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CHAPTER 2.3. STOCHASTIC APROACH TO ECONOMICAL ANALYSIS OF BIOMASS POWER PLANTS

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ABSTRACT

The global community is motivated to move towards renewable energy supply and market based operation in power systems. In the core of this change is an aspiration of the reduced the influence of power generation on the environment and the increased power supply efficiency, which is achieved through market conditions and free competition within generation and sales of energy. These new conditions define significant changes in the design and planning of the operation of the biomass stations.

First step in the power plant development project is pre-feasibility study. As a result of such study, a developer would choose a place of construction, type of fuel, the connection scheme to the power grid, would estimate the necessary capital expenses, the energy to be produced, production costs and profits from the energy sales. Economic analysis is an important part of the pre-feasibility study of the power plant. Usually, power plant design is evaluated in terms of the profit maximization and the following economic criteria, e.g. NPV, IRR, payback time.

The introduction of the markets in power systems substantially changes the approach to economic analysis of the power plant profitability. Free market and competition implies uncertainty. Consequently, the energy prices and revenues of power producers are subject to significant fluctuations. The criteria for profit maximization for the stakeholders shall be reformulated. The uncertain and random parameters, such as the ambient temperature, thermal energy consumption, price of energy has to be taken into account. The task assumes a stochastic form. An additional input information is needed in a large volume. As a result, the problem becomes much more complicated and requires new algorithms and software tools to solve it.

This paper proposes a procedure to estimate the average value of these criteria taking into account random nature of the variables and using the historic values of parameters. Besides, we use neural network based algorithm to predict processes in future from the historical data. We capture information on various input parameters, such as temperatures prices etc from the internet. A case study is conducted on a realistic project of the cogeneration biomass power plant (2 MW) and demonstrates the advantages of the stochastic approach.

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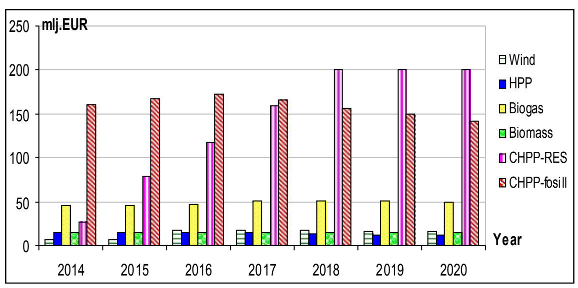
It is concluded that the proposed approach to profitability analysis, developed algorithms, the data capture from Internet, enhanced user friendly interface shall support and enable improved decision making.

Key words: power plant, renewable energy, market price, stochastic optimization

Introduction

An objective to prevent the climate changes, to increase security and reliability of the power supply stimulates construction of the large number of power plant (PP) with renewable energy sources (RES). In the period from 2000 to 2014 biogas, biomass, wind and photovoltaic were member has its own share of renewable energy amount, which should be significantly increased by 2020. Sufficiently ambitious target beyond 2010 are established. According to European Union (EU) Directives each EU country has a target of at least a 20 % share of energy from renewable sources in the EU gross final consumption of energy in 2020. Each EU member has its own share of renewable energy amount, which should be increased by 2020. In Figure 1 a) are represented the planed investments in Latvia till 2020. For country with 2 millions habitants investments should be recognized as substantial.

a)



b)

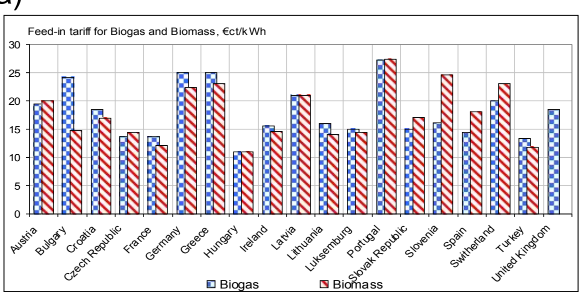


FIGURE 1. a) The prognostication of investments into RES and b) feed-in tariff of biogas and biomass PP in Europe.

