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"Assessment of potentials and cost of renewable energy sources in the Murmansk region of Russia"

A Master's Thesis submitted for the degree of "Master of Science"

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Vienna, November 30th of 2015.

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Affidavit

I, **Svetlana Kirilyuk**, hereby declare

1. That I am the sole author of the present Master Thesis, “Assessment of potentials and cost of renewable energy sources in the Murmansk region of Russia”, 96 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. That I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Abstract

Russia is rich in mineral resources and fossil fuels. Resources are distributed disproportionately on the territory of Russia; hence some regions are strongly dependent on imported fuels. Furthermore, there are cases where there is no infrastructure for the delivery of natural gas, thus liquid oil is used as the main energy source. This has negative economic and environmental impacts – it causes a substantial amount of greenhouse gas emissions, associated with the actual burning of fossil fuels as well as with the transport of these fuels. At the same time, the regions with little or no fossil fuels potentially have their own sources of energy; such as biomass, wind, solar, hydro and etc. Therefore, every region in Russia should be researched to identify the potential of the locally available renewable energy sources to decrease the dependence on the imported fuels; releasing some of the economic and environmental pressure.

The selected region of Murmansk strongly depends on imported heavy oil for heat generation. Considering the harsh and cold climate of the region, where number of days require heating up to 350 days in some locations and on average for the region its 280 days, thus it is crucial to have sustainable heating system by decreasing the dependence on imported oil as a heating fuel. To explain precisely regional need in heating, the average heating degree days for Murmansk city (not the coldest location), and considering the outside temperature as 15,5 0C as minimum temperature after which the heating is required the heating degree days indicator is 5676 HDD, accordingly, (Degreedays, 2015).

From the assessment made, it can be concluded that heating generation facilities based on biomass are not economically feasible in the absence of dedicated financial support. Overall, these can cover up to 7% of the total regional heating demand in 2030. For electricity demand the analysis shows that apart from hydropower and tidal all renewable energy sources reviewed in this thesis were found not to be economically feasible under current market and framework conditions. However, considering that Russia has implemented a law establishing investment grants for hydro, solar and wind energy in the electricity sector wind energy is feasible under the certain conditions.

Russia has vast territory with various climate conditions and different types of energy sources. Some of these regions are rich with traditional fuels, while others are rich with biomass and/or wind energy. This abundance of natural resources calls for an analysis of the sources available in the different regions of Russia, as this would be

useful to optimize energy systems, which can potentially lead to better economical as well as social aspects and better life quality.

Table of content

Affidavit ii

Abstract iii

Table of content v

List of Tables viii

List of Figures x

Introduction 1

1. Method of approach 3

2. Murmansk region description 5

2.1 General 5

2.2 Economic development of the region 6

2.3 Population and birth rate in the region: 7

2.4 Future development of the region: 7

3. Current energy system in the Murmansk region 8

3.1 Energy distribution system in Russia 8

3.1.1 Electricity 8

3.1.2 Heating: 10

3.2 Energy in Murmansk region 10

3.3 Electricity generation in the Murmansk region 10

3.3.1 Electricity system in the region 10

3.3.2 Electricity generation in the region 11

3.3.3 Electricity generation forecast 11

3.3.4 Electricity cost forecast 13

3.3.5 Conclusion: 14

3.4 Heating 16

3.4.1 Heating system in region 16

3.4.2 Heat generation in the region 16

3.4.3 Heat generation forecast 17

3.4.4 Heat generation tariffs 19

3.4.5 Conclusion: ... 20

4. Locally available energy sources ... 22

4.1 Natural Gas: ... 23

4.1.1 Availability in the region as a primary source of energy ... 23

4.2 Biomass ... 23

4.2.1 Forest residuals availability as a primary energy source in the Murmansk region 23

4.2.2 Peat: Availability as a primary energy source in the Murmansk area. ... 29

4.2.3 Municipal Solid Waste (MSW): Availability as a primary energy source in the Murmansk area ... 32

4.2.4 Biomass as an energy source in the Murmansk area (technical) ... 35

4.3 WIND ... 36

4.3.1 Wind: Availability as a primary energy source in the Murmansk region .. 36

4.3.2 Wind: technical potential of electricity generation ... 37

4.4 SOLAR ... 40

4.4.1 Solar: availability as a primary energy source ... 40

4.4.2 Solar: Technical potential of electricity generation ... 41

4.5 TIDAL: ... 43

4.5.1 Tidal: technical potential of electricity generation ... 45

4.6 Hydro ... 47

4.6.1 Hydro: Availability in Murmansk region ... 47

4.6.2 Hydro: technical potential of electricity generation ... 48

4.7 Renewable energy's technical potential in the Murmansk region: ... 51

4.7.1 Electricity technical potential: ... 51

4.7.2 Heating technical potential: ... 52

5. Economical assessment of locally available energy sources ... 53

5.1.1 Biomass Electricity generation costs ... 55

5.2 Solar: Electricity generation cost ... 62

5.3 Tidal: Electricity generation cost ... 65

5.4 Wind: Electricity generation cost ... 67

5.4.1 Wind energy potential, considering premium payments for capacity. ... 68

5.5 Hydro: Electricity generation cost ... 72

6. Cost of heating generation from renewable energy sources. ... 75

6.1 Biomass heating generation cost: 75

7. Conclusions and recommendations 79

List of reference 83

List of Tables

Table 1 Electricity losses during transmission 12
Table 2 Nuclear reactor decommissioning schedule 13
Table 3 Heat generation open by locations (2010) 17
Table 4 Heat generation projection for the energy systems of Russia 17
Table 5 Main sources of the heating 19
Table 6 Heavy oil cost projection including logistic 20
Table 7 Targeted energy sources are selected as below: 22
Table 8 Forest economic zones highlights 24
Table 9 Total forests area and volume by the Designation 25
Table 10 Forest harvesting in Murmansk region (actual data) 25
Table 11 Timber volume projection for Murmansk region 25
Table 12 Energy content for wood with different moisture level: 26
Table 13 Theoretical electricity generation from forest residuals 27
Table 14 Theoretical heat generation from forest residuals 27
Table 15 Peat resources in Murmansk region 29
Table 16 Combustion properties of different peat types 30
Table 17 Theoretical electricity generation from peat briquettes 31
Table 18 Theoretical heat generation from peat briquettes 31
Table 19 Forecasted volume of the MSW generation in Murmansk region 32
Table 20 Heat content of components of MSW 33
Table 21 Potential electricity generation from MSW in Murmansk region 33
Table 22 Technical potential of heat generation from MSW 34
Table 23 Biomass potential for electricity generation in Murmansk region 35
Table 24 Biomass potential for heating generation in Murmansk region 35
Table 25 Murmansk region land usage, 2014 37
Table 26 Wind speed at the height 80-100 m 37
Table 27 Technical potential of Electricity generation from wind in Murmansk region 38
Table 28 Terskiy region land usage, 2013 41
Table 29 Potential electricity generation from 20 MW PV plant 42
Table 30 Selected areas for the tidal generating stations construction 44
Table 31 Tidal energy potential in Murmansk region 45
Table 32 Tidal electricity output in Murmansk region: 46
Table 33 Hydrographic characteristics of the selected rivers 48
Table 34 Theoretical potential of electricity generation from hydro sources 50

Table 35 Electricity from renewable sources technical potential in Murmansk region 51
Table 36 Heat generation from renewable sources technical potential in region.....52
Table 37 Timber feedstock cost 57
Table 38 Electricity generation feasibility from Forest residuals 58
Table 39 Electricity generation feasibility from peat briquettes 59
Table 40 Electricity generation feasibility from MSW 61
Table 41 Electricity generation feasibility from Solar..64
Table 42 Bay Dolgay technical parameters..65
Table 43 Actual costs of the tidal energy facilities:...65
Table 44 Electricity generation from tidal economical feasibility 66
Table 45 Wind parks costs in different locations: 67
Table 46 Electricity generation from wind (economical feasibility); 68
Table 47 Premium capacity payment decrease rate for the wind energy 69
Table 48 Wind energy feasibility assessment, with consideration of premium capacity payments 70
Table 49 20 MW onshore wind farm feasibility in Murmansk region 71
Table 50 Hydropower Station in Murmansk Region with average parameters 73
Table 51 17 MW hydropower station in the Murmansk region, feasibility study.......74
Table 52 Forest residuals heat generation feasibility 76
Table 53 Heat generation cost using Peat Briquettes 77
Table 54 Heat generation from MSW, feasibility study 78
Table 55 Electricity generation potential by energy sources 79
Table 56 Electricity generation feasibility 80
Table 57 Heat generation technical potential 81
Table 58 Heat generation projects feasibility 81

