Every simulation run could constitute a possible state, which will be realised in reality with a specific probability. The availability of each power unit thus influences the resulting carbon emission factor.

In order to describe the most probable operation of the power systems for forecasting the most probable development of the carbon emission factor, a Monte Carlo Simulation is performed. The Monte Carlo Simulation simulates a sufficiently high number of possible operations of the power system as well as the carbon emission factors. With this interrelation frequencies can be calculated that describe the probability of the development of the carbon emission factor.

In the course of the development of the Power System Simulation Model it has been found out, that the impact of the availabilities of the power units on the actual development of the carbon emission factor is relatively low.

Especially the Operating Margin is hardly influenced by the units' availabilities. In few cases the availabilities can change the annual generation of single power units in that way, that the composition of the Build Margin changes. In theses specific cases the Build Margin can deviate from the value realised in the majority of the cases. However, these deviations are relatively seldom. The maximum deviation of the Combined Margin emission factor in the Ukraine of 0.33% occurs in 2009. The standard deviation in UPS Ukraine counts for 0.21%. Due to this observation it has been found that the number of one hundred simulation runs per system per year is sufficient in order to calculate the most probable development of the annual carbon emission factor.

The described value which is realised in the majority of the cases is expressed by the median of the distribution of the one hundred simulations. Nevertheless, for the sake of completeness the corresponding minimum and maximum values are presented in order to provide an overview on possible ranges of the corresponding carbon emission factor.

4 POWER GENERATION DISPATCH AND CORRESPONDING CARBON EMISSION FACTORS

Whereas Chapter 3 focussed on the methodology of the dispatch analysis as well as on the rules of the calculation of the carbon emission factors, Chapter 4 presents the results of the conducted power system simulations and calculations.

For the Ukrainian electricity system, firstly the forecasted electricity demand and particularly its load curve are presented, followed by a description of how this demand is being satisfied. For this purpose exemplary diurnal generation dispatch profiles are shown as well as the development of the annual energy generation mix.

With this information about the future operation of the respective electricity system, the carbon emission factors have been calculated. These are presented in Chapter 4.3.

4.1 Forecasted Load Duration Curves

The load curves of future years have been forecasted following the methodology described in Chapter 3. Exemplarily, the simulated load curve of 2012 is depicted in Figure 4-1.

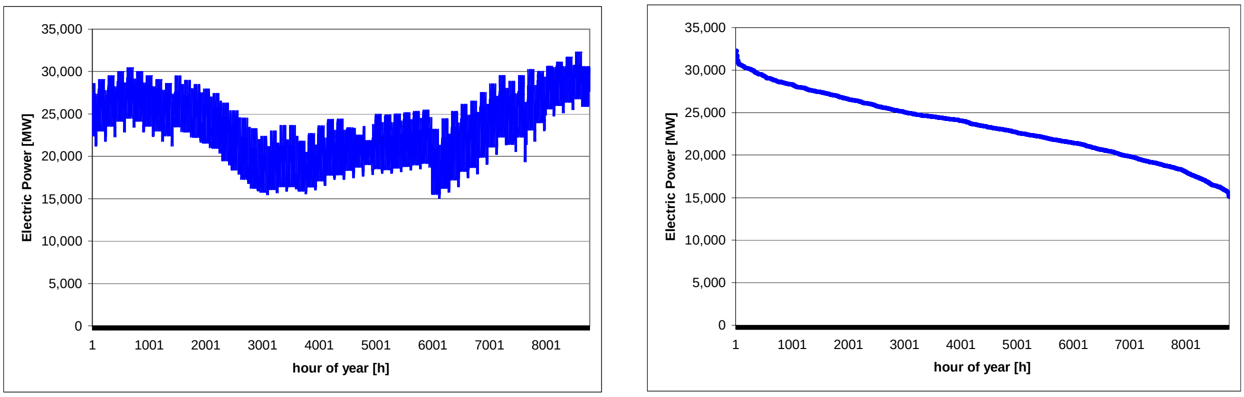


Figure 4-1: (a) Forecasted hourly load curve for 2012 inclusive imports/exports and (b) corresponding hourly load duration curve

Due to missing hourly load data, this forecasted load curve was synthetically generated with eight representative days (one working day and one weekend day for each season) and the monthly peak load measured in 2009, which was made available by Ukrenergo.