Striving to ensure planed objective consummation global community has established favorable national feed-in support schemes for the renewable electricity. Renewable energy is promoted through these schemes in the whole world and, particularly, in European Union (EU). The existing support schemes include quotas for construction, investment grants, feed-in tariffs, tax measures, green certificates (Final Report of Energize Missouri, 2012; RESLegal, 2014).

Frequently, the support is provided by a guaranteed purchase price, which is significantly higher than the market price of electricity. Supported by feed-in tariffs (Figure 1. b)) the biogas and biomass PP are developing especially rapidly in the northern Europe. It is nature to require that RES development shall be achieved in a possibly most cost efficient manner. First and highly important for effectiveness ensuring step in the design of new power plants should be devoted to the feasibility study. As a result of this study is selected place of construction, type of fuel, the connection diagram to the power grid, is estimated the necessary capital expenses, the amount of produced energy, the proceeds from its sales and cost of production. Usually, power plants planning issues are formulated in the form of profit maximization problems. For this purpose, designers use a number of economical criteria, such as NPV, IRR, payback time (Bennett, 2003; Buljevich *et al.*, 1999). In this paper we limit ourselves using only NPV, while generality is not lost, since outlined below algorithm can be easily extended to compute and other economical criteria.

In general, the goal of this paper is to propose a new methodology of feasibility studies, that allows selection of PP structure and parameters taking into account the hourly variation of a market situation. We solve such problem using stochastic approach for a small bio PP feasibility study (first contribution of the paper). We apply data bases, which are available by Internet and Smart grids means; artificial neural network for random processes prediction

The second contribution of the paper is the case study that demonstrates the proposed methodology and algorithm workability.

The rest of the paper is organized as follows: first, the shortcomings of existing methodologies are formulated, second, the algorithm of revenues calculation is presented, and the third, the case study illustrating the proposed methodology in the realistic set-up is described.

Shortcomings of existed methodologies

The complicated process of the technical-economical evaluation of the highly expensive energy units installations, in particular power plants, include several stages, as follows:

- Forecasts of the demand for the energy supply (heat and the electricity) for the period of 20 – 30 years;
- Preliminary choice of the competitiveness of the various options for the energy supply for the customers;
- Development of the sketches for the chosen alternatives and feasibility studies;
- The choice of the best alternative and decision making on the implementation of the project;
- The implementation of the project.

The last three stages are connected with the necessity to evaluate main economic indices: NPV, IRR, (Bennett *et.al.*, 2003; Buljevich 1999). To evaluate these indices we need to determine the income $I(T_i)$ from the energy sales and the expenses $E(T_i)$ for its production. Usually T_i equals to a year period. If we know $I(T_i)$ and $E(T_i)$ it is easy to determine cash flow $R(T_i)$

$$R(T_i) = I(T_i) - E(T_i). \qquad (1)$$

Value NPV is given by equation below:

$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \qquad (2)$$

where t – the year of the cash flow, i – discount rate (rate of return that could be earned on an investment in financial markets with similar risk. Cash flow within 12 months will not be discounted for NPV purpose. Investments during the time interval from the initial design to power plant start-up are summed up with a negative cash flow.

In NPV criterion value assessment greatest difficulties arise in computing the net cash flow R_t , because profits depend from chart (working diagram), construction (structure) and regime of the power plant, fuel and energy prices, ambient temperature. One can state that the parameters determining the economic efficiency of the power plant are subjected to the seasonal, monthly, weekly and hourly variations and can be described in terms of stochastic functions (Korn *et al*., 1968; Seifert *et al*., 1960).

To avoid difficulties in estimating of power plant economic efficiency a scenario approach and replacing random variables and stochastic processes by their time average values are used (Karagiannopoulos *et al*., 2014; Neimane, 2001).

Time average values could be chosen in different ways. There is known and applied methodology that is based on the division of the year into the seasons (winter, spring, fall, and summer) and a selection of typical days (working or holiday) for each season. In this case, the mean values of each day are used and revenues are calculated for each season based on the number of typical days (Neimane, 2001).

Another methodology is based on a division of the year on the months and use of the corresponding mean values for cash flow calculation. The disadvantage of these methodologies is the impossibility of considering the real price (the examples are presented in Figures 3) changes in market conditions that occur every hour. Prices, temperature changes have influence on choice of mode of PP operation and cash flow R_t.estimation.

