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**«НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ»
/ NATIONAL RESEARCH TOMSK POLYTECHNIC UNIVERSITY**

Институт – Энергетический / Institute – Power Supply
Направление подготовки – Электроэнергетика / Direction – Electric Power
Магистерская программа – Оптимизация развивающихся систем электроснабжения / MA Course – Optimization of developing power supply systems
Кафедра – Электроснабжения промышленных предприятий / Department – Industrial Electric Power Supply

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ / MASTER'S THESIS

Тема работы / Theme
«Применение миниТЭС в изолированной системе / High Efficiency CHP Plant in isolated system»

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Томск / Tomsk – 2014

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ЗАДАНИЕ / TASK
на выполнение выпускной квалификационной работы
/ for the execution of the graduate qualification work

В форме / Form:

магистерской диссертации / master thesis

Студенту / Student:

Группа / Group (Class)	**ФИО. / Surname Name**
5АМ4Ч	Будин Ян / Budin Jan

Тема работы / Theme:

«Применение миниТЭС в изолированной системе / High Efficiency CHP Plant in isolated system»	
Утверждена приказом директора (дата, номер) / Approved by order of the Rector (date, number)	

Срок сдачи студентом выполненной работы / Deadline student work done::	02 июня 2016 года / 2d June 2016

ТЕХНИЧЕСКОЕ ЗАДАНИЕ / PRELIMINARY SPECIFICATIONS:

Исходные данные к работе / Initial data	Сделать обзор по существующим возобновляемым источникам энергии, оценить их потенциал, с точки зрения выработки электрической энергии. Провести анализ характеристик основного энергетического оборудования автономной

	системы электроснабжения. Исследовать динамику выработки и потребления энергии. Разработать общую схему комбинированной электростанции. Выбрать материальную базу комбинированной электростанции в соответствии с разработанной схемой. Оценить экономическую эффективность применения для электроснабжения объектов инфраструктуры города.
Перечень подлежащих исследованию, проектированию и разработке вопросов / List to be investigated, design and development issues	– Combined heat and power systems; – Heating Sector in Russia; – CHP in Russia; – Case study on High Efficiency CHP plant in Tomsk; – Heat load duration curve coverage; – Power load duration curve coverage; Предусмотреть раздел социальной ответственности применительно к разрабатываемой системе электроснабжения.
Перечень графического материала / List of graphic material	Figure 1 cogeneration principle Figure 2 rankine cycle and related t-s diagram Figure 3 possible back pressure steam turbine configuration Figure 4 possible configuration of chp system with extraction condensing steam turbine Figure 5 gas engine cogeneration configuration Figure 6 possible configuration of cogeneration system with combined cycle gas turbine Figure 7 schematic diagram of orc process Figure 8 chp power generation in % of gross electricity generation in 2010 (russia 2007) Figure 9 fuel used to produce heat in russia (in petajoules) Figure 10 industrial energy supply with a chp plant

	payback period Figure 31 impact of changing heat tariff on payback period

Консультанты по разделам выпускной квалификационной работы / Consultants for the chapters of the graduate qualification work

(с указанием разделов / specifying chapters)

Раздел / Chapter	Консультант / Consultant
Финансовый менеджмент, ресурсоэффективность и ресурсосбережение / Financial management, resource efficiency and resource saving»	Старший преподаватель Потехина Нина Васильевна / Potekhina Nina
Социальная ответственность / Social Responsibility	Доцент к.т.н. Сурков М.А. / Surkov M.

Названия разделов, которые должны быть написаны на русском и иностранном языках / The titles of sections, which must be written in Russian and foreign languages:

Introduction

1. Combined heat and power systems

1.1. Description of CHP principle

1.2. Advantages of CHP

1.3. Description of Technologies

2. Heating Sector in Russia

2.1. Current State and Structure of Russian Heating Sector

2.2. Heat Tariffs in Russia

3. CHP in Russia

3.1. Current state

3.2. Priority of Dispatch for CHP Electricity

3.3. The Cross-Subsidization Issue of CHP in Russia

3.4. Industrial on-site CHP in Russia

4. Case study on High Efficiency CHP plant in Tomsk

4.1. Description of settlement and supplier

4.2. Heat load duration curve

4.3. Power load duration curve

4.4. Overall estimated production of CPH plant

4.5. Examined CHP unit’s configuration

4.6.	Heat load duration curve coverage
4.7.	Power load duration curve coverage
4.8.	Economic evaluation of the examined CHP system
4.9.	Sensitivity Analyses
6	Conclusion
7	References
8	Appendices

ТЕХНИЧЕСКОЕ ЗАДАНИЕ / PRELIMINARY SPECIFICATIONS:

Дата выдачи задания на выполнение выпускной квалификационной работы по линейному графику / Date of issuance of the task for the graduate qualification work on linear graph	11.10.2015

Задание выдал руководитель / Task issued supervisor:

Должность / Position	ФИО / Surname Name	Ученая степень, звание / Degree, title	Подпись / Signature	Дата/Date
Доцент	Сурков М.А. / Surkov M.	к.т.н.		