List of Figures

Figure 1 Murmansk region on the map of Russia 5
Figure 2 Districts of Murmansk region 5
Figure 3 Map of transportation system in Murmansk region 6
Figure 4 Population, death/birth rate in Murmansk region 7
Figure 5 Electricity trading zones 8
Figure 6 Wholesale electricity trading system 9
Figure 7 Map of energy systems of Russia (light blue is North West energy system)9
Figure 8 Heat and electricity generating facilities of Murmansk region 10
Figure 9 Electricity transmission lines in Murmansk region 11
Figure 10 Electricity generation forecast, up to 2030 12
Figure 11 Electricity generation forecast open by the energy source, TWh/year 13
Figure 12 Electricity wholesale tariffs by 2030 in US$/MWh 14
Figure 13 Electricity generation as of 2007, open by energy source 15
Figure 14 Heating season length in different districts of Murmansk region 16
Figure 15 Heat generation actual/projection 18
Figure 16 Heat generation by fuel, 2010 18
Figure 17 Heat generation by fuel, 2010 20
Figure 18 Energy mix for heating (actual 2010) 21
Figure 19 Energy mix for heating (projection for 2020) 21
Figure 20 Geographical limitations for wind and solar energy 22
Figure 21 Map of the Murmansk region with forest economic zones indicated 24
Figure 22 Learning curve for direct combustion 26
Figure 23 Map of peat fields in Murmansk regions 30
Figure 24 Average wind speed in Murmansk region, measured at 10 m height. 36
Figure 25 GE wind turbine performance 2.5 MW 38
Figure 26 Average insolation level in Murmansk region KWh/sqm/year 40
Figure 27 Kislogubskay tidal electricity station 43
Figure 28 Gulfs/bays of Murmansk region coastline examined for tidal potential 44
Figure 29 Rivers in the Murmansk region 47
Figure 30 Weighted average capacity factors for small/large hydro stations 49
Figure 31 CAPEX for biomass based power plants 55
Figure 32 PV utility scale installation cost 62
Figure 33 Capacity subsidies for wind energy 69
Figure 34 Average installed cost for small/large hydropower projects 72

Introduction

In Russia as of 2012, the estimate of the resources of oil and natural gas of Russia were more than 17.8 bln tons and 164 trl m^3 respectively. Traditional fossil fuels resources are mainly concentrated in regions such as West Siberia, Yamal, Caspian Sea and a few new areas such East Siberia and the Arctic. Other regions hold less fossil fuels resources, however these regions are potentially rich with other sources of renewable energy, which may have a high potential to be developed. For example, the north and coastal territories have high wind speeds, other areas like the southern part of East Siberia and Irkutsk city have high solar insolation level (i.e. more than 5 KW/m2/day). West Siberia, which is known as the capital of oil production in Russia, with its depleting oil resources, is rich with peat and biomass. The region of Kamchatka has geothermal energy potential and etc.

Considering that the resources are distributed unequally in the territory of Russia, particularly traditional fossil fuels, some regions are heavily dependent on imported fuels. Hence, it could be beneficial from many aspects to analyze the availability and technical potential of different energy sources for each region, with the target of increasing the usage of locally available sources without concentrating solely on fossil fuels, and eventually developing and creating sustainable and efficient energy systems in those regions. The key benefits of developing such a system would be: economic benefits, as the cost of imported fuels can be a significant part of the regions' budget, thus with the local sources developed, RGP will grow in mid to long term view. Socio-economic benefits, as the development of renewable energy sources will introduce new jobs to the region. Moreover, the better the regions are developed, in terms of the efficiency of the energy systems and the usage of local renewable energy sources, the bigger the portion of produced oil/gas can be exported.

The Murmansk region was selected due to its strategic location, in regards to the Arctic (which is significant due to the expected development of the oil and gas fields located there); as well as the expected decommissioning of the nuclear station in that region (which may create an energy deficit). Moreover, due to climatic conditions, the region requires heating almost all year around. The selected region is rich with different types of minerals. There are over 60 large deposits of various raw minerals. These minerals include apatite, nepheline and cyanate ores and other rare metals. There are natural gas fields discovered on the Barents Sea offshore, however due to complex conditions and the presence of cheaper natural gas, these fields are not economically feasible for development yet and it is not foreseen to be so up to 2030, particularly in the case of the well-known Shtokman field. Thus, natural gas cannot be considered as a feasible locally available energy source, for the purpose of this thesis, up to 2030.

In regards of electricity, the area is currently saturated due to the nuclear power station there, however the station is scheduled to be decommissioned gradually starting from 2018, undoubtedly creating an electricity deficit. As for heating, the region is currently heavily dependent on imported fuels; with most of the heating generating facilities not making profit and relying on government subsidies to maintain a certain tariff level.

It is necessary to mention that the estimation of the amount of locally available sources are based on different references (no first-hand empirical investigations were done). Along with the aforementioned references, the region's characteristics (landscape) is also considered in the estimation of the amount of locally available sources. For the technical potential, commercially available and mature technologies were selected. Calculations are done separately for electricity and heating. The main challenge was in identification of the economical feasibility, which is crucial for facility construction and operation. For economical feasibility, Long Run Marginal Cost (LRMC) was used as an indicator together with Net Present Value (NPV); both calculated for each source separately.

Based on the findings of this report, it was concluded that all heating generation facilities based on several types of the biomass are not economically feasible; thought altogether, these facilities can cover up to 7% of total regional heat demand of Murmansk region in 2030.

In the case of electricity, forest residuals, wind, hydro and tidal are economically feasible based on the findings (wind in case if premium payment subsidies will be applied). Tidal, hydro and forest residuals together, can cover almost 10% of Murmansk region electricity demand in 2030. Wind as an energy source, can cover more than 100% of the regional demand itself (with potential generation 83 TWh/y), however the winds farms has to become operational by 2020 in order to receive financial support as currently granted by the government.

To conclude, precise analyses of locally available energy sources in each region of Russia would be beneficial for many reasons; including economical and environmental ones. Each region should focus on its local sources of energy, including renewable, in order to increase energy security of Russia.

1. Method of approach

The main objective of this thesis is to examine the technical possibility and economical feasibility of constructing of heating and electricity generating facilities using locally available renewable energy sources. In order to verify if the locally available energy sources are economically feasible it is necessary to understand, first of all the technical potential of the energy source in the region (for both electricity and heating generation). Secondly, to estimate the cost of the construction of such a facility and cost of the potential output.

After brief examination of the available sources, it was decided to use data issued by the Ministry of Energy (MOE) of Russia for consumption/generation forecasts and cost projection estimations. For the data related to the costs of the generating facilities construction and any other such associated costs, IRENA's and IEA's various reports and researches were selected as the most reliable.

The analytical work in this thesis is presented in the subsequent chapters. The following chapter 2 (Murmansk region general description) is concerned with clarifying the current energy situation in the Murmansk region; including, electricity and heat generation as well as projection (up to 2030) and energy mix. The projection will be based on the data from (MOE of Russian Federation, Agency of energy balances forecasting, 2011). For the electricity projection, the effects of the decommissioning of the nuclear power stations will be considered, which will undoubtedly lead a deficit of electricity in the region. As for the heating, keeping in mind further regional development is expected (due to the aforementioned Arctic development), depending largely on imported heavy oil puts the region at a low energy security level.

For the economical assessment it is critical to estimate the projected tariffs of electricity and heating in the region. Murmansk is the part of the wholesale electricity trading zone, with regulated tariffs for the electricity. In case of heating, generating facilities usually supply the heat directly to the end user via transmitting lines, however the sales price to the end user is regulated by the Government, and in the majority of cases in the Murmansk region, heat generating facilities are not profitable.

The chapter number 4 (Locally available energy sources) is devoted to the evaluation of locally available renewable energy sources from the technical prospective. Besides the various energy sources available in the Murmansk region; the offshore of Barents sea is rich with fossil fuels such as natural gas, however due to numerous reasons from technical to political the production of these fields may not start before 2030, thus natural gas cannot be considered in the calculations as a currently viable locally available energy source, even though natural gas in the Murmansk region is a good alternative to some existing energy source used in the current energy mix. Additionally, it is necessary to mention that different lists of the energy sources for heating and for electricity generation are selected. Firstly, for electricity generation, the energy sources are wind, solar, hydropower, tidal, and biomass (of different types; Timber, peat, and MSW). Secondly, for heat generation, the list of the sources is: Biomass of all types. Each energy source has to be considered separately, and the methodology for estimating potential of each is different; still, the general idea is to estimate the potential amount of the energy source, and to calculate its max technical potential using existing technologies.

To understand the potential and availability of some sources in the region different information sources were used, most of which are in reports and scientific articles from local scientific institutes such as the “Kola science center” branch of Russian Academy of Science. For every energy source the approach is unique, however the similarity is that no empirical researched done, and analyses is based on the second hand or secondary available information. The result of the chapter is technical potential output for both electricity and heat generation from locally available renewable energy sources and its potential role in regional energy mix.