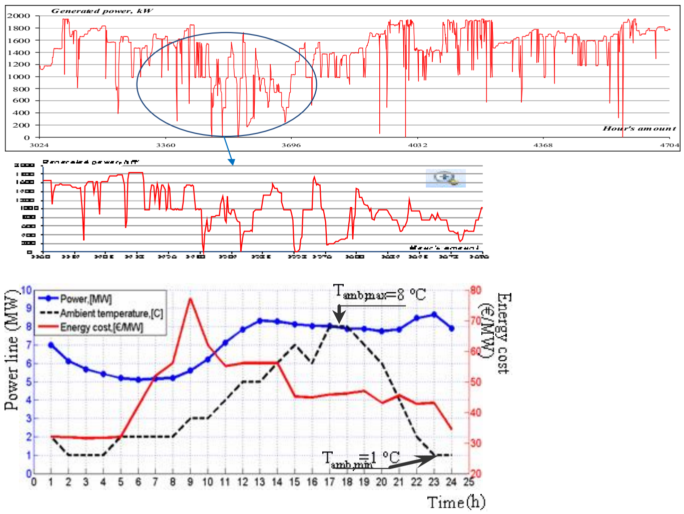


FIGURE 3. Stochastic processes daily curves examples.

As a result, in the absence of detailed information on changing operational environment of power plant impossible to prove its mode of operation. Irregularity of the power generation is taken into account very roughly by introducing the concepts - the number of hours of use maximum power or availability factor (Grace, 2011). The example of the real bio PP power generation process is shown in Figure 3. Presented curve demonstrate large variation of generation conditions and difficulties to apply named above concepts.

The second problem is related to the need to deal with uncertainty by using the scenario approach.

With this approach the variables describing the scenario lose their uncertain nature. However, this simplification is achieved due to the fact that final decision making process becomes more complicated (Neimane, 2001).

Number of scenarios, which have to be examined, number of the combination of uncertain parameters can be very large, what complicates the choice of suitable alternatives of power plant design and decision about choosing the best among them. In practice, the progress of the project is accompanied by negotiations with investors, with companies - suppliers of equipment, landowners. Some of the values initially uncertain parameters become known and a necessity to recalculate the criteria appears. As a result, feasibility studies of project are performed multiple times that leads to additional time and cost.

Essence of new method

The NPV estimation task is based on calculation of the net cash flow, which can be described as:

$$R(t,\Delta t)=\varphi[x_1(t),x_2(t),...x_n(t);\Delta t;\Pi], \qquad (3)$$

where $x_1(t)$, $x_2(t)$, are time depending parameters which influence cash flow, namely plant electrical and thermal power, energy and fuel prices, ambient temperature. *Δt* – time interval under consideration; *П* – include parameters which are time independent (investment and maintenance cost, investors and stakeholders interest rate).

Analyzing (3) it can be claimed that powers, energy price and temperature are random, time dependent parameters which are correlated to each other. Correspondingly, also R_t is a random time function. Multidimensional random process can be transformed by discretization of the function *R(t)* to a number of time periods (Korn *et al*., 1968):

$$\begin{aligned} &t_1,\, t_2,\ldots,\, t_n < T_{PL}\,, \\ &t_1, t_2,\ldots,\, t_K \end{aligned} \tag{4}$$

where T_{PL} is length of planning period.

Multidimensional probability distribution function *Φ* can be assigned for each random value $x_i(t_i)$ and for each time period t_i. These distribution functions can be described as:

$$\Phi[x_i(t_i)] = \Phi[x_1(t_1); x_2(t_2); \ldots x_n(t_1); \ldots x_1(t_k); \ldots x_n(t_k); \ldots]$$

(5)

Having the probability distribution functions the average cash flow can be calculated as:

$$M[R(x(t_i))] = \int_{-\infty}^{+\infty} \ldots \int_{-\infty}^{+\infty} R\big(x(t_i)\big) d\Phi\big(x(t_i)\big) \tag{6}$$

