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Chapter 2

Modernization and Development Scenarios of the Power Plants in the Present Energy Market Context

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Additional information is available at the end of the chapter

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Abstract

The aim of this study is to analyze several possible hypotheses for the development of a power plant in the context of the local electricity and heat market. The energy market may be constraint by the probable cessation of the activity of the most important customer in the industrial market, hereinafter referred to as "strategic customer." Stopping its activity would deprive the power plant of an annual electricity supply of 28.02% of the electricity production estimated in the "continuity" hypothesis with the strategic customer, namely an annual heat of 78.19% of the heat output of the same alternative. It is very clear that stopping the activity of the company constitutes a disability for the power plant, whose magnitude has been highlighted by the comparative analysis of several possible scenarios of modernization, modernization-development, and development. As far as the electricity market is concerned, the power plant belongs to the area that is strongly equipped with sources of electricity production. With regard to the thermal energy market, the power plant, following the decoupling of the strategic customer, loses an important and stable consumer and stays only with the production of heat for heating the buildings and the preparation of domestic hot water for the residents of the city. The study's result is the hierarchy of the proposed technical scenarios from the point of view of the necessary investment, the variation of the electricity tariff on the market, and the environmental impact.

Keywords: energy market, optimization, power plant, steam generator

1. Introduction

The energy system and the related market have gone a long way, from the vertically integrated model to a decentralized system, from centralized programming to obtaining the right to produce through the bidding process, the daily bidding process referring to 24 hour the next

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day. The opening of the electricity market fundamentally altered the trading environment, with a residual energy demand at regulated prices. This is mainly due to the fact that small companies and residential consumers have low volumes, and the costs of changing the vendor may indicate that the decision is uneconomic [1, 2]. The fundamental position in the development of a power plant is to minimize the risks (in the case of PPP—public-private partnership projects) ensuring that in the sizing of the transaction and in the market activity, each risk is identified and allocated to the entity capable of administering, diminishing, or supporting it [3, 4]. Main risks in the development of a power plant are considered to be:

- The overall risk of the deregulated market—appears to be a challenge to all electricity producers, except for the "must run" type. In a deregulated market, the most common ways to significantly reduce this risk are bilateral physical contracts and hedging contracts.
- Risk of nonscrutiny—can be contracted through contracts, or if possible, export contracts.
- General regulatory risk—applies to any manufacturer; keeping it at an acceptable level is achieved through the knowledge of long-term energy policy and political stability.
- The risk of regulating the environmental impact—the most difficult to appreciate and manage; shall apply in the same amount to all competitors, who produce electricity using the same type of fuel.
- Risk of noncredulity—a robust economic and financial analysis to persuade the banks on the feasibility of the project substantially reduces this risk.
- Fuel price risk—one of the most visible risks. Even if it is difficult to quantify, it is obvious that the trend for the price of fuel, especially hydrocarbons, is on the rise.

The power plant has as its activity, the production of electric and thermal energy (steam and hot water), for industrial and urban consumers in the city. The plant has the following capacities installed: steam generators of 420°t/h, 140 bar, 540°C operating with primary fuel—lignite and support fuel—HFO for the flame and 50 and 25 MW turbo generators. The evacuation of the produced electric power is done through the 110 kV connection substation to the National Energy System. The evacuation of thermal energy to its main consumer, the industrial and urban consumers in the city, is achieved through technological and heating networks.

2. Current position of the power plant in the energy market

2.1. Electricity market

The plant's electricity production is based on the existence of traditional consumers such as the most important economic agent, the "strategic customer" and the adjacent locality.

Although the share in total deliveries differs considerably between consumers, the customer portfolio is characterized by the fact that:

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- SEN is an important customer, requesting 75% of the total deliveries.
- The economic agent is a strategic customer, considering the level of safety in the electricity supply.

The strategic customer's consumption was approximately constant; the electricity production increased with the optimization of the operation of the power plant.

In **Tables 1–3,** the values resulting from the statistical processing of the average monthly powers are presented.

It is noted that unlike other consumers, the strategic customer records consumption averages close to the maximum/minimum values, emphasizing the continuity of the power supply. During the operation of the power plant, it has emphasized "minor" energy exchanges: consumers connected directly, termed third parties—0.11% of total deliveries made to the contour of the power plant.

Clearly, the future of the power plant depends on the evolution of the demand for electricity, primarily in the area, but also on the entire national market and export prospects, respectively.

Parameter, UM	Condensation	Heat	Total
Maximal peak power, extrapolated, MW_e	145.008	139.111	272.126
Weighted average multiannual power, MW_e	72.923	75.021	147.944
Minimum average monthly power, MW_e	18.062	23.108	51.582
Average standard deviation, MWe	34.054	31.799	53.583

Table 1. The "raw" energy production.

Parameter, UM	TOS	Deliveries	Total
Maximal peak power, extrapolated, MW_e	43.112	221.932	262.989
Weighted average multiannual power, MW_e	27.993	120.101	148.667
Minimum average monthly power, MW_e	13.307	42.105	55.309
Average standard deviation, MWe	8.021	46.988	54.860

Table 2. Technological consumptions and energy supply.

Parameter, UM	Strategic customer	NES	Deliveries
Maximal peak power, extrapolated, MW_e	32.014	190.996	222.072
Weighted average multiannual power, MW_e	29.987	90.012	120.126
Minimum average monthly power, MW_e	23.026	10.877	42.396
Average standard deviation, MWe	1.563	47.084	47.424

Table 3. Energy supply to strategic customer and to the NES.