Задание принял к исполнению студент:

Группа / Position	ФИО / Surname Name	Подпись / Signature	Дата/Date
5АМ5Ч	Будин Ян / Budin Jan		

Guidelines

1. CHP technology description
2. Current state of heating sector in Russia
3. Current state of CHP in Russia
4. Opportunity study on high efficiency biomass-fired CHP plant in Tomsk

Thanks

Thanks to mine supervisor of this master’s thesis to Doc. M. A. Surkov, Ph. D. for help during consultations and all advices, which were always gladly provided.

In Prague on …………………………………………….. ………………………………..

Author’s signature

Declaration

I declare that thesis has been made independently and consistent with guidelines on compliance with ethical principles for the development of theses, and that I indicated all the information sources.

In Prague on …………………………………………….. ………………………………..

Author's signature

Abstract

This master's thesis deal with the high efficiency combined heat and power in Russia, particularly in Tomsk. Description of various types of cogeneration technologies, its advantages and disadvantages is given. Also, detailed description of Russian heating and CHP sectors is presented.

Based on this research, an opportunity study on biomass-fired high efficiency CHP plant in Tomsk was carried out. Considered CHP plant is to be operating off-grid. It leads to the need of balanced electricity supply and demand. Therefore, Apart from biomass-fired CHP unit based on an ORC unit, biomass-fired hot water boiler and peak/backup diesel generators an electric boiler is used in order to transform excess electricity into heat.

Content

List of tables

List of figures

Introduction

Combined heat and power, also referred to as cogeneration and abbreviated as CHP, is an efficient, reliable and in case of biomass-fired CHP units also clean approach to generating power and heat. Furthermore, in case of decentralized system there are practically no transmission and distribution losses, which usually accounts for 5 to 15 % of total electricity and heat output. [4] When properly designed, decentralized CHP plant also increase flexibility and reliability of the respective heating system.

As it is in detail described in the section 1.3., there are several types of CHP units, which differ in the fuel on the one side and in the energy conversion technology on the other side. Regardless the type of CHP unit, it usually provides primary energy savings.

In the European Union, high efficiency cogeneration is defined in the DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency by above mentioned primary energy savings that shall be at least 10 % compared with the references for separate production of electricity and heat in case of CHP unit with an installed capacity above 1 MWe. Production from small-scale (installed capacity below 1 MWe) and micro-cogeneration units (installed capacity below 50 kWe) is considered to be high efficiency if positive energy savings are provided. [28]

CHP is used extensively in the Russian Federation. According to the International Energy Agency (IEA), Russian district heating system comprises almost 500 CHP stations that account for about 30 % of heat production in Russia. [9] Regarding electricity, as of 2013, CHP plant's total installed capacity was 76 GW (or 35 % pf the total installed capacity of Russian power plants). [10]

Although Russia's installed capacity of CHP plants is among the largest in the world, there is little reliable data on their efficiency of primary energy use. It is highly probable, that most of the CHP plant operating in Russia wouldn't be classified as high efficiency according to above mentioned European directive.

The Russian government is aware of the need to improve energy efficiency of the Russian economy. Regarding the heating sector, the World Bank and Russian energy experts estimate that Russia could cut energy consumption in the heat production by more than 8%, and that large energy savings can and should be achieved by developing high efficiency CHP. Russia's Energy Strategy 2030 aims to reduce network losses from current 20-30% in 2008 to 8-10% (which is common practice in most of Europe) by 2030. [10]

This reduction could be partially achieved by the development of decentralized high efficiency cogeneration, which could be used for both industrial and settlement applications.

Apart from the description of the current state of heating sector and combined heat and power area in the Russian Federation, one of the main objective of this thesis is to carry out an opportunity study on high efficiency CHP plant in Siberia, particularly in Tomsk.

Since Siberia is an abundant source of biomass, biomass-fired high efficiency CHP plant is examined. Furthermore, it was decided to focus on off-grid CHP system taking into account that there are several settlements in Siberia that are not grid-tied. Detailed description of considered settlement, CHP plant, heat and electricity demand and the coverage of heat and power load duration curves are given in the last section of this master's thesis. In order to find out whether considered CHP plant would be viable, economic evaluation of the project was carried out.

4.8. Economic evaluation of the examined CHP system

In this section an economic evaluation of the investigated CHP plant is carried out. In order to be able to calculate desired evaluation criteria, several I had to accept several assumptions. These assumptions are presented in the following subsection. Furthermore, it is needed to calculate expected expenses and revenues.

Having accepted assumptions and calculated expenses and revenues, it is possible to perform the calculation of respective investment evaluation criteria. In this master's thesis, following criteria were examined:

- Payback period
- Discounted Payback period
- Internal rate of return
- Net present value

Since most of the input variables are determined by my assumptions based on historic development and current state in relevant areas, it is desired to carry out sensitivity analysis on how particular inputs change the outputs of the mathematical model. Impact of several variables on obtained outcomes will be examined. Among these variables belong:

- Investment costs
- Operating costs
- Electricity price
- Heat Price
- WACC

Apart from sensitivity analysis, optimal value of electricity price was found. In this case, optimal means the guarantee of discounted payback period of 10 years. In other words, under several assumptions, discounted payback period is longer that desired one (10 years) and, thus, electricity price was increased in order to guarantee the discounted payback period to the potential investors. Guaranteeing a reasonable discounted payback period by paying the investor so called green premium is widely spread practice in Europe. Therefore, requested green premium for considered high efficiency biomass-fired CHP unit was calculated.