Chapter 5 is the economical assessment of the heating and electricity generating projects. Considering derived costs, the recommendations on the generating facilities construction will be given, as well as the potential share of renewable energy sources in the existing energy mix of the Murmansk region in 2030. One way (the most common), for generating a project’s economical feasibility, is to measure the LRMC (long Run Marginal Cost); Another financial indicator should be considered as well; particularly the NPV (Net present value). In case the NPV is negative for a project, that project will not be considered as economically feasible from today's perspective in the absence of dedicated support.

To calculate the LRMC, some additional information is required, such as the CAPEX and O&M costs of the facilities. In addition, it is necessary to consider some other contributors to the generation costs, such as infrastructure costs (e.g. in areas that require road development); This chapter’s results are the costs of the generated electricity and heating from the potential facilities which will be based on the locally available renewable energy sources.

Taking into consideration the results on potentials and costs of locally available energy sources, conclusions are drawn and recommendations are provided in regards of energy sources projected usage. The environmental impact of switching to renewable energy sources or adding renewable sources to the energy mix will not be calculated (because it is out of the scope of this paper); these impacts are significant, as it may further encourage the use these sources. That being said, 80% of heating is generated from imported heavy oil today in the Murmansk region; with the pollutants associated with the transportation of the oil as well as the burning of oil for heating generation.

2. Murmansk region description

2.1 General

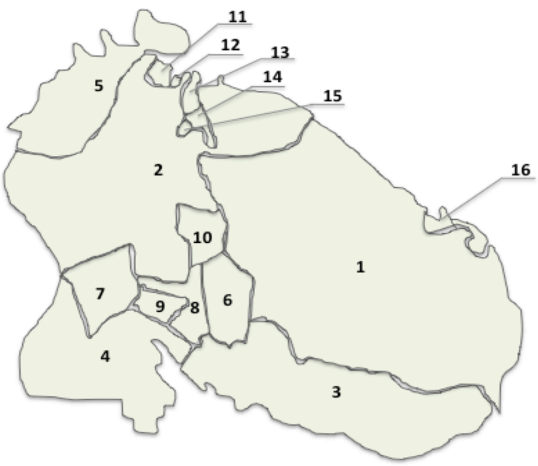
The Murmansk region is part of the North-West Federal district of Russia. The total area of the region is 144.9 Th km^2, or equivalently 0.86% of Russia. The targeted area is located on the Kola Peninsula and is surrounded by the Barents Sea and White Sea; the total coastal area is approx. 2 Th km^2. The Murmansk region borders with Finland on the west and with Norway on the North West. The location of the region is shown in Figure 1.

Figure 1 Murmansk region on the map of Russia

Source: (prowton, 2012)

The Murmansk region consists of 16 districts and other populated areas (such as rural areas), see Figure 2.

Figure 2 Districts of Murmansk region



Region	Name
1	Levozerskiy district
2	Kolskiy district
3	Terskiy disctrict
4	Kandalakshskiy disctrict
5	Pechengskiy disctrict
6	Kirovsk
7	Kondorskiy district
8	Apatiti
9	Polar Zori
10	Olenegorsk
11	Zaozersk
12	Vidyevo
13	Polyrnii
14	Snezhnogorsk
15	Murmanks
16	Ostrovnoy

Source: own assessment based on (Goverment of Murmansk region, 2013)

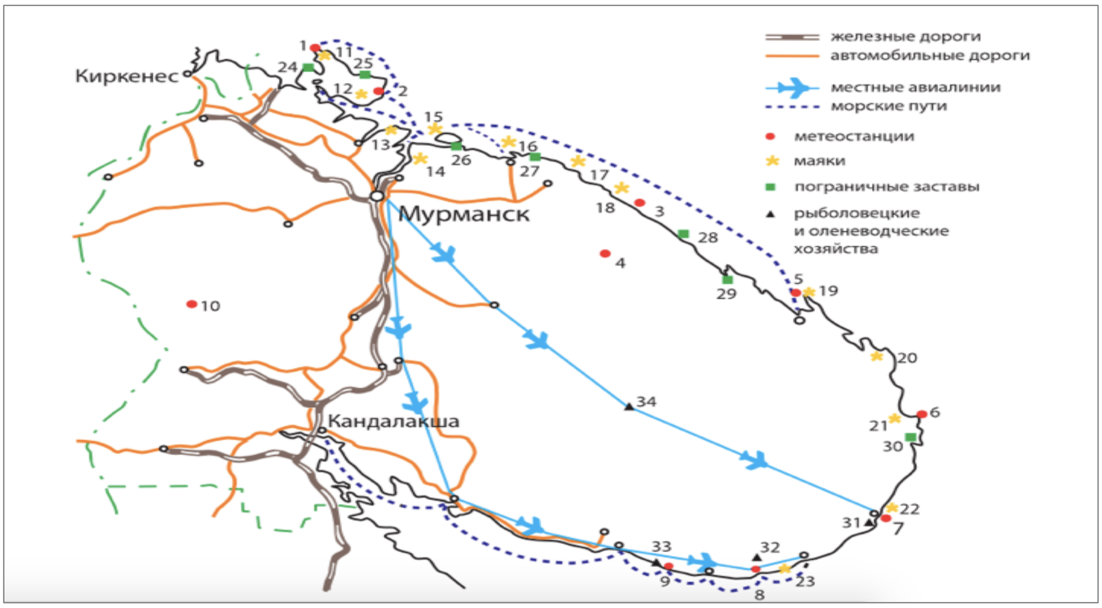
The region is highly urbanized; with more than 90% of the total population living in cities. Climate in the region varies and due to the northern location, the average number of days requiring heating is on average 280 days per year. There is polar night in the region, which is from the beginning of December to the middle of January, and polar day, which starts from the end of May to the middle of July.

2.2 Economic development of the region

Historically, the main source of income in the region has been mining of various minerals. In 2013, income coming from minerals extraction in Murmansk region was around 17% of total RGP (Regional Gross Profit) (Federal Statistical Agency, 2015). Around 60 fields are currently under exploration in the region. Besides metal and ore minerals, the region is relatively rich fossil fuels, including gas and gas condensate. Discovered fields are located on the Barents Sea offshore mainly, such as the well-known Shtokman field. Currently, available gas resources are not economically feasible for production due to offshore location and complex infrastructure required to start the production, particularly LNG plant.

The Murmansk region has well developed logistic infrastructure, however mostly between the biggest populated areas. There are two major and five small airports, most of which are located in the coastal areas of the region, to ensure year around access to the areas. A map of the transportation system is shown below, in Figure 3.

Figure 3 Map of transportation system in Murmansk region

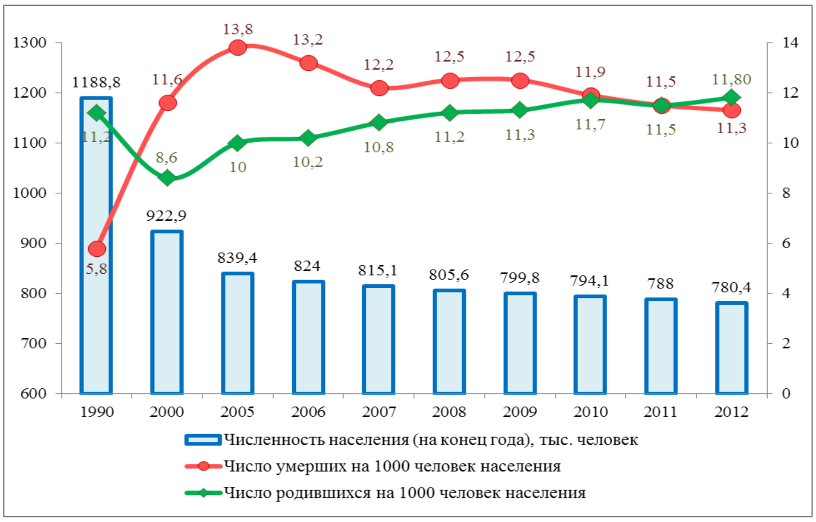


Source: (Minin V. A., Economical Aspects of small scale renewable energy development in remote locations, 2011)

2.3 Population and birth rate in the region:

Population level in the Murmansk region as of 2013 was 780.4 Th. inhabitants, with population density being 5.4 inhabitants per km^2. In the region, there are more than 104 areas where the population is not more than 1000 people and in some cases not more than 100 people. The level of population heavily depends on the economical situation and in the 1990s, after the USSR collapsed, the region lost 30% of its population in a few years. In 2012, for the first time since 1990, birth rate offsetting death rate was recorded, shown below in Figure 4.

Figure 4 Population, death/birth rate in Murmansk region



Source: (Goverment of Murmansk region, 2013)

Comments: red line- death rate (per 1000 inhabitants), green line- birth rate (per 1000 inhabitants). Blue chart-number of inhabitants in the region

2.4 Future development of the region:

The Murmansk region is considered to be a future gate to the Arctic development for Russia; (Ministry of transportation of Murmansk region, 2011) including fossil fuels production. Currently, Murmansk port is the main port for “Prirazlomnoe” field exploration. Although, Intensive extraction of mineral resources has already created environmental issues, considering sensitive ecosystem of the Arctic.