Of great importance is the existence of eligible consumers in the area, who can conclude contracts at longer intervals. Their motivation may be: a certain tradition of previous collaboration with the power plant, the possibility of negotiating convenient clauses, an advantageous price due to the low transport and distribution tariff, and preferential financial arrangements including price variations in time that share the risk of variations of high fuel prices.

2.2. Thermal energy market

The portfolio of consumers active on the power plant's thermal energy market has a less disadvantageous structure, given that the strategic customer has a significant share. The power plant produces heat and delivers heat using thermal agents: industrial steam at a pressure of 40 bar for the strategic customer, industrial steam at a pressure of 13 bar for the strategic customer, and hot water for "urban" consumers in the locality. The disappearance of the strategic consumer will dictate decisively the structure of the plant's operating scheme. In terms of supplying the city with thermal energy, it is made through a branched type hot water network. The thermal power to cover the current heat demand is approximately 154 MWt for the maximum winter regime and 15 MWt for maximum summer mode when intermittent hot water is delivered.

Maintaining the current centralized heating system from a cogeneration source is appropriate due to the absence of a viable technical and economic alternative in the medium term; the town is not connected to the natural gas network. This makes it impossible to replace the cogeneration source with quaternary, block, or apartment heating plants. Individual stove heating is excluded in condominiums. **Tables 4** and **5** synthesize the data related to thermal energy production and supply corresponding to various thermal levels and to various types of consumers.

Parameter, UM	Max.	Monthly averages	Socket	SRR
Maximal peak power, extrapolated, MW_t	99.38	98.86	89.18	50.67
Weighted average multi annual power, MW_t	87.92	85.04	66.92	19.83
Minimum average monthly power, MW_t	52.01	50.11	37.89	0.00
Average standard deviation, MW_t	7.06	7.37	15.62	13.94

Table 4. Characteristic values of 40 bar technological steam deliveries.

Parameter, UM	Steam, 13 bar	District heating	Deliveries to TP
Maximal peak power, extrapolated, MW_t	192.01	155.32	95.57
Weighted average multiannual power, MW_t	127.43	66.98	37.29
Minimum average monthly power, MW_t	73.88	10.92	1.08
Average standard deviation, MW_t	25.68	49.31	34.83

Table 5. Characteristic values of 13 bar technological steam and hot water supply.

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Compared to the electricity market, which has at least national coverage, thermal energy has, for obvious technical reasons, a strictly local character. The eventual disappearance of the major thermal consumer creates relatively pessimistic premises in terms of the potential for the evolution of demand for thermal energy and its exploitation.

Even if the power plant currently occupies a strong position in the energy market, its evolution may change either through the development of the most important economic agent or through the predictable development of the city.

The existence of eligible customers is very important for the evolution of power plant. They can conclude contracts on the long terms—their competitive strength depends on their own development programs and financing schemes.

At the same time, it is estimated that in about several years, the city will be connected to the natural gas network, which may lead to disconnections of urban consumers, respectively, a decrease of the demand for heat by 3–5%. To this can be added the self-limiting trends of the consumption of heat and hot water, which will be manifested with the development of measurement systems and the "individualization" of invoices due to the generalization of the thermal points and the blocks or stairs, the introduction of hot water meters and using thermostatic valves and cost allocators.

However, there are number of directions for increasing the area in terms of the development of the thermal energy market using hot water: development of a new housing district—an average consumption of 32% (10.5 MWt) of the current average annual urban consumption of about 35 MWt is estimated. The development of greenhouses at the outskirts of the city will increase the average annual heat supply in the hot water network by 7.2 MWt (16%). These, summed up at the peak of winter with the current thermal load, outline an increase of about 52% of peak demand for thermal energy.

3. Technical analysis for modernization and development of the power plant

The following evolving alternatives for the power plant are developed:

- Modernization alternatives (AM), which will keep the plant's current architecture and add a DKAR 22 turbine and desulphurization plant.
- Modernization-development alternatives (AMD), which will keep part of the current scheme of the boiler plant, namely the cogeneration stage that provides the heating and domestic hot water needs of the city.
- Alternative of development (AD), which relies on closing the existing power plant and building/installing new groups.

The "development" groups can keep current energy conversion technology, the Rankine-Hirn water-steam cycle, or they can work on mixed water-steam cycle technology. In both cases, the

required heat demand for the city is met and the fossil fuel energy is converted into electricity and heat at higher yields than the current scheme. The fuels to be used are lignite (L), coal (H), and natural gas (G).

3.1. Modernization alternatives

3.1.1. Modernization of the existing facilities with existing fuels and strategic customer operation, A_1-AM_1

This is the "continuity" alternative, involving the commissioning of the steam counter pressure at 22 bar turbine, nominal parameters 135 bar, 535°C. The plant will consume primary energy generated by the combustion of 9,402,028 MWh/year fuels, lignite, and a combustion support fuel, delivering to the fence an amount of electricity of 1,697,729 MWh/year and thermal energy, 36 bar industrial steam, 16 bar industrial steam, and hot water, respectively 2,970,201 MWh/year.

3.1.2. Modernization of existing fuel exchanges and strategic customer operation, A_2-AM_2

The alternative consists of the change of lignite fuel in coal to reduce fuel/ash flows and the costs of transporting, handling, and storing them. The power plant will consume primary energy generated by the combustion of 9,205,007 MWh/year fuels, delivering 1,766,108 MWh/year to the fence. The amount of annual heat is the same as in the previous case.