4.8.1. Key assumptions

In order to find out whether considered is a viable investment several assumptions had to be accepted. Firstly Investment and operating cost of high efficiency biomass-fired CHP unit with an ORC process were derived from [18], even though this CHP plant was built in Austria, where a price level is quite different from Russia. It is assumed that given the fact that Austrian CHP plant was built put into operation in 2003 when price level was much lower than the current one, presented values could be close to the expected costs in Russia at present. Furthermore, a correction factor 0,75 was used.

Further, it is assumed the constant costs and revenues over the lifetime of CHP plant that is assumed to be 20 years (based on the lifetime of the Austrian plant). As for the biomass-fired hot water boiler, electric boiler and diesel generators, assumed lifetime is also 20 years. No recovery of equipment is assumed.

As for the weighted average cost of capital (WACC), it was determined to equal 12 %, based on the information on WACC from Russian Utilities. [24] Income tax is not considered in the performed calculation.

4.8.2. Investment costs

Assumed investment costs of respective technologies are given in the following table. Based on the information from [18], investment costs of high efficiency biomass-fired CHP unit with an ORC process are divided to electricity related investment costs and heat related investment costs. Both values were derived from the specific values of Austrian CHP plant [18]. Presented investment costs include both electricity and heat related investment costs.

Regarding investment costs of Biomass HW boiler they were derived from [22]. As for the investment costs of electric boiler, they were derived from [25]. Investment cost of diesel generators was estimated based on the market prices of this product.

Technology	Investment costs [EUR]
Biomass-fired CHP with ORC	2 643 540
Biomass-fired hot water boiler	350 000
Electric boiler	33 000
Diesel generators	237 000

Total	**3 263 540**

Table 1 Estimated investment costs

4.8.3. Operating costs

Estimated operating costs of respective technology are presented in the following table. Similarly to the investment costs, operating costs of the high efficiency biomass-fired CHP unit with an ORC process were derived from [18]. These costs comprise consumption costs, operation costs and other costs.

Operating costs of biomass-fired hot water boiler are considered to cover only fuel costs. Wood rests are considered to be a utilized in this boiler. Considered price of one ton of wood rests in Siberia is 350 RUB (or 3,9 EUR) based on the consultations with Mr. Surkov. Using the assumed lower heating value of 12,5 GJ/t fuel cost of biomass-fired hot water boiler are 0,001123 EUR/kWh. [26]

Regarding diesel generators operating costs, only fuel was considered. Diesel price in Russia assumed in this master's thesis is 0,45 EUR/l [or 0,0415 EUR/kWh]. All of presented fuel costs were subsequently multiplied by inverse value of efficiency in order to obtain operating costs per one kWh of produced energy (heat or electricity).

Technology	Operating costs [EUR/kWh$_{el/th}$]
Biomass-fired CHP with ORC - electricity	0,0386
Biomass-fired CHP with ORC - heat	0,0166
Biomass-fired hot water boiler	0,0013
Electric boiler	0,0393
Diesel generators	0,1484

Table 2 Estimated investment costs

Operating costs of electric boiler were calculated as follows:

$$N_{o,eb} = \frac{N_{o,bCHP}}{\eta_{eb}}$$

Where $N_{o,bCHP}$ stands for operating costs of high efficiency biomass-fired CHP unit,

η_{eb} stands for efficiency of electric boiler.

After substitution of anticipated annual production of respective units, total operating costs equal **474 262 EUR**.

4.8.4. Revenue streams

Revenue streams comprise revenues from sold electricity and from sold heat. Considered price of electricity sold to customers is 0,13 EUR/kWh (or 10 RUB/kWh) based on the consultations with Mr. Surkov (relatively high price is a result of off-grid application). Regarding heat tariffs, in Russia they vary greatly (see Table 1). As for this master's thesis. considered price of heat sold to customers based on the consultations with Mr. Surkov (relatively high price is a result of off-grid application) is 0,05 EUR/kWh (or 4 500 RUB/Gcal). As written above, income tax is not included in these calculations.

Based on the electricity and heat production given in the sections 4.6. and 4.7. following values were obtained.

Technology	**Revenues [EUR/a]**
Biomass-fired CHP with ORC - electricity	181 142
Biomass-fired CHP with ORC - heat	440 714
Biomass-fired hot water boiler	82 201
Electric boiler	17 633
Diesel generators	227 410
Total	**949 101**

Table 3 Estimated revenues

As it is shown in the table above, greatest revenue stream is the revenue from heat sold that is produced by the high efficiency biomass-fired CHP unit. Second one is electricity sold that is produced by diesel generators (mostly in DG1, see section 4.7.).

Since both electricity and heat prices are based on the estimation, in the section 4.9. there is a sensitivity analysis of calculated investment decision criteria on this input.