3. Current energy system in the Murmansk region

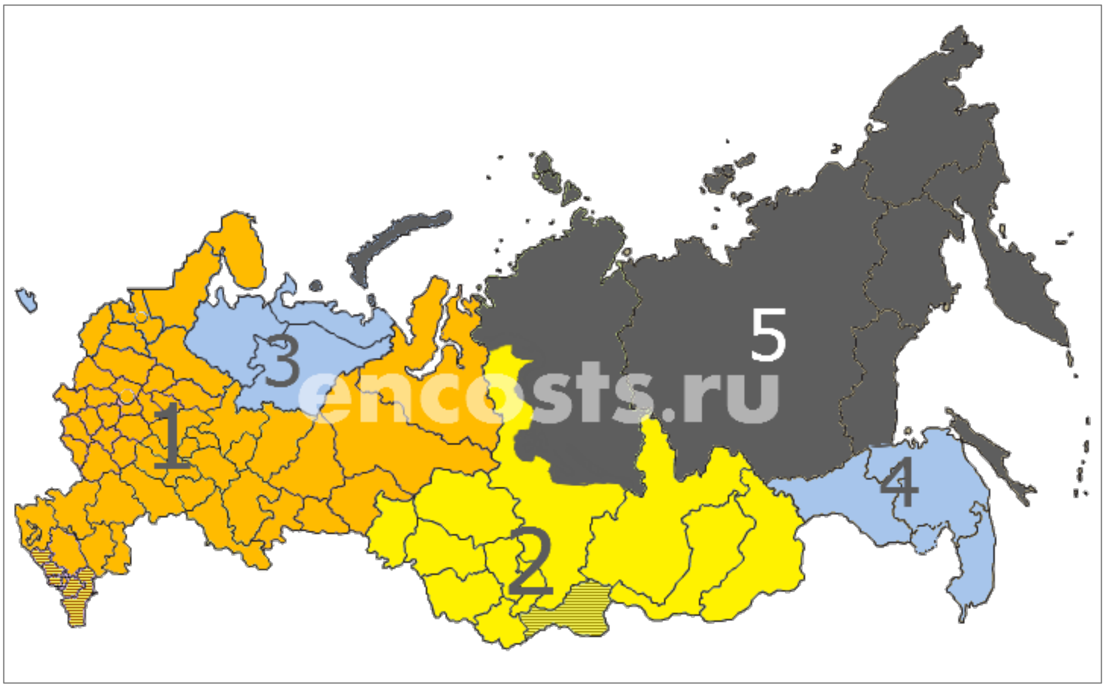
3.1 Energy distribution system in Russia

3.1.1 Electricity

There are two main electricity trading systems in Russia (Ministry of energy of RF, 2010). Wholesale market and retail market. Wholesale market designated for a large scale generators and mainly major consumers, particularly trading companies, which sell and supply electricity further on to the end users. At the moment wholesale market divided into several independent parts (or regions): where tariffs are regulated and non regulated respectively. Wholesale market in regulated areas is a well developed competitive market with a high number of electricity suppliers. In contrast to the regulated part of the wholesale market, the trading system for non regulated market is on the process of developing, and not properly settled yet. And retail electricity market consists of the isolated energy systems.

In Figure 6 below, the following zones of electricity system are presented: Zones 1 and 2- wholesale market with regulated tariffs, Zones 3 and 4- wholesale market with non regulated tariffs, and zone 5- retail market. The Murmansk region is a part of wholesale market with regulated tariffs, zone 1 as in the Figure 5 below.

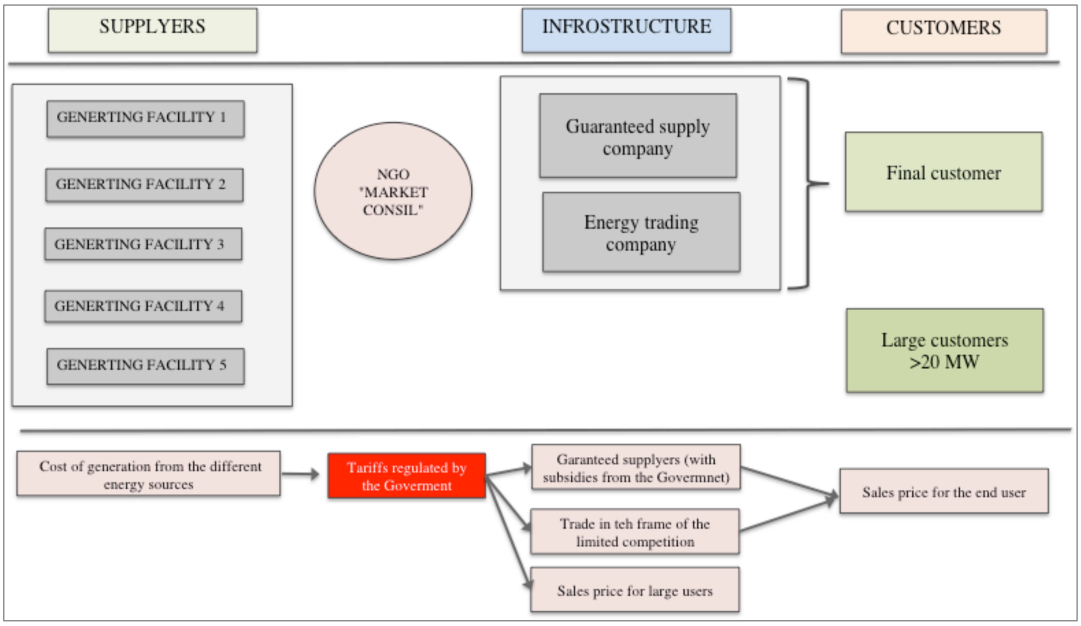
Figure 5 Electricity trading zones



Source: (Encost, 2014)

The wholesale market's functionality is represented in Figure 6, below. To understand the economical efficiency of potential renewable energy usage in the Murmansk region, the tariffs, given by NGO «Market consul» will be used as the main baseline for comparison with the cost of the energy generation (electricity and heating) from newly constructed facilities, based on the renewable energy sources, available in the Murmansk region.

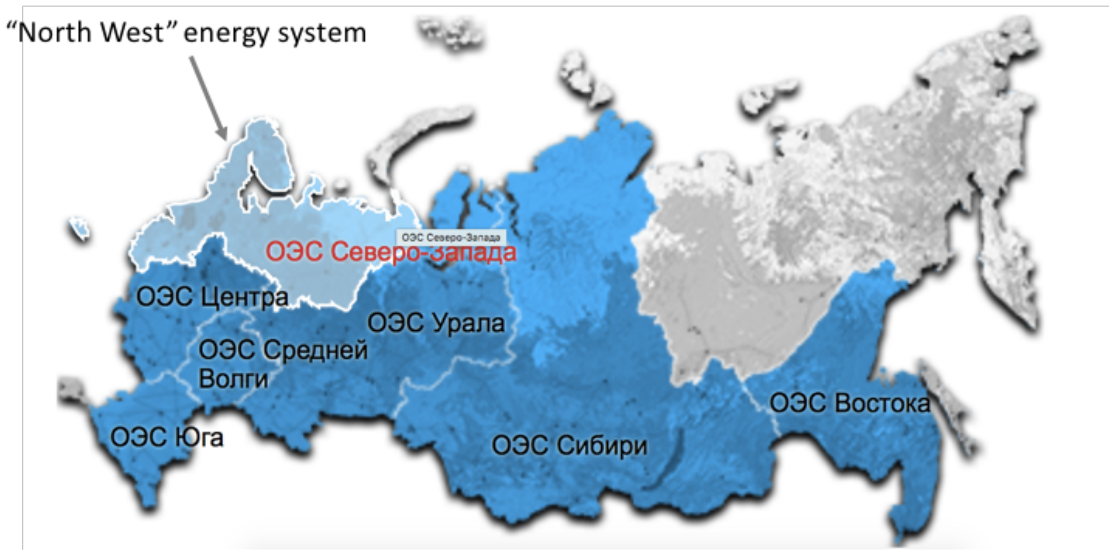
Figure 6 Wholesale electricity trading system



Source: Own assessment

Additionally, there is a geographical division of the energy systems of Russia as presented in Figure 7. The Murmansk region is part of the "North West" energy system.