Annual as well as daily and weekly seasonal patterns can be observed. Correspondingly, the load in summer months is lower compared to the one during winter. Depending on daytime as well as on the weekday the mean grid load counts for approximately 17,000 MW to 22,000 MW, whereas the value rises up between 20,000 MW and 29,000 MW during winter time. System's peak load occurs in winter (December, daytime 5 p.m.) when the hourly load counts for 32,750 MW.

The depicted values represent the "domestic" load of clients within the United Power System of Ukraine and imports/exports of neighbouring systems. The balance of annual imports/exports was allocated equally among the total number of hours per year, i.e. 8,760 hours. Since the development of the technical & non-technical losses within the Ukraine is already included in the figure for the annual electricity demand which is used in order to scale future power demands, the stated figures above are on so-called "sent-out level". Hence, their amounts have actually to be generated by the power plants operating in Ukraine. This value represents thus the basis of electricity generation when calculating the carbon emission factor for the Ukrainian electricity system.

4.2 Forecasted Energy Mix

According to the methodology described in Chapter 3, the previously depicted load has served as input parameter into the power system simulation which then dispatched the power units following their merit order as well as spinning reserve restrictions. In Figure 4-2 the dispatch for the exemplary workday 17 September 2012 is given.

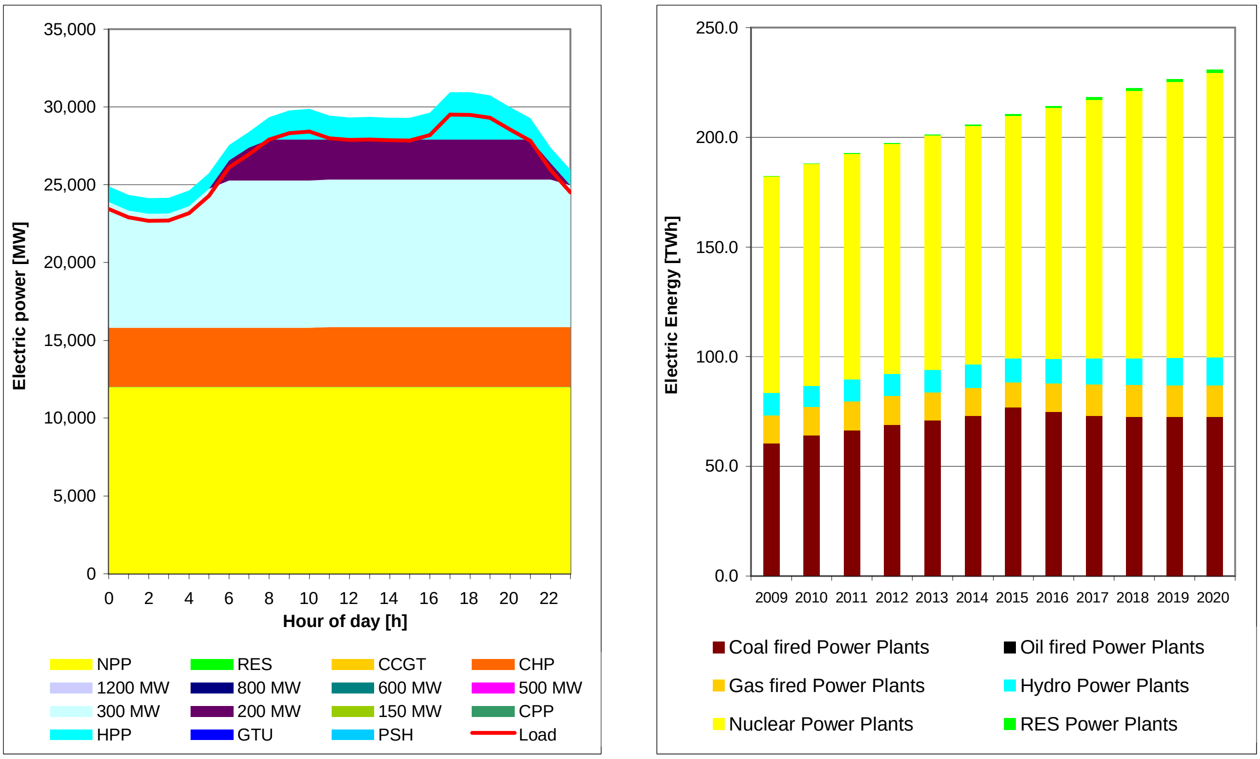


Figure 4-2: (a) Diurnal dispatch forecast for 01.12.2012 and (b) Forecast of annual (electrical) energy mix