4.8.5. Payback period and discounted payback period

Having calculated costs and revenues, it is possible to proceed to the investment evaluation criteria. Cash flow model along with calculated investment decision criteria is given in Appendix C.

The first calculated investment decision criterion is payback period (abbreviated as PP), which gives the number of years it takes to break even from undertaking the initial investment. By formula it can be expressed as follows:

$$\sum_{t=0}^{PP} CF_t = 0 \quad [EUR]$$

Where PP stands for payback period

CF_t stands for cash flow in year t.

For calculation, simpler formula in case of even cash flow over the project's lifetime can be used:

$$PP = \frac{I}{ACF} \quad [years]$$

Where I is initial investment

ACF is annual cash flow.

After substitution of initial investment 3 263 540 EUR and annual casfh flow 474 839 EUR (revenues minus operating costs), **PP** period equals **6,87 years**.

Regarding discounted payback period (abbreviated as DPP), time value of money is respected. Future anticipated cash flow are discounted to the time of initial investment. . By formula it can be expressed as follows:

$$\sum_{t=0}^{DPP} DCF_t = \frac{CF_t}{(1+r)^t} = 0 \quad [EUR]$$

Where DPP stands for discounted payback period

DCF_t stands for discounted cash flow in year t

r stands for discount rate (equals to WACC) .

Obtained **DPP** is equal to **15,38 years**. Both PP and DPP are graphically given in the figure below.

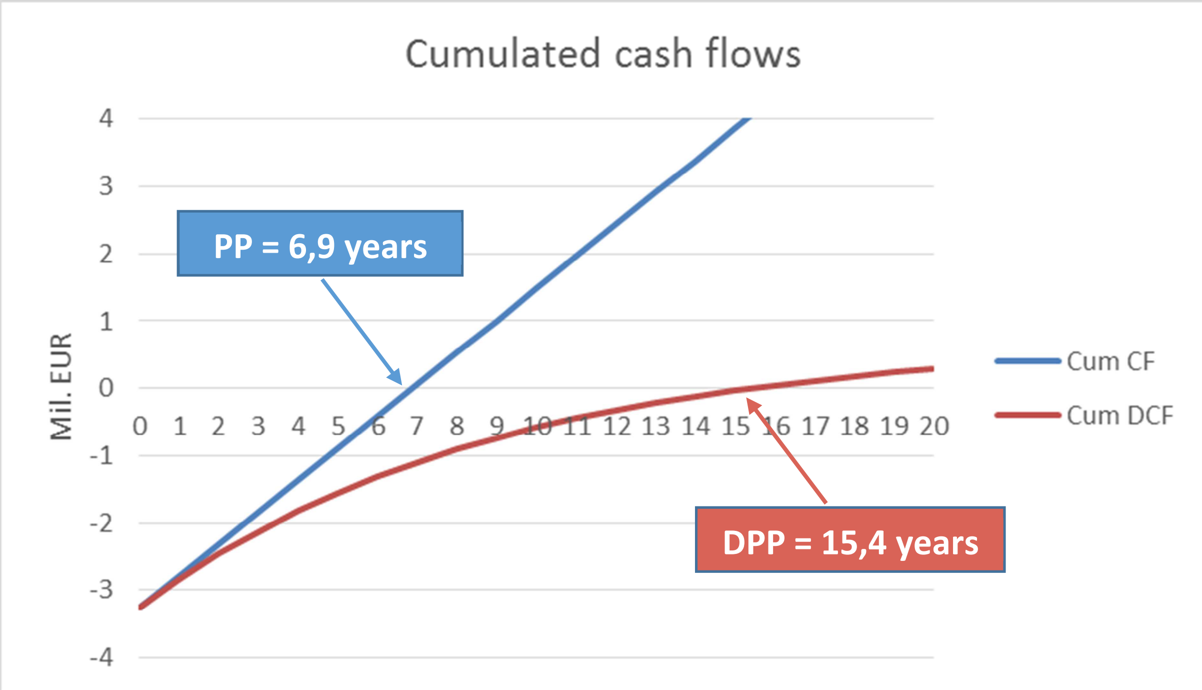

Figure 1 Cumulated cash flow and discounted cumulated cashflow

4.8.6. Net present value

Another investment decision criterion that was calculated in this master's thesis is Net Present Value (abbreviated as NPV). NPV is defined as the sum of the present values of incoming and outgoing cash flows. In other words, it's the sum of DCF.

$$NPV = \sum_{t=0}^{T} DCF_t = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} \quad [EUR]$$

Where T stands for CHP plant's lifetime.

After the substitution of above calculated values and presented key assumptions such as the lifetime of 20 years and WACC equal to 12 %, NPV of considered project equals **283 246 EUR**. Since NPV is greater than zero, construction of investigated CHP power plant should be recommended to the investors.

As it is apparent from the above given formula, NPV is strongly dependent on considered discount rate. That's why the sensitivity analysis of NPV on discount rate is carried out in the section 4.9.