3.1.3. Modernization of existing facilities with existing fuel and without the strategic customer, A_3-AM_3

In this hypothesis, the plant will consume primary energy generated by the combustion of 5,591,227 MWh/year fuels, delivering to the fence an amount of electricity of 1,189,662 MWh/year and thermal energy from the hot water, respectively 1,008,164 MWh/year.

3.1.4. Modernization of existing facilities with fuel change and without strategic customer, A_4-AM_4

This alternative is similar to A_3-AM_3 and consists of the change of lignite fuel in coal based on the same boiler and turbine equipping schemes as in the previous case.

Thus, the power plant will consume primary energy generated by the combustion of 5,385,005 MWh/year fuels, delivering to the fence an amount of electricity of 1,301,104 MWh/year. The amount of annual thermal energy is the same as in the previous case.

3.2. Modernization-development alternatives

3.2.1. Modernization of existing installations and development with a new unit of 100 MW, without changing the conversion technology, A_5-AMD_1

It is a development modernization solution, which consists of coupling a 420 t/h steam generator with a simple cycle turbine, new investment, to increase the electric energy output from the power plant.

The plant will consume primary energy generated by the combustion of 8,262,441 MWh/year fuels, delivering to the fence an amount of electric energy of 1,981,112 MWh/year. In this and in the previous case, the amount of annual thermal energy is the same.

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3.2.2. Modernization of existing installations and development with a new 100 MW unit without changing the conversion technology with fuel change, A_6-AMD_2

The alternative is similar to the one above, except that there is a change of solid, lignite-fired fuel into coal.

3.2.3. Modernization of existing installations and development with a new 220 MW with intermediate overheating, without changing the conversion technology, A_7-AMD_3

It is a modernization solution consisting of the transformation of two (three) boilers for intermediate overheating, in the 2 × 50% scheme, with a new 220 MW turbine. The power will be 343 MW in winter mode and 297 MW in summer mode.

In this hypothesis, the power plant will consume primary energy generated by the combustion of 8,901,121 MWh/year fuels, delivering to the fence an amount of electric energy of 2,1981,787 MWh/year to the fence.

It is the scenario with the largest amount of electric energy.

3.2.4. Modernization of existing installations and development with a new 200 MW unit without changing the conversion technology with fuel change, A_8-AMD_4

The hypothesis is similar to the one above, except that the shift of solid lignite fuel into coal, with additional investment, is also emerging.

3.2.5. Modernization of existing installations and development with a new unit with conversion technology change—CCGA 110 MW single shaft, A_9-AMD_5

This alternative preserves some of the existing capacities of the lignite energy conversion technology, introducing in addition a combined gas-steam cycle. The plant will consume primary energy generated by combustion of 6,401,117 MWh/year fuels, delivering to the fence a quantity of electric energy 1,911,027 MWh/year.

3.2.6. Modernization of existing facilities and development with a new unit changing conversion technology—CCGA 110 MW single shaft and fuel, A_{10}-AMD_6

The scenario is similar to the one above, except that the shift of solid lignite fuel into coal, with additional investment, is also emerging.

3.3. Scenarios of development

3.3.1. Development with a new 225 MW with intermediate overheating without changing conversion technology, A_{11}-AD_1

The current equipment with turbines is abandoned and a new group with intermediate overheating and urban outlet is installed, operating on two existing boilers and delivering in the system a maximum power of 190 MW in winter and 220 MW in summer. The plant will consume primary energy generated by the combustion of 5,552,219 MWh/year fuels, to the

fence a quantity of electric energy 1,397,782 MWh/year to the fence. The amount of annual thermal energy is the same as in the previous case.

3.3.2. New 225 MW with intermediate overheating without change of conversion technology with fuel change, A_{12}-AD_2

The alternative is similar to the one above, except that the change of solid, lignite-fired, coal-powered fuel with supplementary investment increases.

3.3.3. Development with a new unit and change of conversion technology—CCGA 220 MW triple shaft, A_{13}-AD_3

This scenario completely abandons the equipment of today's turbines and installs a mixed gas-steam cycle consisting of 273 MW gas turbines, a rehabilitation boiler, and a 68 MW steam turbine running on natural gas.

The power plant will consume primary energy generated by combustion of 3,567,884 MWh/year, delivering to the fence an amount of electric energy of 1,698,117 MWh/year. In this and in the previous case, the amount of annual thermal energy is the same.

4. Technical and economic analyzes of hierarchy of proposed technical scenarios

The purpose of the economic analysis is to:

- identify and assess the costs and revenues of the various scenarios of developing and/or upgrading the power plant in order to optimize the production of electric and thermal energy;
- compare costs and revenues for the proposed scenarios;
- establish a ranking of the proposed scenarios based on the technical and economic efficiency achieved with the help of the established performance indicators;
- perform the sensitivity analysis of the main performance indicators on changes in the economic input data, validating the proposed scenario ranking.

The forecast for financial flows is based on direct costs (which may be associated with the production of electricity and heat) and revenues.

Thus:

- Direct costs include entries calculated based on material costs, staff costs, overhead costs, and maintenance costs.
- The investment includes engineering costs, equipment costs, construction and assembly costs, and design and study costs.

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The total investments for each scenario are shown in **Table 6**.

The most important observations regarding the values presented are: switching from lignite to charcoal operation entails very high costs, which create discrepancies between solutions of the same type in terms of investment; the most expensive solution turns out to be the A_8-AMD_4 scenario, and the cheapest is maintaining the current profile with the introduction of desulphurization facilities.