Figure 7 Map of energy systems of Russia (light blue is North West energy system)



Source: (System Operator of the Unified Power System, 2015)

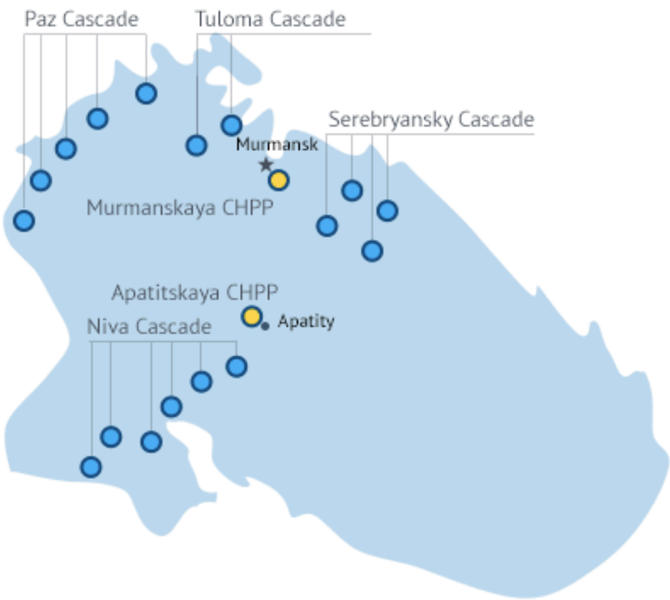
3.1.2 Heating:

Trading system for heating is conventional: direct heat trading from generating facilities to the end user via the utilities companies. Heating generation cost heavily depends on the cost of fuel, according to some sources for around 50%.

3.2 Energy in Murmansk region

Major source for the electricity generation in the region is nuclear power station. The main source for heating in the Murmansk region is heavy oil (heating oil). Electricity and heat generation facilities (the bigger ones) in Murmansk region are presented on the map below, see Figure 8.

Figure 8 Heat and electricity generating facilities of Murmansk region



Source: (TGC-1 JSC, 2015)

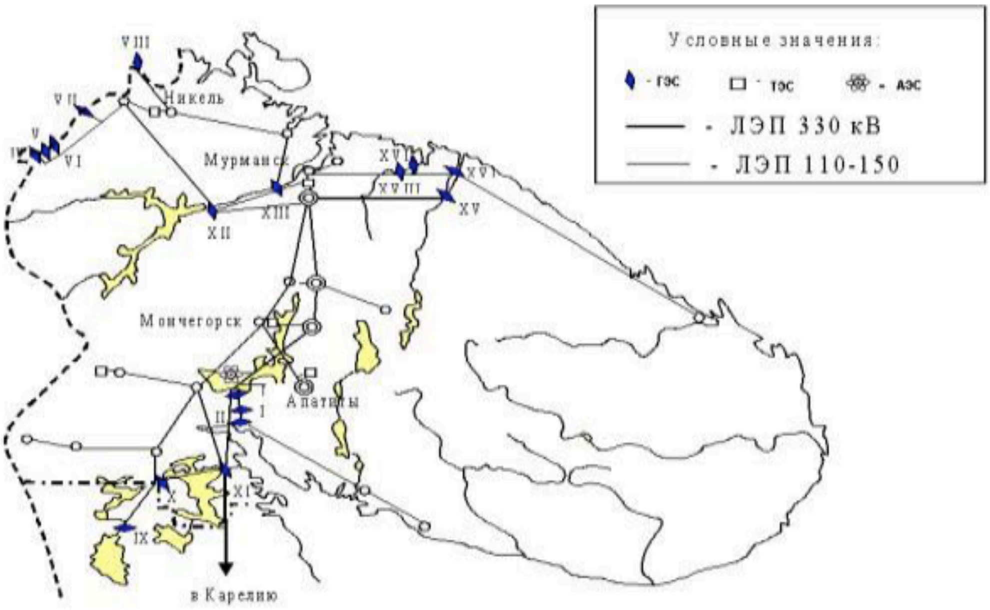
Energy generating and transporting system in Murmansk region is well worn out, which leads to lower efficiency higher losses. The conditions of the energy system are hindering development and creating a risk of energy security in the Murmansk region.

3.3 Electricity generation in the Murmansk region

3.3.1 Electricity system in the region

The Murmansk region is highly urbanized and the majority of the electricity distribution is centralized, see below in Figure 9 (electricity grids map). Electricity coming from the diesel generators, devoted to the remotely locate consumers is minor and around 1% out of total electricity consumption (Goverment of Murmansk region , 2009). For all further calculations in this thesis, centrally distributed electricity will be considered as 99% of total consumption in the Murmansk region and the one of the remote and isolated areas (areas disconnected from the central electricity distribution system) is around 1%; the latter will not be considered in the report as it requires a separate extensive research.

Figure 9 Electricity transmission lines in Murmansk region



Source: (Goverment of Murmansk region , 2009)

3.3.2 Electricity generation in the region

Generated electricity in the Murmansk region is mainly coming from the nuclear station (around 60%), the second important energy source is hydro, with the chain of the hydropower stations (around 37%). 3% Energy sources, apart from hydro and nuclear some small scale projects; such as the tidal generation facility and waste to energy plant (Goverment of Murmansk region , 2009). Currently the region is electricity abundant, due to the nuclear power station.

3.3.3 Electricity generation forecast

As electricity consumption usually depends on the economic development of the region, the Increase in is projected by (MOE of Russian Federation, Agency of energy balances forecasting, 2011). This is due to expected Arctic development and plans of Government of Russia to transform the Murmansk region into a transportation hub to ensure access to new areas of development in the Arctic (Ministry of transportation of Murmansk region, 2011). According to the report, the electricity consumption is projected to reach a level of 20.79 TWh/year by 2030.

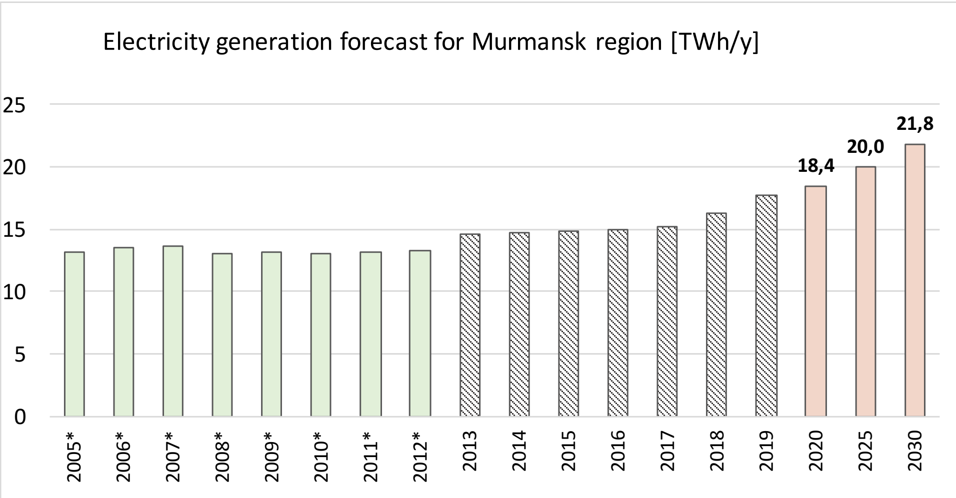
To understand the required level of the generation for the period up to 2030, it is necessary to add up expected losses. In the Table 1, below, the data on the historical losses devoted to electricity transmission is presented. As of 2007, the level reached 4.8%, this % will be used to project required generation of electricity. Electricity generation projection by 2030 is presented below in Figure 10.

Table 1 Electricity losses during transmission

Losses in the transportation lines, %	2003	2004	2005	2006	2007
	7.83%	7.84%	7.7%	5.3%	4.8%

Source: (Goverment of Murmansk region , 2009)

Figure 10 Electricity generation forecast, up to 2030



Source: Own assessment based on (MOE of Russian Federation, Agency of energy balances forecasting, 2011)

3.3.3.1 Electricity generation in the Murmansk region by fuels

Shares of the sources for electricity generation as of 2007 are allocated as following: the major part (around 60%) is coming from the nuclear power station; second biggest share (around 40%) is from Hydro electricity stations.

Currently the Murmansk region is electricity abundant, due to the electricity coming from nuclear power station. The nuclear power plant in the Murmansk region is one of the oldest in Russia and needs to be upgraded or closed due to the wear and tear of the equipment. There is a project for stage decommissioning of nuclear reactors, starting from 2018. And by 2030 all nuclear reactors will be closed (decommissioned). In Table 2 below, the nuclear reactors decommissioning schedule is presented.