4.8.7. Internal rate of return

Another investment decision criterion that is widely used and that was calculated in order to find out the profitability of considered investment is internal rate of return (IRR). IRR is defined as follows:

$$NPV = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} = 0$$

$\boxed{IRR}$

IRR of considered project equals **13,4 %**. As for this value, it is quite high value in case of investment in stable investing environment. In Russia it is adequate value taking into account WACC of utilities that varies from about 9 to 15 %. Essentially, if IRR of the project was lower than 9 %, investment wouldn't be viable under accepted assumptions. On the other hand, if IRR of the project was greater than 15 %, considered investment would be profitable. In this master thesis considered WACC is 12 %, as stated above.

4.8.8. Required green premium

In this section calculation of required green premium is presented. Green premium could be defined as an extra payment to the operator of CHP plant that is paid in order to promote effective and environmentally friendly means of generating electricity.

Awarding the operator of high efficiency CHP plant with the green premium is common practice of the promotion of high efficiency cogeneration in the European Union. According to the DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, High-efficiency cogeneration should be defined by the energy savings obtained by combined production instead of separate production of heat and electricity. The definitions of cogeneration and high-efficiency cogeneration used in Union legislation should be without prejudice to the use of different definitions in national legislation for purposes other than those of the Union legislation in question. [28]

In accordance with [28], for the purpose of determining whether cogeneration can be classified as high efficiency, following criteria are observed:

- Cogeneration production from cogeneration units shall provide primary energy savings (calculated according to the formula given in ANNEX II, the point (b) of [28]) of at least 10 % compared with the references for separate production of heat and electricity.
- Production from small-scale (installed capacity below 1 MWe) and micro-cogeneration units (installed capacity below 50 kWe) shall provide positive energy savings.

In the Czech Republic green premium paid to the operator of CHP plant depends on operating hours and on fuel. Overall provided promotion of the high efficiency cogeneration in years 2013 and 2014 is given in the following table along with the volume of electricity promoted. [29]

	2013	**2014**
Promoted electricity [GWh]	8 387	6 802
Overall promotion paid [mil. CZK]	1 970	1 664
Overall promotion paid [mil. EUR]*	72,96	61,63
Average promotion paid [EUR/kWh]	0,0087	0,0091

Table 4 Statistics of high efficiency cogeneration promotion in the Czech Republic. [29]

**Considered currency ratio CZK/EUR is 27.*

It is important to note, that CHP units with the installed capacity below 5 MWe are supported with much higher promotion than units with the installed capacity greater than 5 MWe. It reflects the the fact, that smaller units are much costlier than bigger units. Average promotion of small (below 5 MWe) and big (above 5 MWe) between years 2009 and 2013 is given in the following table. [30]

Year	**2009**	**2010**	**2011**	**2012**	**2013**
Units above 5 MWe [CZK/MWh]	45	45	45	45	176
Units above 5 MWe [EUR/MWh]*	1,67	1,67	1,67	1,67	6,52
Units below 5 MWe [CZK/MWh]	615	695	683	603	679
Units below 5 MWe [EUR/MWh]*	22,78	25,74	25,30	22,33	25,15

Table 5 Statistics of high efficiency cogeneration promotin in the Czech republic according to the installed capacity [30]

**Considered currency ratio CZK/EUR is 27.*

As for the considered high efficiency CHP plant in Tomsk, required green premium was calculated in order to obtain the discounted payback period of 10 years. Considering above given costs and revenues, required green premium for this plant equals **0, 0326 EUR/kWh** (or 2,508 RUB/kWh).

When calculated green premium was applied, following values of investment decision criteria were obtained.

Criterion	Value
Net Present Value [EUR]	1 048 714
Internal Rate of Return [%]	16,9
Payback Period [Years]	5,65
Discounted Payback Period [Years]	10,0

Table 6 Investment decision criteria values after application of the required green premium

In the following figure, cumulated cash flow and cumulated discounted cash flow are given graphically.