On the referred day altogether 675 GWh of electricity are produced. In the chart it can be recognized that nearly half of the power is supplied by nuclear power plants which operate at around 12,000 MWh/h. Furthermore, base load generation is provided by combined heat and power plants (CHP) with approximately 3,800 MWh/h. The 300 MW power plants also play a significant role as they generate 7,300 MWh/h on average during that day. However, their generation increases during peak times, bringing up their generation to 9,500 MWh/h. Within the peak hours, also the 200 MW power plants contribute to the energy with their output ranging from 1,000 MWh/h to 2,600 MWh/h. Further notable share to the peak load is supplied by the hydropower plants as it increases up to 3,000 MWh/h around 5 p.m.

In the annual comparison of energy generation mixes it can be observed that the share of all power plant types increases proportionally with regard to total power production.

The largest contribution generated by nuclear power increases from 99 TWh in 2009 to 130 TWh in 2020 amounting to 56% of total generation. Furthermore, coal fired power production is rising constantly over the corresponding period from 60 TWh to 76 TWh in 2015 and decreasing again to 72 TWh in 2020 being equal to 31% of the total generation. The generation of gas fired units increases from 13 TWh to 14 TWh while hydropower generation increases consequently from 10 TWh to 13 TWh. By contrast, the share of renewable power generation increases throughout the period, but being still insignificant with a share of 0.6% in 2020.

4.3 Corresponding Carbon Emission Factors

Following the UNFCCC Tool, the previously described energy generation mix has been taken into account together with the corresponding efficiencies of the respective power units as well as the fuel carbon emission factors in order to compute the development of the annual carbon emission factors. The results for the UPS are depicted in Figure 4-3:

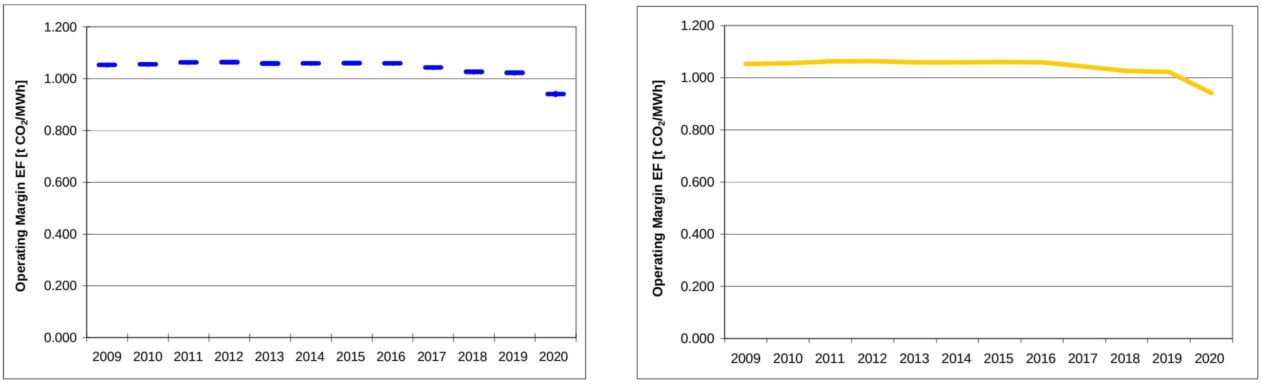


Figure 4-3: Results of Monte Carlo Simulation: (a) Distribution (median, min, max) for Operating Margin Emission Factor and (b) Forecasted Development for Operating Margin Emission Factor

As stated in Chapter 3.1.2 the Operating Margin represents the applicable baseline emission factor of the actual operation of the power system. The Operating Margin emission factor starts at 1.052 t CO_2/MWh in 2009 and increases slightly in 2011 and 2012 to a maximum of 1.063 t CO_2/MWh. After 2012 the Operating Margin decreases to 0.941 t CO_2/MWh in 2020.