Table 2 Nuclear reactor decommissioning schedule

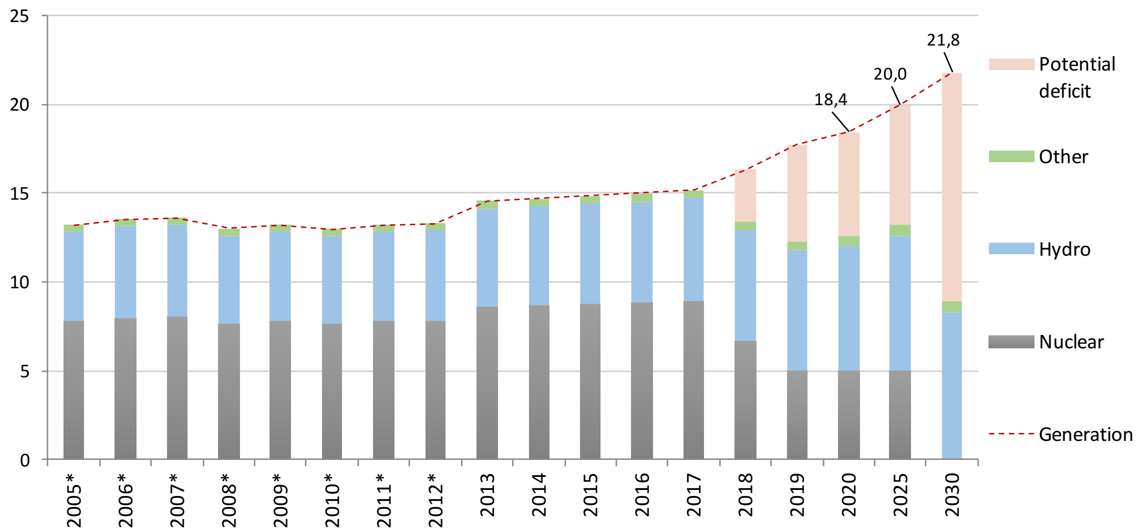
Name	# Reactor	Build capacity [MW]	Year of constraction	Year of validity	Scheduled decommissioning
Kolskay nuclear station	1	440	1972	2002	2018
	2	440	1974	2004	2019
	3	440	1981	2011	2026
	4	440	1984	2014	2029
Total capacity to be decommissioned [MW]		1760			

Source: (MOE of Russian Federation, Agency of energy balances forecasting, 2011)

Still, the active debates is ongoing, in regards of the reactors discharging (RIO news, 2015), due to regional electricity demand and high risk of the potential deficit (as no alternative developed yet). However, for the report the decommissioning as it is scheduled will be considered as a basic scenario.

To anticipate the percentages of energy sources in the regional energy mix for electricity by 2030, the following approached applied: Role of Hydro power and others will be considered on the same level up to 2030, however the share of nuclear power will be decreased gradually in accordance with the schedule. The below Figure 11, shows electricity generation forecast for the region up to 2030; the red area is the potential deficit of the electricity generation in the Murmansk region (in case only the current generation facilities are considered and the nuclear power station reactors will be gradually decommissioned as planned).

Figure 11 Electricity generation forecast open by the energy source, TWh/year

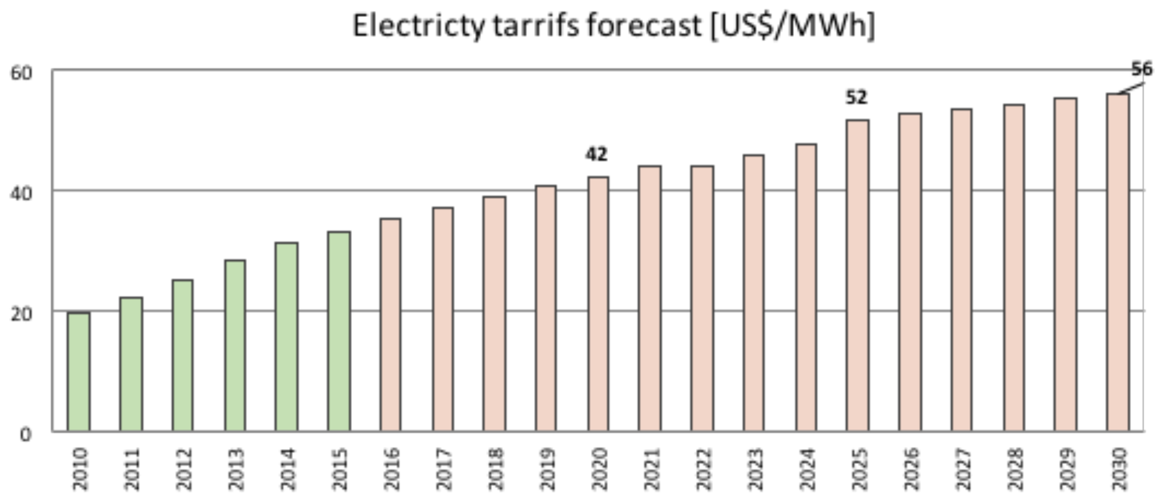


Source: Own assessment

3.3.4 Electricity cost forecast

The aim of the thesis is to evaluate the feasibility of the locally available energy sources usage, thus, it is critical to understand the current tariffs and to estimate the potential cost of electricity generated from local renewable energy sources. As a benchmark for electricity cost, the available forecast of wholesale tariffs, prepared by the (MOE of Russian Federation, Agency of energy balances forecasting, 2011) will be used. It is assumed, the projection is prepared in nominal terms. The mentioned cost projection is given for "North West Energy system" and Murmansk region is a part of it Figure 8. In the report prepared by MOE (MOE of Russian Federation, Agency of energy balances forecasting, 2011). Tariffs are presented in rubles (Russian currency), however, as US$ being used in the feasibility study (as globally understandable currency), the provided tariffs have been converted to US$, with the exchange rate as of 2011 (28 RUB/US$), in accordance with (Central Bank of Russia, 2011). Thus, the below mentioned tariffs in Figure 12 will be used for feasibility evaluation of the electricity generating projects based on the renewable energy sources.

Figure 12 Electricity wholesale tariffs by 2030 in US$/MWh

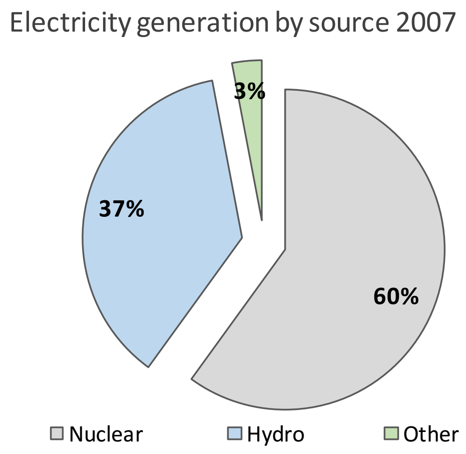


Source: Own assessment based on (MOE of Russian Federation, Agency of energy balances forecasting, 2011).

3.3.5 Conclusion:

As aforesaid, Murmansk region is electricity abundant currently, with the partially operative nuclear power station; However, starting from 2018, after the decommissioning launching, the Murmansk region may face an electricity deficit if no actions taken before. Below in Figure 13, the actual electricity generation by fuel.

Figure 13 Electricity generation as of 2007, open by energy source



Source: (Goverment of Murmansk region , 2009)

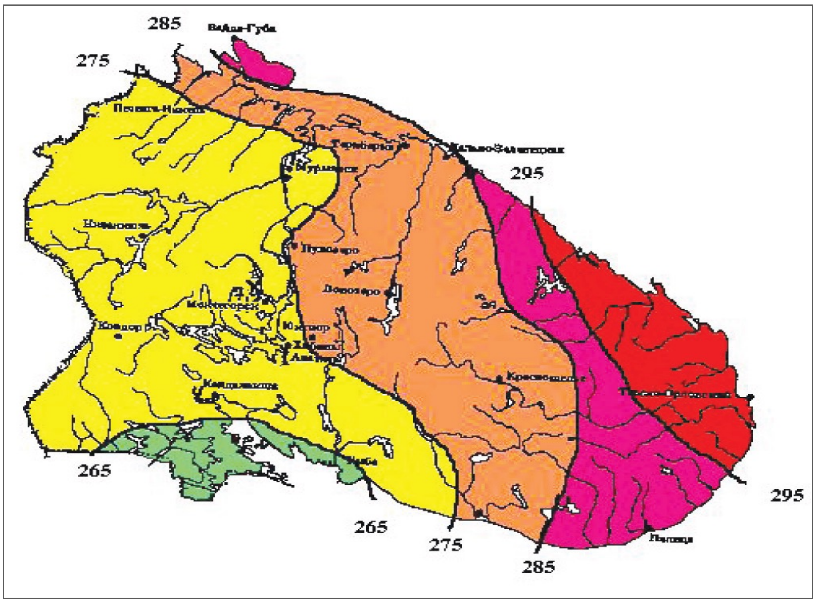
Since the year of 2018 (start of the scheduled nuclear reactors decommissioning) the Murmansk region may face the electricity deficit and with gradual decommissioning of the nuclear reactors, by 2030, electricity deficit may reach 60% (current share of nuclear power).

