Министерство образования и науки Российской Федерации
Федеральное государственное автономное образовательное учреждение высшего образования «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 – Электроснабжение 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»

УДК 621.31.031:628.97:621.472

Студент / Student

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Томск / Tomsk – 2014
ЗАДАНИЕ / TASK
на выполнение выпускной квалификационной работы / for the execution of the graduate qualification work

В форме / Form:
магистерской диссертации / master thesis

Студенту / Student:

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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 / 2<sup>rd</sup> June 2016

ТЕХНИЧЕСКОЕ ЗАДАНИЕ / PRELIMINARY SPECIFICATIONS:

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<th>Сделать обзор по существующим возобновляемым источникам энергии, оценить их потенциал, с точки зрения выработки электрической энергии. Провести анализ характеристик основного энергетического оборудования автономной</th>
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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.

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<td>– Case study on High Efficiency CHP plant in Tomsk;</td>
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<td>– Heat load duration curve coverage;</td>
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(с указанием разделов / specifying chapters)

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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
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3. CHP in Russia
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   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
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8 Appendices

TECHNICAL TASK / PRELIMINARY SPECIFICATIONS:

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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.
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FIGURE 26 POWER LOAD DURATION CURVE COVERAGE
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.

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</tr>
<tr>
<td>Diesel generators</td>
<td>237 000</td>
</tr>
</tbody>
</table>
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).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Operating costs [EUR/kWh(_{el/th})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass-fired CHP with ORC - electricity</td>
<td>0,0386</td>
</tr>
<tr>
<td>Biomass-fired CHP with ORC - heat</td>
<td>0,0166</td>
</tr>
<tr>
<td>Biomass-fired hot water boiler</td>
<td>0,0013</td>
</tr>
<tr>
<td>Electric boiler</td>
<td>0,0393</td>
</tr>
<tr>
<td>Diesel generators</td>
<td>0,1484</td>
</tr>
</tbody>
</table>

Operating costs of electric boiler were calculated as follows:

\[
N_{o,eb} = \frac{N_{o,b,CHP}}{\eta_{eb}}
\]

Where \(N_{o,b,CHP}\) stands for operating costs of high efficiency biomass-fired CHP unit,

\(\eta_{eb}\) 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.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Revenues [EUR/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass-fired CHP with ORC - electricity</td>
<td>181 142</td>
</tr>
<tr>
<td>Biomass-fired CHP with ORC - heat</td>
<td>440 714</td>
</tr>
<tr>
<td>Biomass-fired hot water boiler</td>
<td>82 201</td>
</tr>
<tr>
<td>Electric boiler</td>
<td>17 633</td>
</tr>
<tr>
<td>Diesel generators</td>
<td>227 410</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>949 101</strong></td>
</tr>
</tbody>
</table>

*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 cash 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](image)

### 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:

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

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]

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

*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]