The corresponding annual carbon emission factors for Ukraine are listed in Table 4-1, regarding the Operating Margin only.

Table 4-1: Annual Carbon Emission Factors for Ukraine

[t CO_2/MWh]		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
UKRAINE	OM	1.052	1.055	1.063	1.063	1.058	1.059	1.059	1.059	1.043	1.026	1.022	0.941

5 CONCLUSION

Based on the previously elaborated results this final chapter compiles the project's main findings and provides recommendations on how to best proceed with the continuous utilisation of the elaborated Power System Simulation Model with special focus on the future development of the analysed electricity system.

The Consultant identified official data sources to be applied in order to establish a comprehensive data base for the setup of the required Power System Simulation Model. In this context the applicable grid boundary was determined in accordance with the official administrative organisation of the national system operator Ukrenergo and considered as one single electricity system accordingly.

In a subsequent step, a dynamic Model was developed which enables the simulation of future developments in above mentioned electricity system. The underlying methodology is accordingly based on already installed and to be built power generation units, transmissions systems and import/export load patterns. Official investment programs were incorporated in order to model the expected system expansion plan by taking into account the overall electricity demand.

By conducting a dispatch analysis based on economic dispatch rules, the most realistic energy demand and supply scenario was simulated on an annual basis for the period from 2009 until 2020. This scenario accordingly serves as basis for the calculation of the corresponding carbon emission factors.

Summing up, the following electricity carbon emission factors for the United Power System of Ukraine have been derived on an annual basis, see Table 5-1. The graphical development of the annual carbon emission factors for the Ukrainian electricity system is depicted in Figure 5-1.

Table 5-1: Carbon Emission Factors for Ukraine for 2009 – 2020

[t CO_2/MWh]		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
UKRAINE	OM	1.052	1.055	1.063	1.063	1.058	1.059	1.059	1.059	1.043	1.026	1.022	0.941