Analyzing the equation (6) one can easily state that probabilistic approach has led us to formulation of extremely complicated target function for given problem. In order to estimate the NPV value according to (6) the multidimensional integral should be calculated. It should be added that for the considered task the dimension of the integral can be huge, since the planning period for the power plants is normally 20-30 years. At the same time the electricity prices, temperature, thermal load can vary considerably on hourly bases. This means that the number of discrete time periods leading to the dimension of the integral can become hundreds of thousands. Moreover, in specified task it is necessary to operate with at least three correlated processes (prices, temperature, and thermal load). In this case autocorrelation and correlation functions should be taken into account. It can be confirmed, that in order to avoid labor-intensive calculations it is necessary to limit the number of sampling time moment, because each moment should be described by the distribution function. For this purpose, as was mentioned above, it is possible to use detachment of year into few specific days The distribution functions of the parameters for each of such days can be approximated for example by Pearson charts (Neimane, 2001). However, this kind of analysis is still demanding a lot of efforts. This paper presents the new approach to solve the problem.

The algorithm for estimation of the power plant net cash flow, described below, is based on the following assumptions:

1) Cost of energy, temperature, power and heat loads are the random, time dependent function;

2) Considerable amount of data from the past is available (databases formed by supervisory control and data acquisition (SCADA) system);

3) The records from the past can be projected into the future processes;

4) Projection of the records from the „past" *xpast* into the „future" processes *xfut* can be performed by using one of the stochastic processes forecasting parametric or artificial intelligence based methods (Gurney, 1997; Hassoum *et al*., 1995).

In this paper the following two procedures are used (see Figure 4. a)):

- the linear algebraic expressions that describe changes in the characteristics of the random process in time (for example average value of prices in the future). It is assumed that such changes reflect the expert's opinion;
- the records of the past processes with anticipated changes are summing up. In this case, the planned future load can be added to the historical load records. For this purpose library of thermal energy consumer's demand records was created.

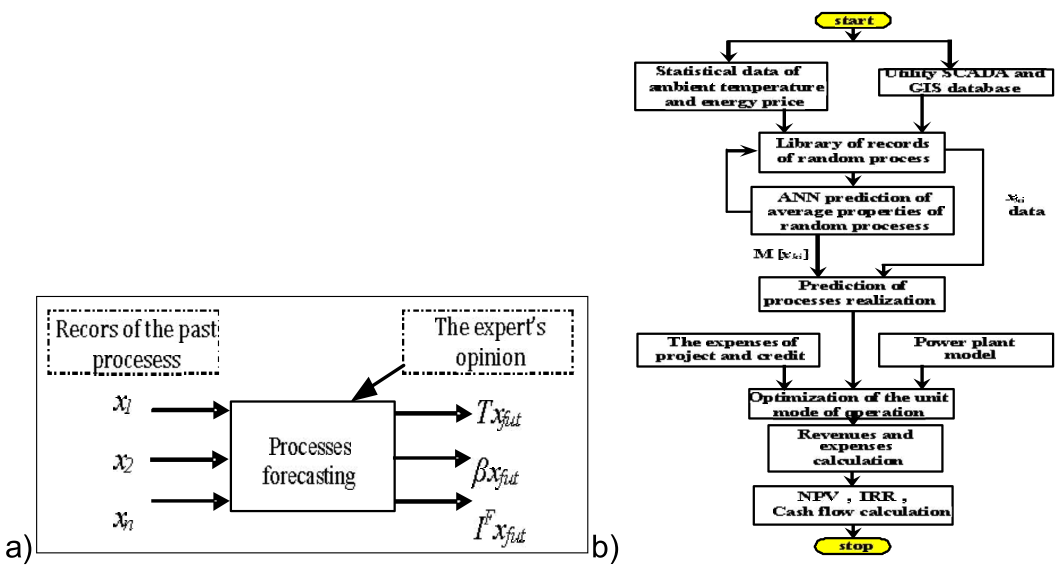


FIGURE 4. Scheme of processes prediction and an algorithm structures.