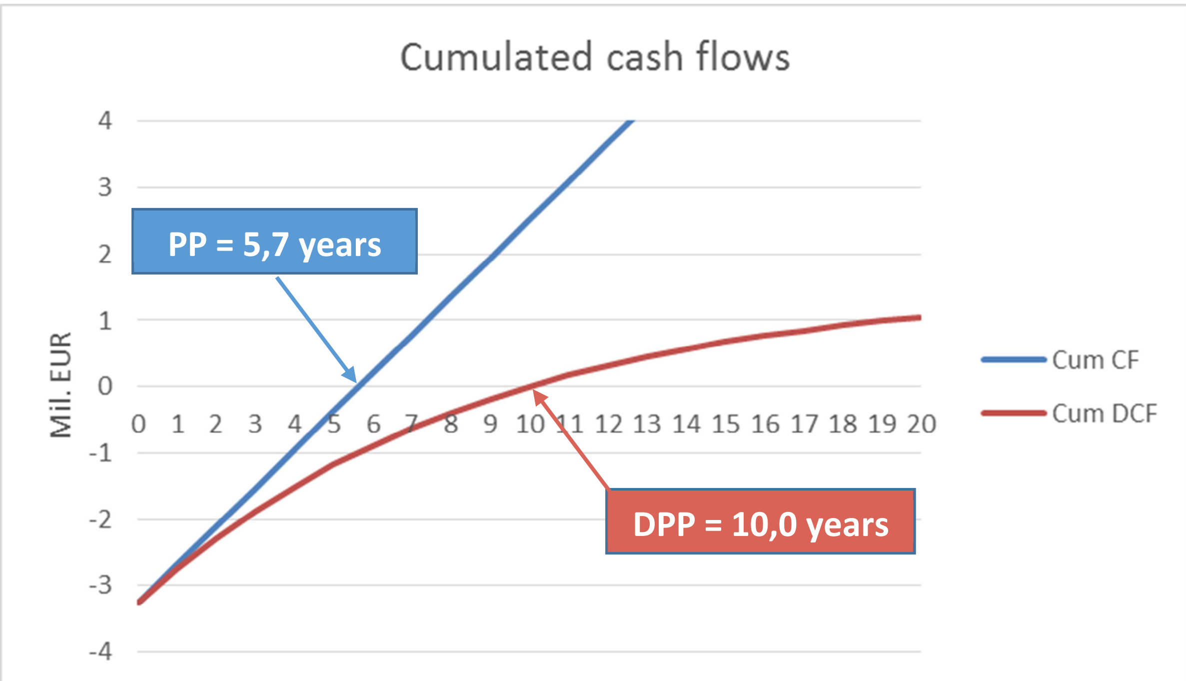

Figure 2 Cumulated cash flow after the application of the required green premium

4.9. Sensitivity Analyses

As most of the input values to the above described economic evaluation of the investigated high efficiency biomass-fired CHP plant were determined with relatively high uncertainty, several sensitivity analyses were carried out. In this section, an impact of following four changing inputs is presented:

- Operating costs
- Electricity tariff
- Heat tariff
- WACC

4.9.1. WACC and Operating costs (NPV)

In the table below an impact of changing operating costs and WACC on NPV is given. In observed range of WACC from 8 to 16 % NPV increase with the decreasing WACC for all investigated values of operating costs.

As for the operating costs, NPV of considered project also increase with decreasing operating costs. It can be concluded, that in an anticipated ranges of operating costs and WACC NPV varies from – 1 854 204 and 3 726 689 EUR.

N_o/WACC	8%	9%	10%	11%	12%	13%	14%	15%	16%
237 131	3 726 689	3 235 713	2 797 864	2 406 112	**2 054 481**	1 737 874	1 451 932	1 192 918	957 618
284 557	3 261 051	2 802 781	2 394 098	2 028 442	**1 700 234**	1 404 717	1 137 822	896 062	676 436
331 983	2 795 414	2 369 849	1 990 332	1 650 772	**1 345 987**	1 071 560	823 712	599 205	395 254
379 409	2 329 777	1 936 917	1 586 567	1 273 102	**991 740**	738 403	509 603	302 349	114 072
426 835	1 864 140	1 503 985	1 182 801	895 432	**637 493**	405 246	195 493	5 493	-167 111
474 262	**1 398 503**	**1 071 053**	**779 035**	**517 762**	**283 246**	**72 089**	**-118 617**	**-291 363**	**-448 293**
521 688	932 866	638 121	375 270	140 092	**-71 001**	-261 068	-432 726	-588 219	-729 475
569 114	467 229	205 189	-28 496	-237 578	**-425 248**	-594 225	-746 836	-885 075	-1 010 657
616 540	1 592	-227 743	-432 262	-615 249	**-779 495**	-927 382	-1 060 946	-1 181 931	-1 291 839
663 966	-464 045	-660 675	-836 027	-992 919	**-1 133 742**	-1 260 539	-1 375 056	-1 478 787	-1 573 022
711 392	-929 682	-1 093 607	-1 239 793	-1 370 589	**-1 487 989**	-1 593 696	-1 689 165	-1 775 643	-1 854 204

Table 7 Impact of changing operating costs and WACC on NPV

4.9.2. Electricity and heat tariffs (NPV)

In the table below an impact of changing electricity and heat tariffs on NPV is given.

H_t/E_t	0,065	0,078	0,091	0,104	0,117	0,13	0,143	0,156	0,169
0,0252	-3 261 382	-2 956 217	-2 651 051	-2 345 885	-2 040 720	**-1 735 554**	-1 430 388	-1 125 223	-820 057
0,0302	-2 857 622	-2 552 457	-2 247 291	-1 942 125	-1 636 960	**-1 331 794**	-1 026 628	-721 463	-416 297

0,0352	-2 453 862	-2 148 697	-1 843 531	-1 538 365	-1 233 200	**-928 034**	-622 868	-317 703	-12 537
0,0403	-2 050 102	-1 744 937	-1 439 771	-1 134 605	-829 440	**-524 274**	-219 108	86 057	391 223
0,0453	-1 646 342	-1 341 177	-1 036 011	-730 845	-425 680	**-120 514**	184 652	489 817	794 983
0,0503	**-1 242 582**	**-937 417**	**-632 251**	**-327 085**	**-21 920**	**283 246**	**588 412**	**893 577**	**1 198 743**
0,0554	-838 822	-533 657	-228 491	76 675	381 840	**687 006**	992 172	1 297 337	1 602 503
0,0604	-435 062	-129 897	175 269	480 435	785 600	**1 090 766**	1 395 932	1 701 097	2 006 263
0,0654	-31 302	273 863	579 029	884 195	1 189 360	**1 494 526**	1 799 692	2 104 857	2 410 023
0,0705	372 458	677 623	982 789	1 287 955	1 593 120	**1 898 286**	2 203 452	2 508 617	2 813 783
0,0755	776 218	1 081 383	1 386 549	1 691 715	1 996 880	**2 302 046**	2 607 212	2 912 377	3 217 543

Table 8 Impact of changing heat and electricity tariffs on NPV

As it is stated above, considered CHP plant is to be operating off-grid. Therefore, electricity and heat tariffs may be subject to negotiation between investor and considered settlement. That’s why quite wide ranges for both heat and electricity tariffs sensitivity analyses where taken into account.