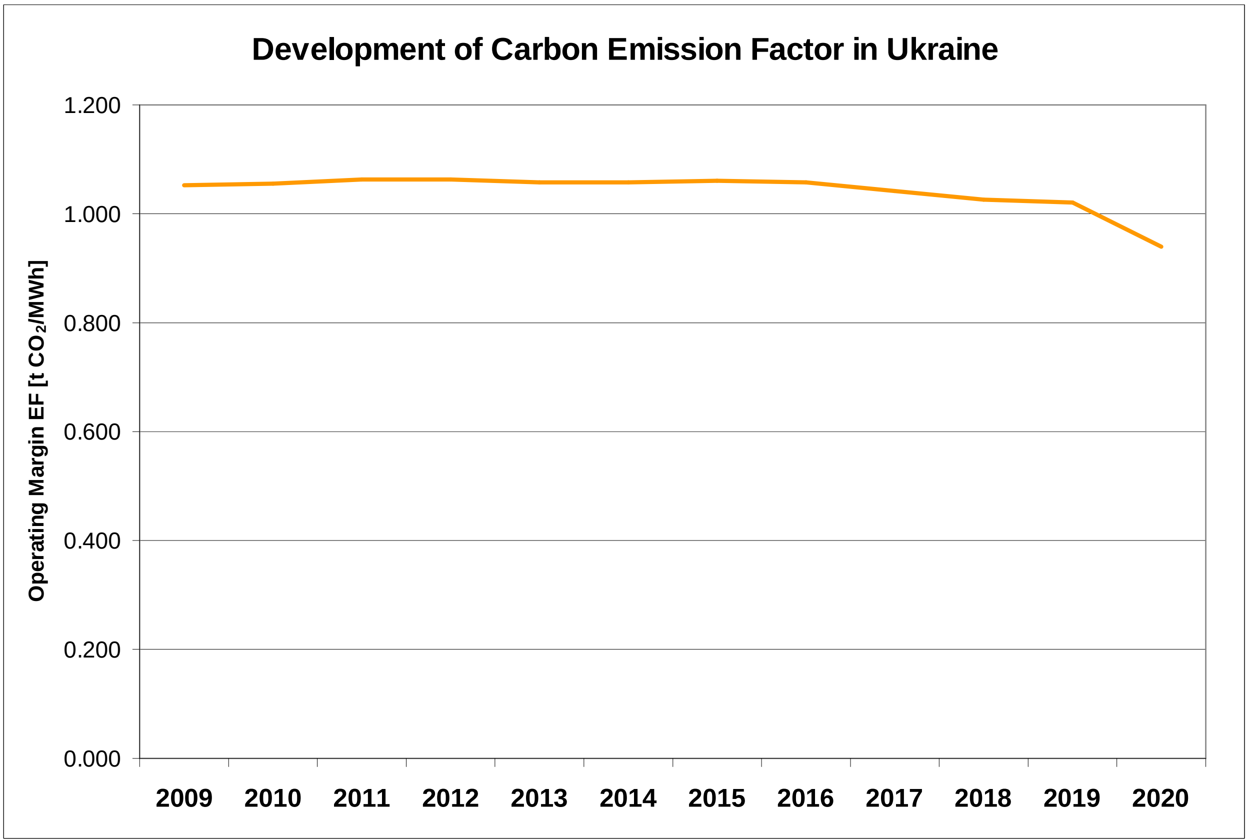


Figure 5-1: Development of Carbon Emission Factors for Ukraine

For the sake of clarity it is noted that the Build Margin, which shall represent most recent capacity additions to the electricity system, has not been considered in Ukraine.

When applying the BM as determined in the UNFCCC Tool, this value would result to almost zero since the Ukrainian electricity system is characterised by a large overcapacity. Accordingly, the consideration of such calculated BM would result in a distorted picture of the overall Ukrainian carbon emission factor.

In line with the preceding Baseline Study "Standardized emission factors for the Ukrainian electricity grid"[4], only the calculated Operating Margin shall be considered as applicable baseline scenario.

Above described carbon emission factors are applicable for supply-side projects. However, for demand-side projects the corresponding demand-side carbon emission factors have to be taken into account. In accordance with the UNFCCC "Tool to calculate baseline, project and/or leakage emissions from electricity consumption" (Version 01), they are derived from the supply-side carbon emission factors by considering the average technical transmission and distribution losses of the electricity system.

In the following the demand-side carbon emission factors for Ukraine for the period from 2009 until 2020 are depicted.

[4] Refer to "Standardized emission factors for the Ukrainian electricity grid" by Global Carbon B.V. dated 2 February 2007

Table 5-2: Demand-Side Carbon Emission Factors for Ukraine for 2009 - 2020

[t CO_2/MWh]	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
UKRAINE	1.160	1.162	1.171	1.172	1.166	1.167	1.168	1.167	1.149	1.130	1.126	1.036