5) The random process of parameters x_{fut} variations is ergodic (Seifert *et al*., 1960) (the term is used to describe a dynamical system which, broadly speaking, has the same behavior averaged over time as averaged over the space of all the system's states). In this case:

$$M[R(x(t_i))] = \sum_{i=1}^{k} R(x(t_i + \Delta t \cdot i)), \quad (7)$$

where k - is the number of hours in year, 8760 hours; $R[x(t_i)]$ – profit in hour i.

The adoption (7) instead of (6) allows us to calculate the average value of the annual expenditure on the basis of multidimensional casual process with x_1, x_2

The new method is based on the following assumptions and requirements (Figure 5):

1. The forecast of influenced parameters of designed power plant should be used. The prediction should cover the entire planning period (20-30 years) up to every hour.
2. Mode of operation of the plant and, accordingly, the cash flow should be defined for each hour, depending on the specific conditions of the planed day. De facto we propose short term planning methodology (Ravn *et al*., 2004) incorporate into long term planning tasks.
3. Feed of huge volume of input data should be provided. For this purpose we are using Internet (power market prices (Nord Pool Spot, 2014) and ambient temperature) and Smart grid technologies (including SCADA and a Geographic Information System (GIS), which allow the creation of multi layered maps and thermal load historical data records).
4. Results of the feasibility study have to be represented in the form of software, providing the ability to change the conditions (scenario) of the operation of power plant.

The introduced algorithm of the Figure 4. b) contains programming blocks which are providing the simulating options and optimization processes for power plant regime planning according set influenced processes (models of influenced processes variation and optimization of the unit mode of operation).

The description of operation mode. The optimization of the unit mode operation goes out from the frames of this paper, because has been extensively discussed in the literature see (Ravn *et al*., 2004). In the task of short term planning various approaches to obtain approximate solution for the PP regime parameters selection over a daily or even longer horizon has been proposed

For the facilitation the power plants designing special software, for example, Termoflow (Termoflow homepage, 2014) are used. These programs contain the knowledge base, which generalizes experience of designing similar facilities, and provides a rational choice of several, the most efficient structures and equipment for implementation of power plant under design. Named software provides ability to calculate the profit of power plant in given mode of operation and prices. Mentioned calculations can be used to create models of plants that can be implemented in programs that are independent of Thermoflow. For this purpose, it is necessary to use a called program to carry out calculations of fuel consumption (S_{fi}) for different modes of power plant operation:

$$S_{fi} = M(Q_{ti}, P_{ei}, T_i), \tag{8}$$

where i is number of modes of operation, Q_{ti} is heat consumption, P_{ei} electrical power and T_i ambient temperature. M is a procedure, generated by the Thermoflow program, which provides calculation of fuel consumption for a given operation mode i. To overcome the issue of the calculations accuracy can take the opportunity of approximating the M via polynomials where coefficients may be selected using, for instance, the method of least squares.

Simulating and forecasting of the random processes realization. Let us make the following assumptions to build the model for the forecasting of the processes realizations:

1. The average properties of the addressed process might be forecasted by the models that are based on the artificial neural networks. The literature review dedicated to this topic one can find for example in (Gurney, 1997; Hassoum *et al*., 1995);
2. Statistical properties of the deviations from the forecasted average values are dependent only on the length of the interval between the instance of the forecast and the instance of the realization, as well as the particular hour in the day.

Once the assumptions above are accepted, we can proceed with the model as in Figure 5. The model frees us from the necessity to use the common yet not always justified hypotheses: independence of the random parameters, normal distribution of the deviation from the mathematical expectation as is frequently adopted in (Karagiannopoulos *et al.*, 2014).

The structure of the neural network for the power market price forecasting is shown in Figure 6. The input parameters are: week number in the year; hour in the day; hourly changes in the air temperature.