4.9.3. Operating costs (Payback period)

In the figure below an impact of changing operating costs on payback period is given. Investigated range of operating costs is 331 983 EUR to 581 983 EUR. Within expected range of operating costs payback period of the project varies between 5,3 and 9,9 years.

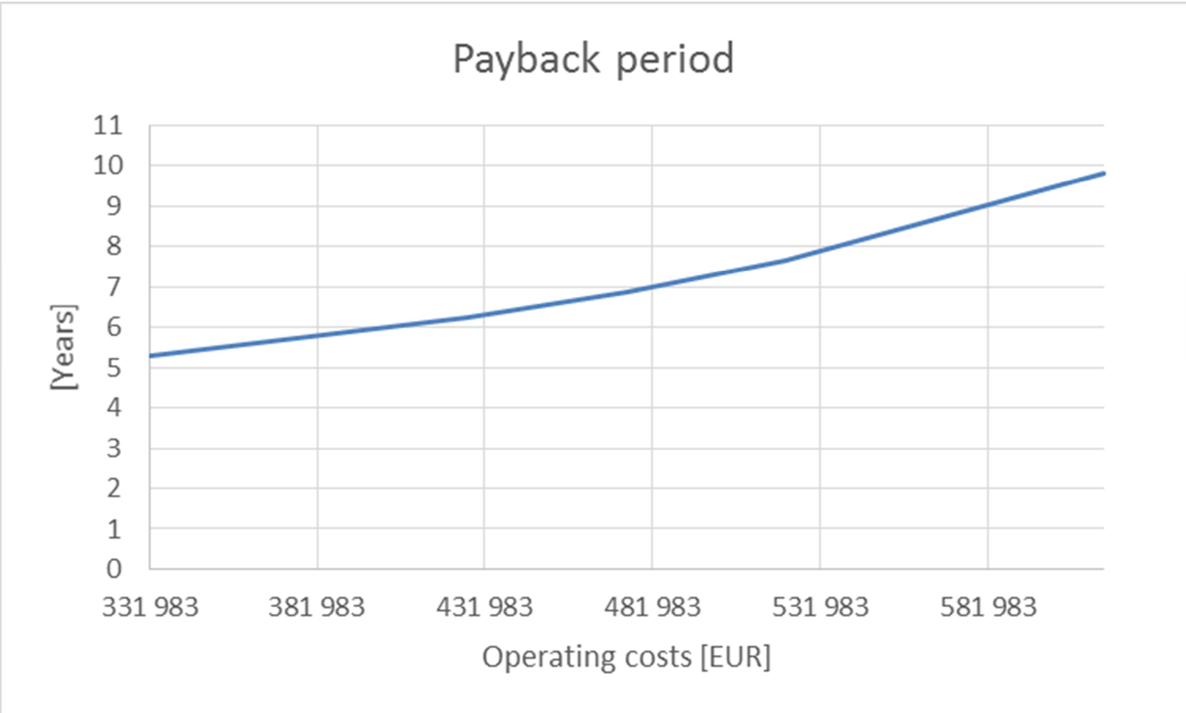

Figure 3 Impact of changing operating costs on payback period

4.9.4. Electricity tariff (Payback period)

In the following figure an impact of changing electricity tariff on payback period is given.