It noted the presence in the first four scenarios of three solutions based on the use of lignite, even if it is not about the evaluation of operating costs, where the price of fuel would be preponderant.

4.1. Economic performance indicators

The economic analysis involves calculating the financial indicators of the projects. For this purpose, the updated financial flow method was used in line with internationally accepted standards. For the calculation of performance indicators, the updated financial flow also includes the amount of the investment [3, 5, 6].

The project performance evaluation criteria are: net income, NI; internal return rate, IRR; and updated recovery period of invested capital, Ta.

Net income is calculated based on the annual financial flow (At), which takes into account investment expenses, operating expenses, and revenues. Future annual flows generated by the investment are updated at the time of commissioning of new plants. The viability of the project is established if the net income, calculated over the entire analysis period (t), is positive for an update rate (a) considered. The relationship for the net income estimation is:

No	Alternative	Investments (mil. Euro)
1	A_3-AM_3	75
2	A_4-AM_4	135
3	A_5-AMD_1	134
4	A_6-AMD_2	207
5	A_7-AMD_3	198
6	A_8-AMD_4	271
7	A_9-AMD_5	170
8	A_{10}-AMD_6	228
9	A_{11}-AD_1	151
10	A_{12}-AD_2	181
11	A_{13}-AD_3	171

Table 6. Estimates of investments by objective.

$$NI = \sum_{t=1}^{n} \frac{A_t}{(1+a)^t} \tag{1}$$

The net income reported under the project to the updated investment is the "net income rate, $R_{NI,}$" expressed in $USD_{NI}/USD_{investment}$.

$$R_{NI} = \frac{NI}{\sum_{t=1}^{PIF} \frac{IE_t}{(1+a)^t}} \tag{2}$$

This efficiency indicator derives from the "3e" rule - identifies the financial efficiency as an effect/effort ratio. It allows not only the appreciation of the project itself (for which R_{NI} higher than one is recommended) but also the comparison of several technical and economic variants (which entail considerably different investment costs).

The internal ratio (IRR) is also based on the updated cash flow and represents the "update" rate for which net income becomes zero. This is an indicator of the maximum interest rate at which borrowings can be made to finance the capital investment. The calculation relation for determining the internal ratio is:

$$\sum_{t=1}^{n} \frac{A_t}{(1+r)^t} = 0 \tag{3}$$

Upgraded recovery time (Ta) is a superior net income concept, especially for large-scale businesses. The method updates the net earnings, recorded each year, determining the period of recovery of the invested capital. It is a clear criterion for accepting projects.

The acceptability criterion is that the recovery period is less than the normal use period. This period corresponds to the moment when the cumulative net cumulative revenue becomes zero:

$$\sum_{t=1}^{T_a} \frac{A_t}{(1+a)^t} = 0 \tag{4}$$

The economic analysis, expressed by the updated net income, internal rate update, and refund time in update values gives the results presented in **Table 7**.

As can be seen from table, the most economically viable comparisons from the economic point of view are: the A_{11}-AD_1 solution presents the best value for economic efficiency indicators; A_3-AM_3 is ranked second; the A_7-AMD_3 solution is ranked third, following the economic analysis.

It is, however, observed that, in the assumptions considered, none of the solutions analyzed leads to positive net income values under the reference prices considered.

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No	Alternative	Investment, mil. Euro	NI, mil. Euro	The internal rate of return, %
1	A_3-AM_3	−1.007	0.63	—
2	A_4-AM_4	−6.107	—	—
3	A_5-AMD_1	−1.912	0.20	—
4	A_6-AMD_2	−9.348	—	—
5	A_7-AMD_3	−1.831	2.66	—
6	A_8-AMD_4	−9.799	—	—
7	A_9-AMD_5	−4.015	—	—
8	A_{10}-AMD_6	−8.346	—	—
9	A_{11}-AD_1	−899	6.33	—
10	A_{12}-AD_2	−5.637	—	—
11	A_{13}-AD_3	−5.548	—	—

Table 7. Values of economic criteria for proposed scenarios.

From these results, there is a group of solutions that are more effective (in relative terms) than the rest of the proposed scenarios. Solutions that involve running on coal cannot be an option for the development of the boiler because of the very high investment involved in boiler modification. Also, solutions that propose natural gas operation do not provide special economic performance, mainly due to the high price of this fuel.

As regards the internal return rate of the investment, in none of the projects it exceeds the discount rate of 10%. In conclusion, none of the projects is profitable, all are accompanied by losses. Solutions selected to be the subject of financial analysis are those that occupy the top four positions of the rankings, namely, A_3-AM_3, A_5-AMD_1, A_7-AMD_3, A_{11}-AD_1 **Table 8**.

It can be concluded that the plant must continue to operate on lignite. The installation of new groups, in parallel or not with the modernization of existing ones, will be decided by the price of capitalizing the electricity that will be produced. With faster growth than the forecasted price of electricity, the solutions will be favored, which increase the installed power of the plant and the annual amount of electricity produced and delivered.

No	Alternative	VNA, mil. Euro	RIR, %	TRA, years
1	A_{11}-AD_1	−899	6.33	—
2	A_3-AM_3	−1.007	0.63	—
3	A_7-AMD_3	−1.831	2.66	—
4	A_5-AMD_1	−1.912	0.20	—

Table 8. Solutions selected to be the subject of financial analysis.

