Security of electricity supply in the framework of sustainable development in Romania

The main objective of the paper is to present various scenarios for development of power generation capacities during the period 2007- 2035. The security of electricity supply is estimated through the global analysis at national power system level taking into consideration the evolution of the energy demand, the reserves of the domestic primary energy resources and the status of the reforms in the energy sector.
Having in view the high degree of uncertainties regarding the electricity demand, the evolution of the fuel costs on the international market, the evolution of environmental requirements it is important to analyze different scenarios for the power plants development on the period of 30 years because the decision makers should know the advantages and disadvantages of various decisions.
For establish the optimum solution of Romanian sustainable power plants development for the period 2007-2035 was used the probabilistic simulation for the estimations of generation costs, of undelivered energy and of security of supply and multi-criteria analysis for optimization of National Power System development programs in conditions of imposed restrictions by Romanian Government energy policy.
The programme proposed for power plants development is in accordance with the economic and social needs of Romania contributing to the achievements of security of electricity supply and respecting of sustainable development principles being in concordance with main objectives of energy policy of EU.

Key words: security of electricity supply, primary energy resources, sustainable development, forecast.

Ph.D. Anca Popescu
Director of Power Systems Division

MSc. Eng. Anca Simona Bardici – Energy Policy Office - Power System Division – Institute for Studies and Power Engineering (Corresponding Author)

Tel: +40-21-2061309
Fax: +40-21-2061317
E-mail: sispe@ispe.ro

Address:
Institute for Studies and Power Engineeering (ISPE)
1-3 Lacul Tei Blvd, 020371,
Bucharest, Romania

1. Introduction

The Romanian power generation capacities development program for the following 30 years must be established after a deep analysis of the whole National Power System (NPS), taking into consideration the Romanian specifical aspects regarding:

- the evolution of electricity and cogeneration heat demand;
- actual situation of NPS existing units (remaining life time of the units, technologies, efficiency, safety, importance);
- primary energy resources rezervs available for internal production;
- electricity reforms stage;
- electricity medium and long terms objectives mainly:
  - increasing of electricity security of supply;

- increasing of competitivity of internal and regional electricity market;
- the use of primary energy resources, which will ensure competitivity and security of supply;
- the increasing of efficiency of the electricity and cogeneration units, using the best available technologies;
- achieving the environmental protection and mitigation of greenhouse gasses (GHG) emissions in accordance with UE assumed obligations and Kyoto protocol;
- maintaining of primary energy imports at an acceptable level;
- the continuation of restructuring and technological modernization and increasing of profitability in electricity and cogeneration sector;
- the promotion of electrictity and heat generation in cogeneration type and of renewable energy;
- privatization of electricity generation companies.

The main objective of the paper is to present present various scenarios for development of power generation capacities during the period 2007- 2025 and estimations for 2035. This development will be established based on:

- electricity and cogeneration demand forecasts during the period 2007-2035;
- the actual stage of the existing units and it evolution for the future;
- the evolution of fuel domestic production;
- international and domestic market fuel cost prognozis;
- units technologies evolution;
- imposed requierements by duration development of the power sector.

For establish the optimum solution of Romanian sustainable power plants development for the period 2007-2035 was used Wien Automatic System Planning (WASP) program available by International Atomic Energy Agency (IAEA). This program uses the probabilistic simulation for the estimations of generation costs, of undelivered energy and of security of supply and uses the dynamic estimation techique for optimization of NPS development programs in conditions of imposed restrictions by Romanian Government energy policy.

In the present economical and geopolitical context it is not possible to establish a sustainable energy development based exclusive on economic order of solutions and must to adopt new criterias which can offer security of supply with energy resources and be satisfaction of the electricity consumers.

The main characteristics of the Romanian power system in the period 2000-2006 are presented in the **table 1.**

Table 1. Romanian NPS main characteristics

Year	Gross electricity production GWh	Net electricity production GWh	Gross peak load MW
2000	51935	47066	8265
2001	53866	48766	8569
2002	54935	50400	8410
2003	56645	51525	8356
2004	56482	51934	8761
2005	59413	54804	8970
2006	62207*)	56392	9620

Source: - National Statistics Institute – National statistical Book for gross production.
- CN Transelectrica SA – DEN – net production and gross peak load.
Observations: *) estimations from Industrial Statistical Bulletin nr. 12/2006

From this table we can notice the increasing of the gross peak load from 8265 MW in year 2000 at 9620 MW in year 2006.