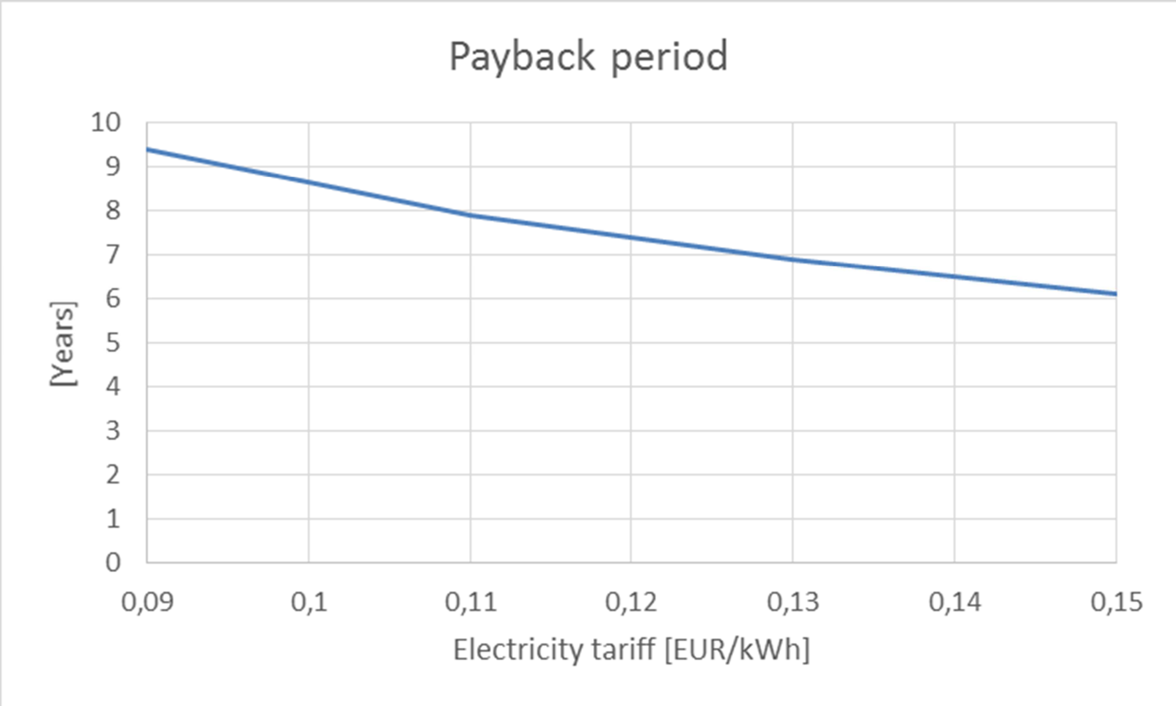

Figure 4 Impact of changing elektricity tariff on payback period

As it is stated above, considered CHP plant is to be operating off-grid. Therefore, electricity tariff may be subject to negotiation between investor and considered settlement. That's why quite wide ranges for both heat and electricity tariffs sensitivity analyses where taken into account.

4.9.5. Heat tariff (Payback period)

In the following figure an impact of changing heat tariff on payback period is given. Similarly to electricity tariff, heat tariff may vary greatly. According to Table 1, heat tariffs in Russia vary from 5 to 100 USD/Gcal (or 0,004 to 0,086 EUR/kWh).

It is also important to stated, in case the requested green premium of 0, 0326 EUR/kWh was rewarded, Payback period would be even shorter.

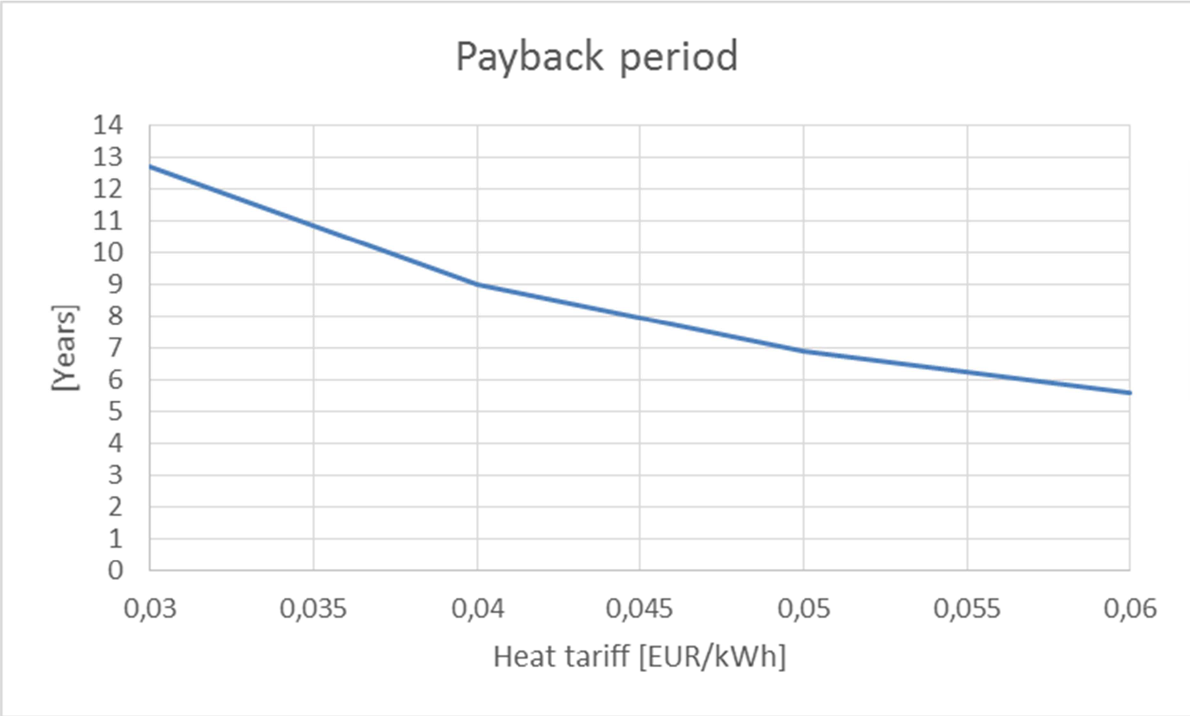

Figure 5 Impact of changing heat tariff on payback period