4.2. Sensitivity analysis

The aim of the sensitivity analysis is to determine the variation of the economic indicators values when certain parameters are changing and to check the ranking obtained from the economic analysis for various scenarios [7].

The most important parameter at which the sensitivity of economic indicators is checked is the slope of increasing electricity price. This increase was considered, as a reference value, to be 10% per year [8, 9]. The sensitivity of economic efficiency (expressed by net income variation) was studied to change this growth slope from 5 to 15%. The values obtained from the calculation for the four proposed scenarios are presented in **Table 9**.

The conclusions resulted from this sensitivity analysis are:

- The efficiency of the project is extremely sensitive to the change in the price of energy recovery; any change in the slope of growth in the next few years may even change the order of the proposed scenarios;
- If there is not an annual increase of at least 10% of the electricity price, the continuity solution with the modernization of the existing equipment is the only one eligible; the conclusion is logical because in the absence of industrial heat consumption and a favorable evolution of the price of energy recovery, it is not efficient to make new investments.
- On the contrary, with an increase of the electric energy tariff up to 15%/year, the A_7-AMD_3 solution becomes the most efficient proposal because it is the project that offers the highest annual electricity for sale. In addition, the solution becomes economically efficient, with a positive NI value.

From the point of view of the variation of the electricity tariff on the market, these simulations were made in the assumption of an annual increase of electricity tariff of 10%/year. When this increase is higher (15%/year), the order is preserved, even NI for the first rank is positive because this is the project that offers the largest annual amount of electricity for sale. When this increase is lower (5%/year), the continuity scenario, A_3-AM_3, is on the first place because,

Alternative	Slope variation of increase of electricity price		
	5%	10% (ref)	15%
A_{11}-AD_1	−2.011	−899	231
A_3-AM_3	−1.982	−1.007	−33
A_7-AMD_3	−3.593	−1.831	−68
A_5-AMD_1	−3.435	−1.912	−390

Table 9. Sensitivity of NI (millions Euro) to the change in the slope of the electricity price increase.

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in the absence of industrial heat consumption and a favorable evolution of the energy recovery tariff, it is not efficient to make new investments [10].

5. Environmental impact

Primary fuel used is Oltenia lignite, support fuel—oil. **Table 10** shows the energy characteristics of fuel use. An environmental impact assessment was conducted for each energy solution, by taking into consideration the energy generators functioning on lignite and fuel oil as support fuel amounting to a 6% heating contribution, respectively; the amount of solid particles issued, the amount—concentration of CO_2, SO_2, and NO_x.

The environmental impact assessment is analyzed on four technical options, all without the main economic agent, namely: A_3-AM_3—equipment: actual—new type turbine, fuel type: 95% coal, 5% liquid fuel support, energy with fuel: coal 5,301,116 MWh/year and liquid fuel 340,006 MWh/year, A_5-AMD_1—equipment: actual—new type turbine—100, fuel type: 95% coal, 5% liquid fuel support, energy with fuel: coal 7,880,065 MWh/year and liquid fuel 498,963 MWh/year, A_7-AMD_3—equipment: actual—new type turbine - 200, fuel type: 95% coal, 5% liquid fuel support, energy with fuel: coal 8,401,060 MWh/year and liquid fuel 528,714 MWh/year and A_{11}-AD_1—equipment: new group with intermediate superheating and urban connection, fuel type: 93% coal +7% liquid fuel support, energy with fuel: coal 5.046.869 MWh/year and liquid fuel 376,981 MWh/year [11].

The calculations impose, in a first stage, the determination of the chemical composition to the equivalent fuel, the coal-HFO mixture. The recurrence relationship is:

$$X = m_c X^i + m_{HFO} X_{HFO} \tag{5}$$

Energy characteristic		Primary fuel	Support fuel
Chemical composition,%	C^i	23.10	87.15
	H^i	1.80	10.70
	O^i	9.60	0.70
	S_c^i	1.50	1.00
	N^i	0.63	0.15
	A^i	21.60	0.20
	W_t^i	41.77	0.10
Low calorific power, H_i, kJ/kg		7753.60	40,595

Table 10. Energy characteristics of fuels.

where m_c, m_{HFO} is the mass participation of the coal and the HFO in the mixture, and X^i, X_{HFO} is the percentage participation of the element in the coal composition, respectively, in HFO composition, to the initial state.

The second stage aims at determining the combustion products [12–15]. Therefore, is determined [16]:

- theoretical amount of oxygen required for combustion, Nm^3/kg:

$$V_{O2}^0 = 1.867\frac{C}{100} + 5.6\frac{H}{100} + 0.7\frac{S_c}{100} - 0.7\frac{O}{100} \tag{6}$$

- theoretical volume of dry air required for combustion, Nm^3/kg:

$$V_a^0 = \frac{1}{0.21}\left(1.867\frac{C}{100} + 5.6\frac{H}{100} + 0.7\frac{S_c}{100} - 0.7\frac{O}{100}\right) \tag{7}$$