The evolution of NPS installed capacity in the period 2000-2006 is presented in the **table 2**.

From this table we can notice the decreasing of installed capacity with about 15%, due to the retirement of thermal units and putting in operation only of hydro units.

Table 2. Evolution of installed capacity in NPS power plants

[MW]

	2000	2001	2002	2003	2004	2005	2006*)
Total installed capacity which of:	21905	20863	19659	19368	19626	19042	18835
- in nuclear power plant	706	706	706	706	706	706	706
- in hydro power plant	6120	6122	6242	6248	6279	6289	6363
- in thermal power plant	15079	14035	12529	12414	12641	12047	11766

Source *: - National Statistics Institute –Statistic Book*
Note *: *) estimations.*

SC Hidroelectrica SA decided to finalize hydro power plants with a total installed capacity of 690 MW in the period 2005-2022.

The S.C. Hidroelectrica S.A. programs for the utilization of hydroenergy potential are presented in the **table 3.**

Table 3. Programes proposed by S.C. Hidroelectrica S.A.

Period	Program	Installed capacity [MW]	Available electricity, [GWh]	
			Medium year	Dry year
2005-2022	HPP decided out of which :	690	2155	1563
	- HPP started with putting in operation in period 2008 -2015	355.8	1132	871
	- candidate HPP	334.2	1023	692
2015-2025	Follow-up utilization of hydroenergy potential: out of which:	895.83	2899	2175
	- candidate HPP	895.83	2899	2175
TOTAL		1585.83	5054	3738

In the **table 4** it is presented a synthesis of installed power in the year 2006 for all Romanian thermal power plants and for various types and for various fuel consumptions (condensing and cogeneration units) and also spitted by fuel consumption.

Table 4. Romanian thermal power plants installed capacity in the year 2006

Type of plant	Total installed capacity	Installed capacity on:					
		Coal	Which from:		Hydro-carbons	Which from:	
			Lignite	Hard coal		Gas	Fuel oil
	11766	5415	5422	1800	4544	3235	1309
Conden-sing (TPP)	7087	5430	4130**	1300	1657	800	857
Cogene-ration (CHPP)	4679	1792	1292	500	2887	2435	452

From the evolution of electricity production structure in the period 2000-2006 in NPS **(table 5)** it can be noticed that the share of thermal energy is about 60%, the share of nuclear energy of about 9% and of hydro energy of about 30% from energy demand.

Table 5.a. Evolution of electricity production structure on power plants type for the period 2000 – 2003

	2000		2001		2002		2003	
	TWh	%	TWh	%	TWh	%	TWh	%
Gross production Of which:	51.93	100	53.86	100	54.9	100	56.64	100
- Nuclear power plant	5.46	10.5	4.92	9.1	5.51	10.0	4.91	8.7
- Hydro power plant	14.78	28.5	14.92	27.7	16.05	29.2	13.26	23.4
- Thermal power plant Of which:	31.69	61.0	34.02	63.2	33.37	60.8	38.47	67.9
• On coal	18.91	36.1	20.1	37.3	20.31	37.0	23.34	41.2
• On natural gas	9.38	18.1	8.66	16.1	9.48	17.3	11.50	20.3
• On fuel oil	3.40	6.5	5.26	9.8	3.58	6.5	3.63	6.4

	2004		2005		2006	
	TWh	%	TWh	%	TWh	%
Gross production Of which:	56.48	100	59.41	100	62.20	100
- Nuclear power plant	5.55	9.8	5.56	9.4	5.63	9.1
- Hydro power plant	16.52	29.3	20.21	34.0	18.33	29.5
- Thermal power plant Of which:	34.41	60.9	33.64	56.6	38.24	61.4
• On coal	21.47	38.0	21.92	36.9	26.72	42.9
• On natural gas	10.75	19.0	9.82	16.5	9.72	15.6
• On fuel oil	2.20	3.9	1.90	3.2	1.80	2.9

Source: National Statistics Institute – Statistical Book;
EC-DGET Statistical packetbook 2000-2006

The majority part of NPS units was achieved with 1970-1980 years technologies. The hydro units which meet the life time of operation represent 37% from total installed capacity. The majority of the thermal power plants are not equipped with performed installations for emissions mitigation for reaching the EU imposed norms situation of thermal units being more dramatic.