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

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Present Value [EUR]</td>
<td>1 048 714</td>
</tr>
<tr>
<td>Internal Rate of Return [%]</td>
<td>16,9</td>
</tr>
<tr>
<td>Payback Period [Years]</td>
<td>5,65</td>
</tr>
<tr>
<td>Discounted Payback Period [Years]</td>
<td>10,0</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>No/WACC</th>
<th>8%</th>
<th>9%</th>
<th>10%</th>
<th>11%</th>
<th>12%</th>
<th>13%</th>
<th>14%</th>
<th>15%</th>
<th>16%</th>
</tr>
</thead>
<tbody>
<tr>
<td>237 131</td>
<td>3 726 689</td>
<td>3 235 713</td>
<td>2 797 864</td>
<td>2 406 112</td>
<td>2 054 481</td>
<td>1 737 874</td>
<td>1 451 932</td>
<td>1 192 918</td>
<td>957 618</td>
</tr>
<tr>
<td>284 557</td>
<td>2 802 781</td>
<td>2 394 098</td>
<td>2 028 442</td>
<td>1 700 234</td>
<td>1 404 717</td>
<td>1 137 822</td>
<td>896 062</td>
<td>676 436</td>
<td></td>
</tr>
<tr>
<td>331 983</td>
<td>2 369 414</td>
<td>2 190 333</td>
<td>1 900 772</td>
<td>1 650 772</td>
<td>1 434 987</td>
<td>1 274 360</td>
<td>1 078 120</td>
<td>892 468</td>
<td></td>
</tr>
<tr>
<td>379 409</td>
<td>2 329 777</td>
<td>2 193 117</td>
<td>1 956 576</td>
<td>1 637 102</td>
<td>1 426 320</td>
<td>1 229 800</td>
<td>1 034 300</td>
<td>850 700</td>
<td></td>
</tr>
<tr>
<td>426 835</td>
<td>1 864 140</td>
<td>1 503 985</td>
<td>1 182 801</td>
<td>895 432</td>
<td>637 493</td>
<td>405 246</td>
<td>195 493</td>
<td>493 543</td>
<td></td>
</tr>
<tr>
<td>474 262</td>
<td>1 398 503</td>
<td>1 071 053</td>
<td>779 035</td>
<td>517 762</td>
<td>283 246</td>
<td>72 089</td>
<td>-118 617</td>
<td>-291 363</td>
<td>-448 293</td>
</tr>
<tr>
<td>521 688</td>
<td>932 866</td>
<td>638 121</td>
<td>375 270</td>
<td>140 092</td>
<td>-71 001</td>
<td>-261 068</td>
<td>-432 726</td>
<td>-588 219</td>
<td>-729 475</td>
</tr>
<tr>
<td>569 114</td>
<td>467 229</td>
<td>205 189</td>
<td>-28 496</td>
<td>-237 578</td>
<td>-425 248</td>
<td>-594 225</td>
<td>-746 836</td>
<td>-885 075</td>
<td>-1 010 657</td>
</tr>
<tr>
<td>616 540</td>
<td>1 592</td>
<td>-227 743</td>
<td>-432 262</td>
<td>-615 249</td>
<td>-779 495</td>
<td>-927 382</td>
<td>-1 060 946</td>
<td>-1 181 931</td>
<td>-1 291 839</td>
</tr>
<tr>
<td>663 966</td>
<td>-464 045</td>
<td>-660 675</td>
<td>-836 027</td>
<td>-992 919</td>
<td>-1 133 742</td>
<td>-1 260 539</td>
<td>-1 375 056</td>
<td>-1 478 787</td>
<td>-1 573 022</td>
</tr>
<tr>
<td>711 392</td>
<td>-929 682</td>
<td>-1 093 607</td>
<td>-1 239 793</td>
<td>-1 370 589</td>
<td>-1 487 989</td>
<td>-1 593 696</td>
<td>-1 689 165</td>
<td>-1 775 643</td>
<td>-1 854 204</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>H/Ei, 0,065</th>
<th>0,078</th>
<th>0,091</th>
<th>0,104</th>
<th>0,117</th>
<th>0,13</th>
<th>0,143</th>
<th>0,156</th>
<th>0,169</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,0252</td>
<td>-3 261 382</td>
<td>-2 956 217</td>
<td>-2 651 051</td>
<td>-2 345 885</td>
<td>-2 040 720</td>
<td>-1 735 554</td>
<td>-1 430 388</td>
<td>-1 125 223</td>
</tr>
<tr>
<td>0,0302</td>
<td>-2 857 622</td>
<td>-2 552 457</td>
<td>-2 247 291</td>
<td>-1 942 125</td>
<td>-1 636 960</td>
<td>-1 331 794</td>
<td>-1 026 628</td>
<td>-721 463</td>
</tr>
</tbody>
</table>
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 were 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](image)

### 4.9.4. Electricity tariff (Payback period)

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