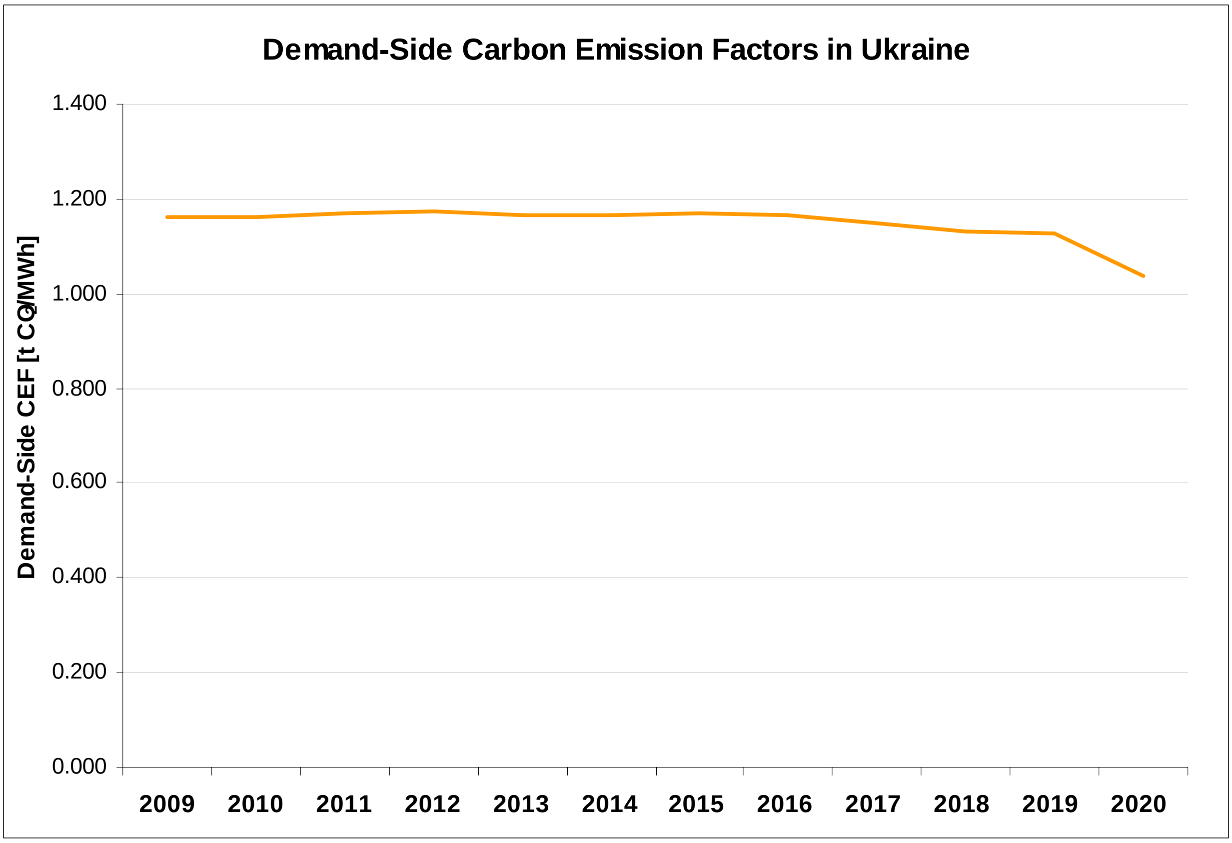


Figure 5-2: Development of Demand-Side Carbon Emission Factors for Ukraine

Regarding the results which were elaborated in the course of the Baseline Study, the following recommendation concerning the future utilisation of the developed Power System Simulation Model is made.

It is noted that the data sources utilised for the derivation of above presented carbon emission factors represent the current level of information, being either published or having made available by official entities in Ukraine.

However, in particular due to the uncertain character of any type of official forecast it is strongly recommended to continuously monitor potential updates of any official data source. In this context reference is made to the ex post calculation possibility of the Power System Simulation Model, see Section 3.2. It allows the user to calculate accurate carbon emission factors on an annual basis by incorporating most recent retroactive grid data.

ANNEX

Utilised Data Sources

DATA	SOURCE
Power Plant Data Base • Installed/available capacity per unit • Efficiency per unit • Type of fuel per unit • Commissioning year per unit • Scheduled decommissioning year per unit	• Ministry of Fuel and Energy (Refer to http://www.mpe.energy.gov.ua) • EBRD Studies • Lahmeyer International's Analysis
Dispatch Data and Load Profiles • Daily patterns of representative day of the United Power System of Ukraine • Daily imports/exports • Operational characteristics of the dispatching of thermal, hydropower and cogeneration plants • Rules of low-cost/must-run power plants	• Ministry of Fuel and Energy • Ukrenergo (Refer to http://www.ukrenergo.energy.gov.ua) • ENTSO-E (Refer to http://www.entsoe.eu) • Lahmeyer International's Analysis
Electricity Demand Development • Updated Forecast for 2009 to 2020 including annual electricity and peak demand	• Ministry of Fuel and Energy • Lahmeyer International's Analysis
Electricity Supply Development • Scenarios for the Power Generation Development up to 2030 • Updated system expansion plan of thermal power plants • Investment Programs for commissioning of new units	• Ministry of Fuel and Energy • Lahmeyer International's Analysis

All data processed in the study are provided in the Annex to the Minutes of the Meeting with NEIA dated 12 March 2010.