2. Analyzed power plants development program options

To establish the optimum power plants development program, the following scenarios were analyzed:

- Reference scenario in which all type of candidate

power plants (nuclear power, thermal power, hydro power, wind) are in free competition, no restriction whatever, the selection order being the economic one to meet the load curve;
- Imposed hydro program (Pi=1230 MW);
- Imposed nuclear program, only 4 units at NPP Cernavoda;
- Imposed thermo program (3100 MW) in the period 2010-2013;
- Imposed wind farm program (4000 MW) in period 2010-2017;
- Imposed hydro program (1230 MW) and imposed thermo program (3000 MW) in the period 2010-2013;
- Imposed thermo program for domestic lignite and hard coal consumption, imposed hydro program (1230 MW), without import gas restriction after 2025;
- Imposed thermo program for domestic lignite and hard coal consumption, imposed hydro program (1230 MW), imposed wind farms program (4000 MW), without import gas restriction after 2025.

For the complete characterisation of the optimum solution for the power plants development, one carries out sensitivity analyses that assess the effect of various key parameters variation (technical and economic) on the optimum solution.

These scenarios were analyzed having in view the coverage of the electricity internal consumption with an average growth rate of about 2.4% for the period 2007-2035 and taking into account the evolution of fuel prices on the international market.

The reference scenario presents the power plants least cost development program resulted during optimization process, taking into account only the economical loading order, without other restrictions. This program is an hypothetical program because takes into account only the economical criteria of loading order of the units, without other criteria resulted from Romanian energetical strategy and energetical policies established by Romanian Government, criteria which takes account of EU requirements.

The alternative analyzed scenarios took into account the key factors, which affect power sector evolution in the conditions of single energy European market. These scenarios present the advantages and disadvantages of reference scenario in accordance with the hypothesis taken account at their definition. It is very important to analyze these advantages and disadvantages as objective possible for obtaining a hierarchy of scenarios with a view of establish the Romanian power plants optimum development program for the period 2007-2035.

For these scenarios hierarchisation was took into consideration beside the economical criteria and criteria resulted from Romanian Government energy strategy regarding security of power supply, primary energy sources efficient use, environmental protection. Thus, for the three hierarchization criteria of development scenarios that means:
- economical criteria;
- security in electricity supply criteria;
- environmental criteria;

were defined indicators for characterization these criteria.

For **economical criteria** was defined as indicator the levelized cost of electricity, which takes into consideration both the capital cost and operation and maintenance costs during 30 years.

For **security in electricity supply** criteria were defined three indicators namely:
- degree of energy independency;
- the Hirschman-Herfindahl (HHI) indicator of import concentration for characterization of primary energy sources diversification;
- primary energy import invoice.

The indicator "HHI" it is defined with the formula:

$$HHI = \sum_i s_i^2$$

where s_i represents quote of imported primary energy source.

An HHI indicator between 8000-10000 means a big concentration of sources, which conduct to a certain vulnerability, while this indicator between 1000-1600 means a diversification of sources, therefore a reduced vulnerability.

The indicator "primary energy import invoice" (FIE) it is defined with the relation :

FIE = Primary energy resources import value/GDP

This indicator was in France 5.2% from GDP in 1981, 1.8% from GDP in 1986, 1.4% in 2003 and 2.3% in 2005.

For **environmental criteria**, taking into account of the importance to achieve the imposed Kyoto protocol obligations, it is defined as main indicator "the carbon intensity" (IC).