- theoretical volume of humid air needed for combustion, Nm^3/kg:

$$V_{aum}^0 = 1.0161V_a^0 \tag{8}$$

- theoretical volume of triatomic gases, Nm^3/kg:

$$V_{RO2}^0 = 1.867\frac{C + 0.375S_c}{100} \tag{9}$$

- theoretical volume of diatomic gases, Nm^3/kg:

$$V_{N2}^0 = 0.79V_a^0 + 0.8\frac{N}{100} \tag{10}$$

- theoretical volume of water vapor, Nm^3/kg:

$$V_{H2O}^0 = 0.112H + 0.01244W_t + 0.00161 \cdot x \cdot V_a^0 \tag{11}$$

- theoretical volume of dry combustion gases, Nm^3/kg:

$$V_{gu}^0 = V_{RO2}^0 + V_{N2}^0 \tag{12}$$

- theoretical volume of the combustion gases, Nm^3/kg:

$$V_{ga}^0 = V_{gu}^0 + V_{H2O}^0 \tag{13}$$

- real volume of the combustion gases, Nm^3/kg:

$$V_{ga} = V_{ga}^0 + (\lambda - 1)V_{aum}^0 \tag{14}$$

- actual flow of the combustion gases:

$$D_{gN} = B_{ech} \cdot V_g(\lambda) \tag{15}$$

Table 11 shows the calculation of the enthalpy of the combustion gases according to the temperature and the coefficient of excess air.

The scheme for calculation of the combustion and the exit temperature of gases in the furnace has been carried out using Matlab-Simulink software [12–15]. In **Figure 1**, the scheme for combustion calculation is given.

Figure 2 shows the scheme for the determination of the equivalent fuel chemical composition.

The amount of particulate matter emitted is given by, [g/s]:

$$M_c = 10\left(A + q_m \frac{H_i}{32700}\right)\alpha_c B \tag{16}$$

and the ash concentration before the electrostatic precipitator, $[mg/Nm^3]$:

$$c_c = \frac{M_c}{D_{gN}} \tag{17}$$

t [°C]	I_g^0	I_a	I^0_{aum}	$I_g = I_g^0 + I_a + (\lambda\text{-}1)I^0_{aum}$	
				$\lambda_f = 1.2$	$\lambda_f = 1.4$
100	434.90	15.24	318.1	514.2	576.9
200	883.04	31.97	638.9	1041.8	1171.3
400	1815.93	69.11	1299.7	2143.9	2402.1
800	3845.12	148.3	2710.2	4541.7	5080.04
1000	4930.64	193.1	3456.8	5811.6	6501.6
1400	7203.18	312.7	4994.8	8506.2	9507.9
1600	8392.33	382.4	5772.5	9912.7	11048.2

Table 11. Enthalpy-temperature—Coal-HFO mixture, q_{HFO} = 6%.

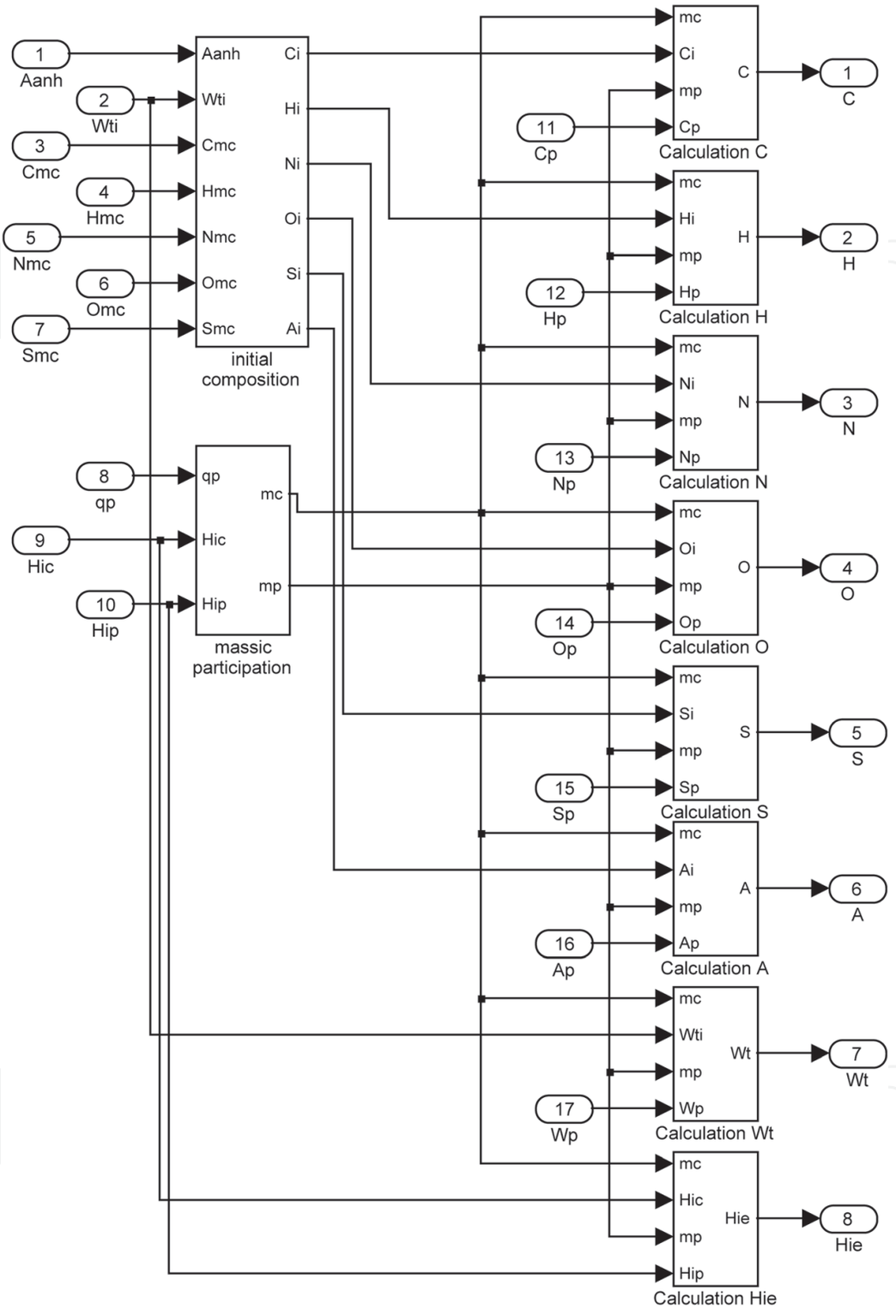


Figure 1. Scheme for determining the equivalent fuel chemical composition [12–15].