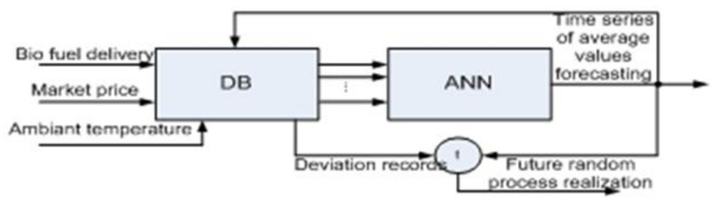


FIGURE 5. The forecasting algorithm of random process realization.
DB – the considered process realization data base;
ANN – an artificial neural network.

a) b)

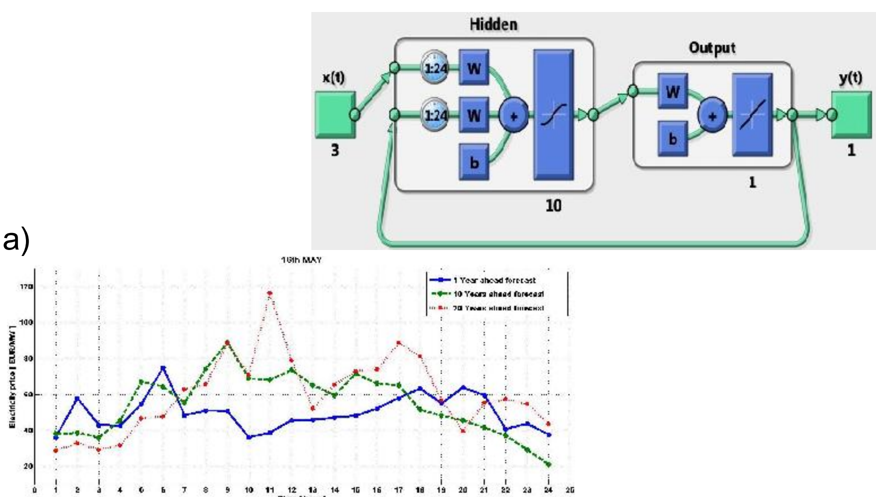


Figure 6. Structure of the neural network and the electricity price forecasting.

The trained neural network uses records of the prices and the temperatures, as well as water inflows in the previous week to create the forecast or to simulate the future process.

For price prediction the opinion of experts of average price increasing for 2% per year are used. Fragment of predicted prices for 1, 10 and 20 years are presents at Figure 6 b).

Software structure. Software development is based on the following assumptions and requirements. First is that software should be developed for windows environment. Second, to simplify the task of software development, it is desirable to use the MATLAB opportunities (Phan, 2006; Huynh *et al*., 2008).

For purpose to build applications and software components program MATLAB Compiler were used. This product lets as share MATLAB programs as applications for integration with common programming languages, which enables deployment for users who do not have MATLAB. Use of the titled product led to need to select the C++ language and Microsoft Visual C++ integrated software development environment. Thereby, we compose Graphical User Interface in C++ using Visual Studio 2013 and MATLAB computing capabilities by connecting modules compiled in the form of libraries or exe modules. Software structure is shown on Figure 7.

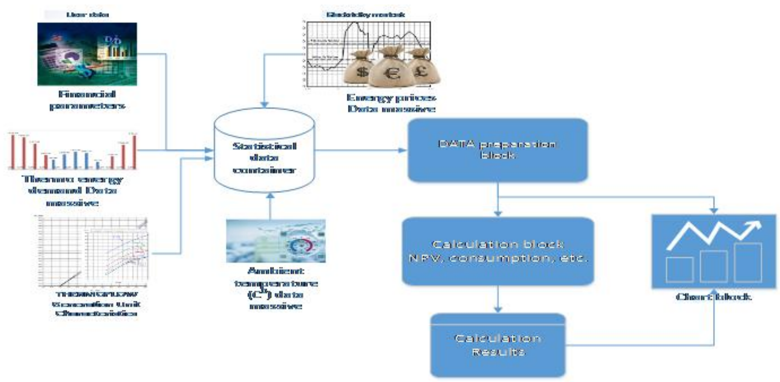


Figure 7. Software structure.

The described software offers the possibility of changing the scenarios and source data. To do this, even a novice user should spend only a few minutes.

The case study

The results below illustrate the main steps of the algorithm, which is proposed to economic analysis of biogas power plants.