The carbon intensity is calculated with the formula:

$$IC = \frac{CO_2 emissions}{GDP}$$

Taking into consideration that it is analysed only power plants development scenarios and it is not analysed the Romanian energy balance, the above defined indicators was adapted for achieve an objective hierarchisation of scenarios according with available data.

The energy independency degree didn't represent an objective risk evaluation factor in the oil international crisis, because the scenarios are characterised only by fuel consumption and there are not considered as renewable resources.

It is important to be achieved a hierarchisation taking into consideration the diversification of sources and the vulnerability and volatility of renewable resources for covering the necessities.

For this purpose the scenarios were hierarchised depending of:

- imported fuel quantity;
- the share of energy generation in hydro and wind farms power plants from total net electricity production in 30 years period;
- the share of imported fuel cost from total fuel cost in 30 years period.

For the environmental criteria, taking into consideration that is not possible to determine the variation rhythm of carbon intensity for the period 2007-2035, for scenarios hierarchisation it is achieved the scenarios hierarchisation based on total CO_2 emissions generated in the period 2010-2035.

In the **table 6** are presented the total CO_2 emissions in the period 2010 – 2035.

Table 6. Total CO_2 emissions for the period 2010 - 2035

No.	Scenario	Total CO_2 emissions [mill.tones]
1.	Reference – Economical order without restrictions	878
2.	Imposed hydro program (P_i=1230 MW)	835
3.	Imposed nuclear program, only 4 units at NPP Cernavoda	1075
4.	Imposed thermo program (3100 MW) in the period 2010-2013	855
5.	Imposed wind farm program (4000 MW) in period 2010-2017	902
6.	Imposed hydro program (1230 MW) and imposed thermo program (3000 MW) in the period 2010-2013	760
7.	Imposed thermo program for domestic lignite and hard coal consumption, imposed hydro program (1230 MW), without import gas restriction after 2025	865
8.	Imposed thermo program for domestic lignite and hard coal consumption, imposed hydro program (1230 MW), imposed wind farms program (4000 MW), without import gas restriction after 2025	895

For economical criteria it is determined the levelised cost of energy generation.

The multicriteria analysis of the development programmes for the power plants presented permits the selection of the programmes taking into consideration the requirements imposed by "New Energy Policy" of EU.

Taking into consideration that the costs imposed by environmental protection can be included in the operation and maintainance costs from objective function, it is avoided the criteria in multicriteria

analysis that the hierarchy after econiomic criteria doesn't change.

In this condidtion it is achieved multicriteria analysis only taking into consideration economic and security criteria with equal weights.

From all indicators defined for security of electricity supply it is used only imported fuels quantity for avoiding double evaluation.

Table 7. Scenarios evaluation taking into account the economical, security of supply and environmental criteria

No. crt.	Scenario	Marks according with the criteria:		Final mark	Scenarios hierarchisation
		Economical	Security of supply		
		Electricity generation levelised cost	Imported fuel quantity		
1.	Reference - Economical order without restrictions	10	1	5.5	3
2.	Imposed hydro program (P_i=334 MW)	9	2	5.5	3
3.	Imposed nuclear program only 4 units at NPP Cernavoda	9	2	5.5	3
4.	Imposed thermo program (3100 MW) in the period 2010-2013	8	4	6.0	2
5.	Imposed wind farms program (4000 MW) in period 2010-2017	8	2	5.0	4
6.	Imposed hydro program (1230 MW) and imposed thermo program (3000 MW) in the period 2010-2013	4	5	4.5	5
7.	Imposed thermo program for domestic lignite and hard coal consumption, imposed hydro program 1230 MW), without import gas restriction after 2025	4	9	6.5	1
8.	Imposed thermo program for domestic lignite and hard coal consumption, imposed hydro program (1230 MW), imposed wind farms program (4000MW), without import gas restriction after 2025	1	10	5.5	3

In the **table 7** is presented the hierarchy based on the marks obtained taking into account the evaluation with mark from 1 to 10 of the programmes in function of the degree in which these programmes satisfay the criteria.