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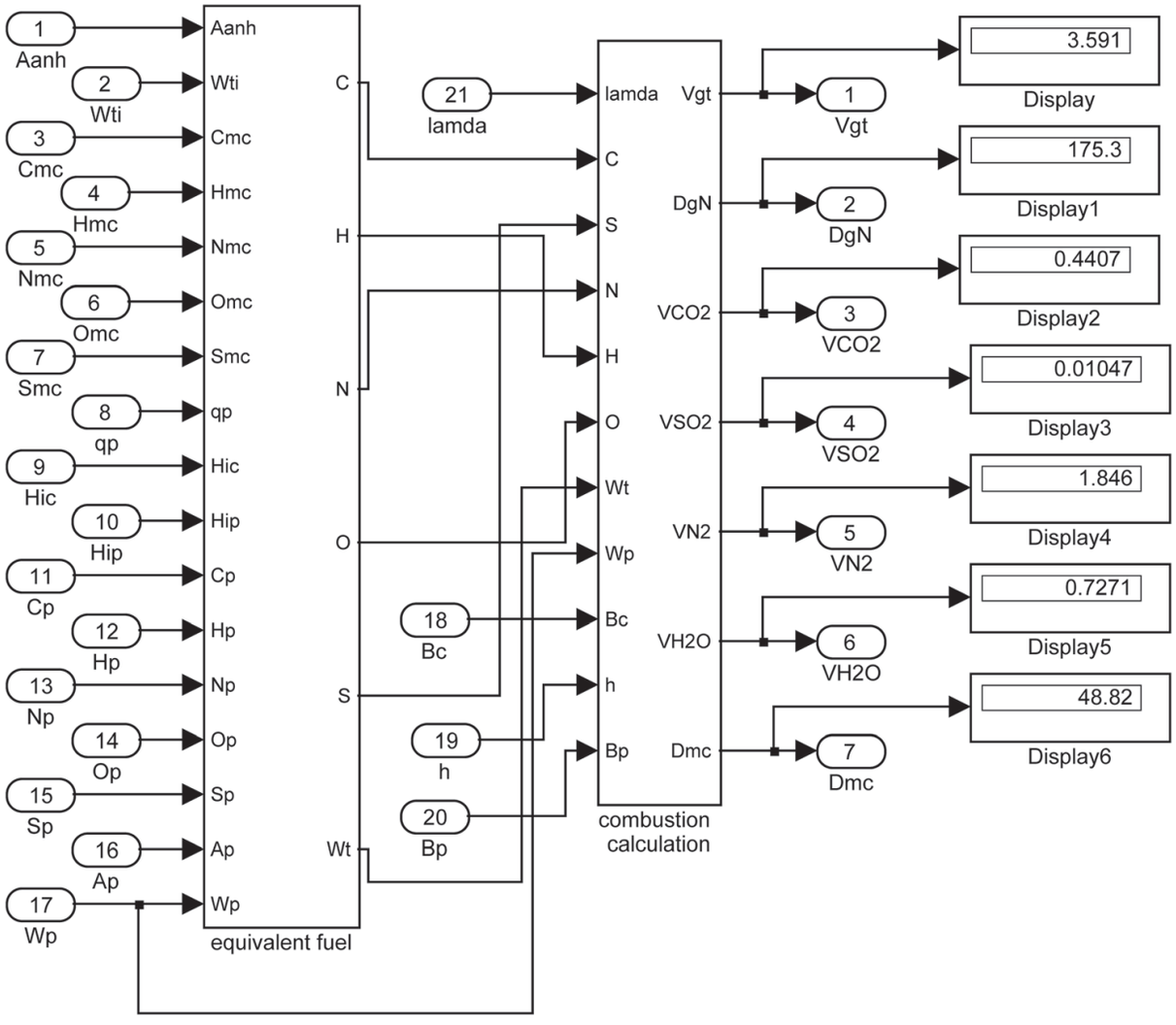


Figure 2. Scheme for the calculation of the combustion products [12–15].

The amount and concentration of CO_2 are:

$$M_{CO2} = 36.66 \cdot C \cdot B \tag{18}$$

$$c_{CO2} = \frac{M_{CO2}}{D_{gN}} \tag{19}$$

The concentration of SO_2 before the desulphurization installation (with $\eta = 0.94$ in order to respect the limit 400 mg/Nm^3) is:

$$c_{SO2} = \frac{M_{SO2}}{D_{gN}} \tag{20}$$

The amount and the concentration of NO_2 are:

$$M_{NO2} = B \cdot H_i \cdot k_{NO2} \tag{21}$$

$$c_{NO2} = \frac{M_{NO2}}{D_{gN}} \tag{22}$$

In order to lower the c_{NO2} value below the regulated one, a primary method of reducing the concentration of NO_2 may be used. For example: low excess air, reducing the preheating temperature of the air, and low NOx burners. Environmental conditions imposed can only be met by imposing minimum technical measures, whatever the scenario being analyzed. **Table 12** shows these measures, namely, efficiency of the electrostatic precipitator, efficiency of the wet scrubber, primary method of NO_x reduction, and reduction of the rate of excess air upon exhaust (to approximately 1.4).