The core characteristics of the biogas PP. The bio power plant has the following characteristics: the PP nominal power - 2 MWel; structure of the PP - Bio reactors, internal combustion engine, thermal energy storage; type of biomass – chicken manure; the main operational regime – cogeneration; estimated capital investments amount – 4 370 000 EUR. In accordance with the granted license, the PP is guaranteed fixed power price of 0.22 EUR/kWh as compulsory purchase price only first 10 years, after their work at market price schedule. For market prices prediction Nord Pool Nord (Pool Spot, 2014) historical data has used. For ambient temperature prediction airport Riga historical data has used and for thermal load prediction Latvian power systems SCADA and GIS records are used.

NPV calculation results. The results of the cash flow calculation are presented in Figure 8 and Table 1.

The curves 1 and 1' show the cash flow which is calculated with the classic methodology. This methodology is based on division of year into seasons, with the displaying typical days and with considering maximum power hour's amount (it is assumed 7000 hours). At first case PP works at market conditions (curve 1) without fixed purchased electricity price. 1'- works according granted price (22 €ct/kWh).

The curves 2, 2' and 2'' show the estimated method usage for cash flow calculation. Curve 2 reflects result without supporting with fixed price, but 2' is results at fixed price for all planed period. The curve 2'' reflects the mixed case (PP is supported first 10 years and after those works without support). The curves 1' and 2' constructed on basis of optimistic scenario use with assuming that feed-in tariff will be extend after first 10 years of work beginning. But curves 1 and 2 are made without considering feed-in tariff and show the need of PP support.

TABLE 1. The input data and the results of regime planning.

Parameters	P_{el}, MW	Q_t, MW	Fuel type	Biomass price, €/ton	Biogas output,m3 /ton	Gas consumption, m3/h	Investments, €/kWel	OveRall investments ,mln. €	Thermal energy price, €/kWh	Infla-tion, forecast per year %	Bank rate %	1st year income,mln. €	Accrued discounted cash flow, mln. € 20^{th} year
Curve 1	1.9	2.44	Biogas CH_4 =60%	7	80	780	2300	4.37	0.03	2	4	0.263	-0.972
Curve 2	1.9	2.44		7	80	780	2300	4.37				0.355	0.491
Curve 1'	1.9	2.44		7	80	780	2300	4.37				2.42	26.774
Curve 2'	1.9	2.44		7	80	780	2300	4.37				2.90	35.348
Curve 2''	1.9	2.44		7	80	780	2300	4.37				2.90	18.584

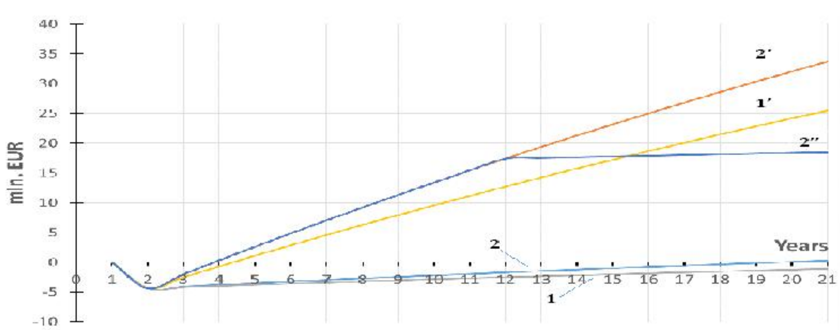


Figure 8. The optimization results in different cases.

The results of offered method are more attractive for investors, and could be explained with factors, as:

1. The forecast of the reduced consumption of PP thermal energy own needs.
2. The prediction of the greater working times of the PP units at maximum price hours.

Conclusion

To diminish the influence of the energy industry on the climate change, the global community involves various renewable resources support schemes. As the result of these measures, the number and installed capacity of the power plants with the renewable energy fuel is growing rapidly.

With the market conditions and tools implementation on power system operation and planning the feasibility study tasks conditions change substantially, necessity to take into account stochastic nature of variables appear.

The stochastic approach to the power plants feasibility study requires a large amount of input information. The difficulties of collecting input data can be overcome by using the opportunities of the Internet and smart grid technologies

The software accompanying the description of the feasibility studies provides wide opportunities to consider additional scenarios and take into account new information

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