It must be emphasized that:
- the priority use of domestic lignite in accordancee with the forecasts indicated by Ministry of Economy and Finance;
- the priority promotion of hydroenergy programmes and
- the reduction of import gas dependency;

lead to the decrease of economic indicators, the average cost per lifetime being 7% higher that the corresponding to the programme for power plants development with „least costs" in reference scenario, but contribute to the increase of security for consumers supply and comply with the requirements of the EU "New Energy Policy".

The objective function value for this programme is 6% higher than the one for the programme of development with minimum costs, which must ensure a reduced vulnerability to the dependency of imported primary energy resources.

3. Conclusions

Romanian Power System is equipped with thermal power generated units achieved at the technological level of year '70 so the efficiency for thermal power generation from fossil fuels is low, about 31% in the conditions in which European Commission in "New Energy Policy" requires the reduction of global primary energy consumption with 20% up to 2020.

One of the achieving way of the objective of "New Energy Policy" is the increasing of the efficiency in the whole chain, from generation to energy consumtion.

The installation of new power in modern units in advance is more economic than the exploitation of existent units with low performances, taking into consideration also the investments for the reduction of emissions at the levels imposed for environmental protection.

The power plants least cost development program is an hypothetical program because doesn't takes into account the security of electricity supply only the economical criteria of loading order of the units, without other criteria resulted from Romanian energetical strategy and energetical policies established by Romanian Government, criteria which takes account of EU requirements.

The programme of plant development in the period 2007-2035 selected for the insurance of the security of electricity supply in Romanian conditions has in view the continuation of nuclear programme, the new modern technologies for electricity generation and thermal energy generation in cogeneration, efficient use of domestic fuels, the increase of share of renewable energy, the decrease of the environmental impact.

This programme establishes the necessity of investment for a new installed power of about 14539 MW in the period 2010-2035, as follows:

- nuclear field-1320 MW in units 3 and 4 at NPP Cernavoda and 1800 MW in new nuclear units;
- thermal power field with cogeneration units - 3530 MW in gas turbine with recovered boilers and combine cycle with gas turbines;
- thermal power field - 3660 MW in condensing units burned lignite with modern technologies (fluidized bed burning, pulverizes lignite);
- hydropower field - 1230 MW in hydropower plants which assure the efficient use of economic hydroenergetical potential;
- hydropower plant with accumulation and pumping - 1000 MW at Tarnita;
- power plant for regulating – 2000 MW in gas turbine.

The installation of wind farms at the requirements of some investors, supplementary given the new installed power indicated. At this point will be beneficial because contributed at the increasing of use renewable energy share, decreasing the use of fossil fuels and GHG emissions.

The installation of these wind farms doesn't result timely in accordance with least cost development program. For the promotion of these investments through the political decision must to create the facilities for the investors and/or to introduce on electricity market the electricity production on these technologies.

The program of development resulted from the analysis taking into consideration Romanian conditions answers at the objectives from Romanian Government energy strategy, namely:

• Energy Security through:

- the limitation of the dependency from imported primary energy resources, using the domestic lignite and hard-coal, hydropower and wind power;
- the diversification of imported energy sources by using the nuclear fuel and natural gas.

• Sustainable Development through:

- the increasing of energy efficiency by using the modern technologies at the level of year "2015";
- the promotion of hydropower energy and wind energy;
- the promotion of the cogeneration plants using the high efficient technologies on natural gas;
- the reduction of negative impact on the environment.

The proposed programme assures the increase of efficiency for fossil fuels use with the annual rate 1.65 in the period 2006-2035 and the increase of GHG emissions from 33.7 mill.tones in 2006 up to 36 mill.tones in 2035 in the conditions when electricity production will increase from 57.2 TWh up to 103.8 TWh. In this situation the CO_2 specific emission will decrease from 0.589 tones/MWh in the year 2006 at 0.347 tones/MWh in the year 2035.

The reduction of the difference between the least cost development program and the development program that assure the security of electricity supply will be achieved in the following conditions:

- the decrease of lignite price in Romania;
- the promotion of efficient technologies;
- the reduction of investment cost for hydropower plants and attracting of the investors which benefit of auxiliary uses.

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