3.4 Heating

3.4.1 Heating system in region

Cold climate of the selected region of Murmansk, creates excessive heating demand. Heating season in the Murmansk region is 280 days (or nine months), average temperature during the winter months is -10 degrees cesium (MOE of Russia, Housing and utilities department of Murmansk region, 2011). Below in Figure 14, the number of the days require heating, in Murmansk region, is presented (from red- the highest number 295 days, to yellow- the lowest 275 days). District heating system, in the selected region of Murmansk, means, the disctribution of the generated heat via transmission lines to a number of consumers. Around 98% of the total consumers in the region are using a district heating system (MOE of Russia, Housing and utilities department of Murmansk region, 2011).
It is stated (MOE of Russia, Housing and utilities department of Murmansk region, 2011) that heating transportation infrastructure in the region is well worn out, in some cases reaching 80% and this has led to high losses and inefficiency. In 2011 installed capacity of heat generation stations was 8329 MW and the annual production 13,7 TWh/y. Heating season length in different districts of Murmansk region

Figure 14 Heating season length in different districts of Murmansk region



Source: (Blinov, 2007)

3.4.2 Heat generation in the region

73% of total supplied heat is coming from generating facilities (43 units), concentrated in 6 major cities (Murmansk, Apatiti, Kirovsk, Monchegorsk, Kovdor, Severomorsk) (Minin V. , 2012). The last 27% is coming from the facilities located in the small populated areas, shown below in Table 3.

Table 3 Heat generation open by locations (2010)

Group	Name	Heat supply [TWh]
Cities	Murmansk	3,74
73,6%	Apatiti	1,49
	Monchegorsk	1,50
	Kirovsk	1,24
	Kovdor	0,96
	Severomorsk	1,04
Populated areas	Olenegorsk	0,78
12,1%	Polar Zori	0,34
	Alexandrovsk	0,70
	Vidyevo	0,08
Municipal districts	Kolskyi	0,51
14,3%	Pechengskiy	0,78
	Kandalakshskii	0,30
	Levozerskiy	0,15
	Terskiy	0,07
Total Murmansk Region		**13,70**

Source: (Minin V. , 2012)

3.4.3 Heat generation forecast

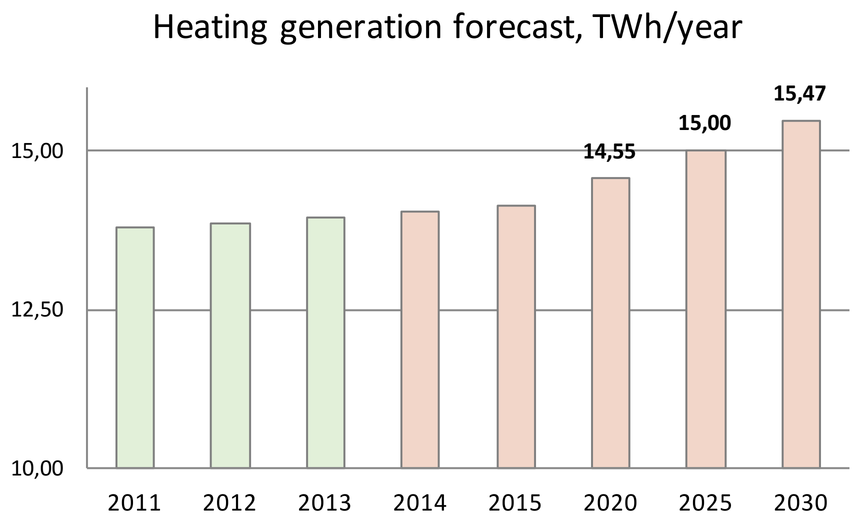
There is no available data on the heat generation forecast for the Murmansk region particularly. In order to assess the required level of heat generation by 2030, the projection for "North West" energy system was used, which the Murmansk region is the part of. In accordance with (MOE of Russian Federation, Agency of energy balances forecasting, 2011) required heating generation will rise up annually by 0.61%. Using the aforementioned approach, the level of required generation of 2011 (13,7 TWh/y) will be extrapolated by 0.61% yearly up to 2030. Heat generation projection for different energy systems of Russia are presented below in Table 4 and forecast for the Murmansk region particularly, is displayed below in Figure 15.

Table 4 Heat generation projection for the energy systems of Russia

Integrated power systems, TWh	2010	2015	2020	2025	2030	Increase in 2030 vs 2010		
						TWh	%	Y-Y increase, %
North West	87	90	93	97	98	11,3	11.5%	0,61
Center	161	161	163	167	170	9,2	5.4%	0,28
Mid Volga	109	114	118	121	122	12,9	10.6%	0,56
South	28	33	34	37	41	13,2	32.3%	1,96
Ural	174	181	183	190	190	16,6	8.7%	0,46

Source: (MOE of Russian Federation, Agency of energy balances forecasting, 2011)

Figure 15 Heat generation actual/projection

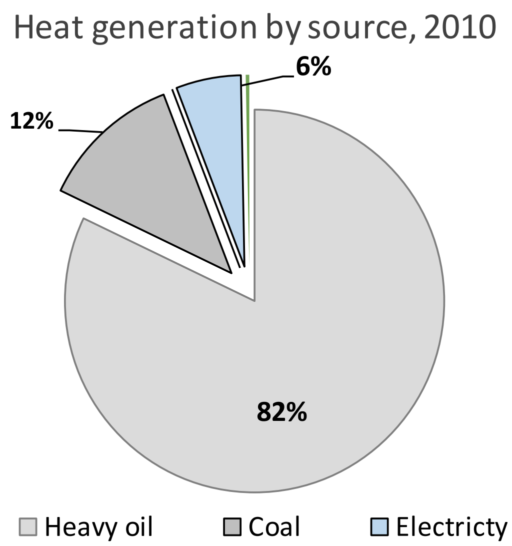


Source: Own assessment, based on Source: (MOE of Russian Federation, Agency of energy balances forecasting, 2011)

3.4.3.1 Heat generation by fuel

In Murmansk region, as of 2010, the main energy source for heat generation (up to 82%) was heating oil (MOE of Russia, Housing and utilities department of Murmansk region, 2011). Coal had a share of 12% out of total generated heating, and electricity took 6%, see Figure 16.

Figure 16 Heat generation by fuel, 2010



Source: (MOE of Russia, Housing and utilities department of Murmansk region, 2011)

By 2020, the regional government has a target to increase the role of the coal in the energy mix of heat generation, and increase the role of biomass in the same (without specifying the type of biomass). Additionally, 10% of the heat is projected to come from natural gas; as mentioned below in Table 5.

Table 5 Main sources of the heating

Energy source for heating generation	2010 (%, actual)	2020 (%, forecasted)
Heavy Oil	82%	54%
Coal	12%	31%
Others (including diesel)	0.3%	0%
Biomass (raw wood and other)	0%	1%
Electricity	6%	4%
Natural Gas	0%	10%
Total	100%	100%

Source: (Kolcov E, 2010), (MOE of Russia, Housing and utilities department of Murmansk region, 2011)

3.4.4 Heat generation tariffs

As stated before, around 80% of generated heat iin the Murmansk region comes from burning of imported heavy oil (heating oil). That potentially leads to higher cost of heat generation in the Murmansk region; additionally, the outworn infrastructure and poor isolation level of houses (MOE of Russia, Housing and utilities department of Murmansk region, 2011) altogether create higher consumption and inefficiency of heating system in general.

Information on the actual cost of heat generation in the Murmansk region is very limited, as for the actual cost as well as for projected once. The heating sales prices (prices for end users) is available at the same time. Heating rates for end users in the Murmansk region, set by the «Murmansk region tariffication department» (Murmansk Region tariffication department, 2015), and they have to be within the range, which suggested by the government of Russia and reviewed annually. In order to estimate the cost of the heating the assumption has been made, that generation cost itself (heating tariff) is around 30-35% out of the heating sales price and the other 65-70% of the heating price is devoted to cover losses and to transport generated heat.

Normally 40-50% of heat generation cost is devoted to the feedstock cost and in Murmansk region particularly the share of the feedstock in heating cost structure is reaching 56% (MOE of Russia, Housing and utilities department of Murmansk region, 2011). Heavy oil price is connected to the prices oil export and additionally logistical expenses (to transportation fuel from region to region) altogether are increasing the cost of the heating generation. Heating cost projection by 2030, will be based on the heavy oil costs increase forecast, which is provided particularly for the Murmansk region, see Table 6.

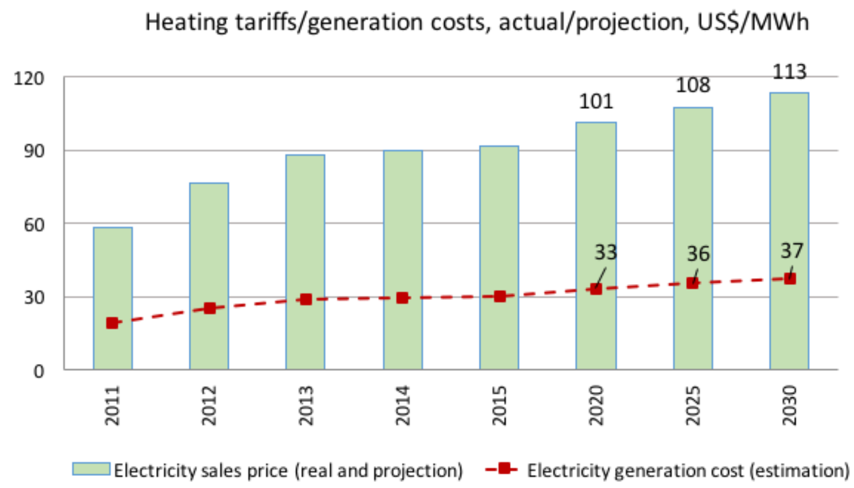
Table 6 Heavy oil cost projection including logistic

Price including transportation [usd/ton]	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Heavy oil	176	179	181	184	187	190	193	195	198	201	202	203	206	209	212	212
Increase		2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	1%	1%	1%	1%	0%

Source: (MOE of Russian Federation, Agency of energy balances forecasting, 2011)

In the given forecast for heating oil cost is growing steadily up to 2030, the % of yearly heavy oil cost increase will be used as an index to forecast heating generation tariffs, results presented in Figure 17.