Comparing the four technical scenarios analyzed, it is noted that the most environmentally friendly are in order: the development scenario with a 200 MW group and the continuity scenario in the current scheme.

No	Parameter	A_3-AM_3	A_5-AMD_1	A_7-AMD_3	A_{11}-AD_3
1	Coal flow, t/h	263.66	422.39	447.98	274.03
2	HFO flow, t/h	4.00	5.69	6.10	4.45
3	Combustion gases flow, m^3_N/h	1124.46	1677.38	1775.87	1084.02
4	Amount retained slag and ash, t/year	522,550	794,122	822,550	510,310
5	Amount CO_2 produced, t/year	2,119,006	3,158,961	3,352,088	2,041,116
6	NOx reduction method	primary	primary	primary	primary
7	Needed limescale, t/year	105,000	159,000	167,144	101,020
8	Production of dry gypsum, t/year	141,011	220,191	224,998	137,200
9	Electrofilter efficiency, %	99.9	99.9	99.9	99.9
10	Wet scrubber efficiency, t/year	93	93	93	93

Table 12. Minimum technical measures require.

6. Result and discussion

The possible cessation of strategic customer activity will drastically reduce the plant's operational efficiency and compromise further participation in its energy market, whatever the scenario under consideration. The only ways to survive the power plant are:

- Administrative integration of the power plant with the mining units so that the lignite price is less than 8 Euro/MWht. In **Figure 3**, one can see the tendency of variation in the operational cost of energy (electrical + thermal) for the four scenarios, compared to the continuity scenario characterized by the maintenance of the strategic client.

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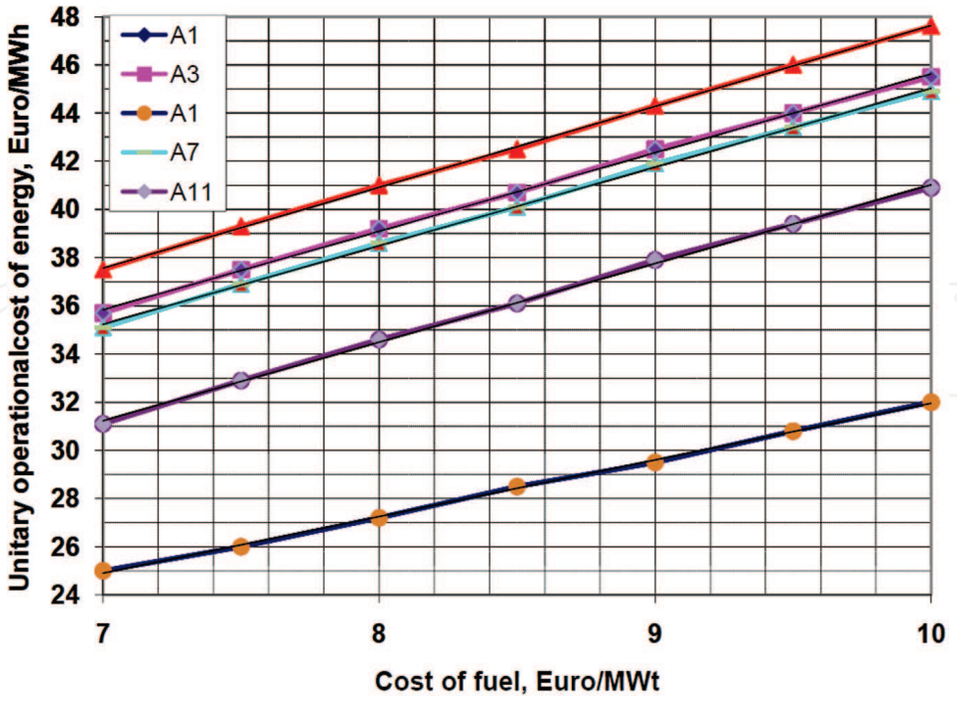


Figure 3. Variation of the specific energy cost depending on the lignite price [10].

The calculation was based on the situation, where the weight of the fuel of 8.5 Euro/MWht is 70% in the total expenses of the boiler plant. The lowest cost is given by the current scheme in operation with the most important customer. The next scenario is the development with a 200 MW group.

- Conclusion of long-term electricity contracts at prices slightly above the market price.
- Efficiency of branch activity by increasing the share of fuel in electricity from 70 to 80–85%.
- Finding an industrial steam consumer to replace the current one in the thermal balance of the power plant.
- Increasing the thermal energy delivered in cogeneration by finding low-level heat consumers (greenhouses); in this case, the operation of the plant can only be profitable in seasonal mode (15 October–15 March).

7. Conclusions

The plant will only be able to operate on scenarios that use primary fuel, lignite. The choice of one or the other of the existing solutions will be based solely on the analysis of the evolution of the price of electricity utilization. If this parameter has an annual growth slope of more than 10%, projects involving the increase of installed power, A_3-AM_3, are preferred and should be taken into account. However, if, in the coming years, there is a slower increase in the price of

electricity used, caution should be exercised when making a decision on new investments in the increase of installed power.

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