Figure 17 Heat generation by fuel, 2010



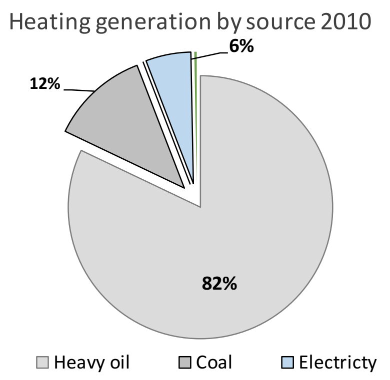
Source: Own assessment

3.4.5 Conclusion:

Despite the fact that the district heating supply system is well developed in the region, there are some issues which are causing inefficiency and increasing the cost of heating generation. The issues are as follows: the outworn heat heat transmitting infrastructure, technically outdated heat generation facilities, the lack of the heating consumption measurement system, poor housing isolation and long winter period, which increases the heat demand.

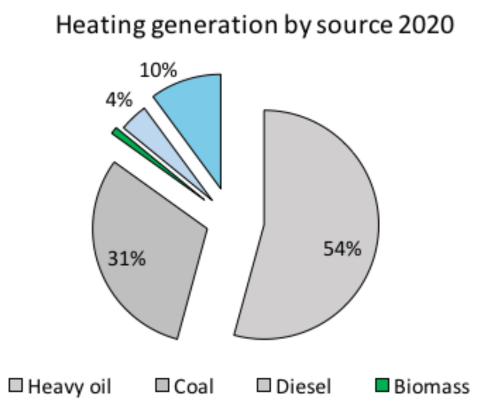
The government has targeted increasing the role of natural gas for heat generation by 10%, expanding the share of heat generated on coal (up to 31% by 2020, from 12% in 2010). Consequently, the share of the heat coming from heavy oil projected to decrease (from 82% in 2010 to 54% by 2030). As mentioned above, in 2020, 10% of the generated heat of the region is projected to come from the natural gas, however gas production is not foreseen to start earlier than 2030. Consequently 10% of heating generation in 2020 can be a potential deficit. In Figure 18 and Figure 19, actual and forecasted heating generation by energy source are presented.

Figure 18 Energy mix for heating (actual 2010)



Source: (MOE of Russia, Housing and utilities department of Murmansk region, 2011)

Figure 19 Energy mix for heating (projection for 2020)



Source: (Kolcov E, 2010)

4. Locally available energy sources

The target of this chapter is to estimate the raw potential of various energy sources which are locally available, and to calculate the technical potential accordingly; for both electricity and heat generation. A list of naturally occurring energy sources targeted for further analyses in this report is shown below in Table 7. Out of this, peat as an energy source, which is so called semi-renewable; peat lands has a very slow restorative ability (1 mm per year) (Northern Ireland Environment Link , 2011). Improper harvesting is affecting the sensitive eco system of the swamps, and they can loose the recovering capability. Harvesting has to be well controlled process, avoiding overproduction. However, considering the vast usage of imported heavy oil in the region (around 80% of totally generated heat is coming from the heavy oil), peat will be considered as a locally available energy source, thought semi renewable.

Out of the scope some energy sources are self limiting (limited volume per year), like biomass (in all its types), and some other energy sources needs to be additionally limited (for example available land for PV field construction). In such cases (PV, wind) the geographical limitations will be applied in order to estimate potential of the energy source in the region. The main geographical limitations are listed below in Figure 20.

Figure 20 Geographical limitations for wind and solar energy

Source: Own assessment

Table 7 Targeted energy sources are selected as below:

Energy source		Electricity	Heating
Forest residuals	[FR]	✓	✓
Peat briquettes	[PB]	✓	✓
Municipal solid waste	[MSW]	✓	✓
Wund	[WE]	✓	
Solar	[SE]	✓	
Hydro	[HD]	✓	
Tidal	[TD]	✓	

Source: Own assessment

The technical potential will be calculated based on the well know and commercially available technologies.

4.1 Natural Gas:

4.1.1 Availability in the region as a primary source of energy

The targeted region of Murmansk is rich with fossil fuels, oil and gas fields are mainly located on the offshore of the Barents Sea; currently, 12 fields are discovered. Initially, the production start was scheduled for 2025. However, the further development remains uncertain under market conditions. The estimated extractable gas resources are 3.8 trl cm. The expected annual production from the Shtokman field is 20 bln cm/year. Still any further development requires massive investments, including infrastructure construction (such as LNG plant). Thus, natural gas is not included in the list of the locally available energy sources, as most probable production wont start earlier 2030.

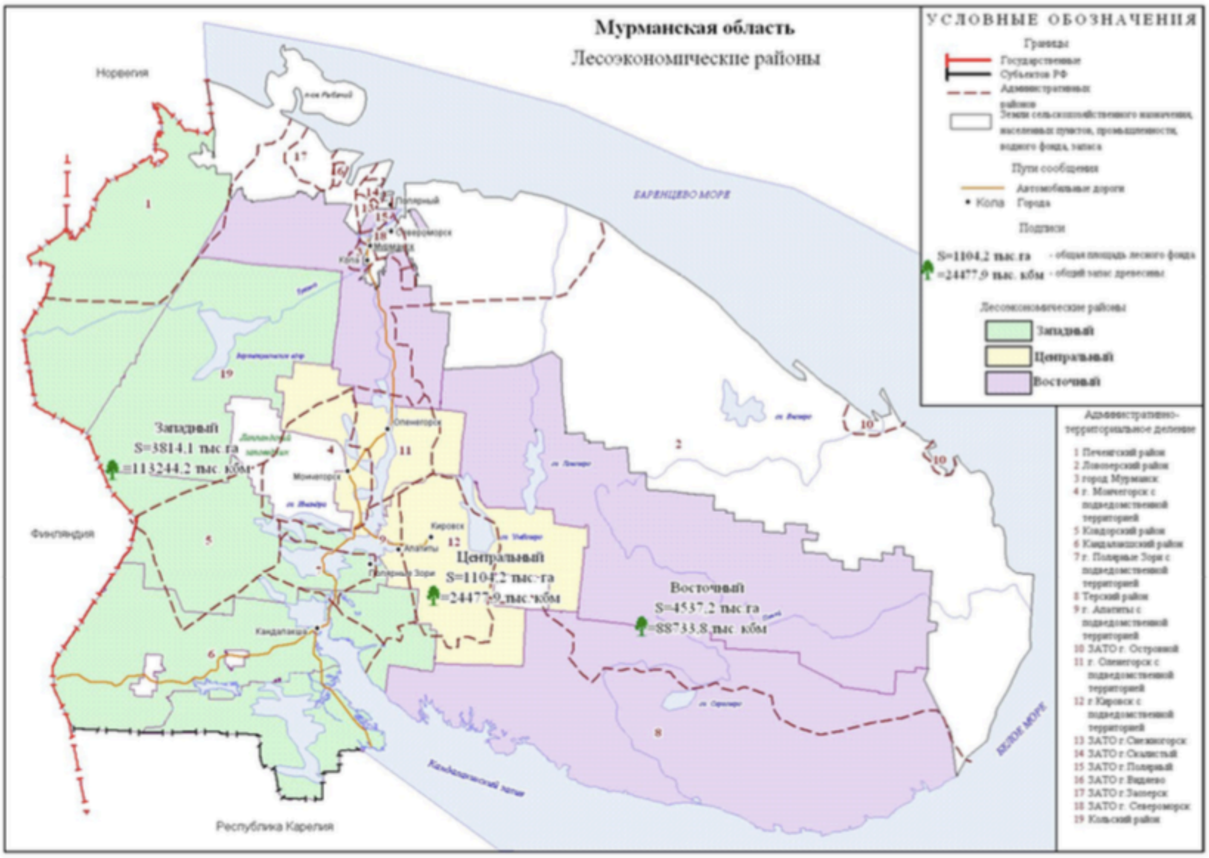
4.2 Biomass

For the analyses further ahead, the main groups of biomass, which will be reviewed in thesis are as follows: Forest residuals, Peat briquettes, and Municipal waste. For each type of renewable source, the availability per year will be estimated as well as the theoretical maximum of electricity and heating generation.

4.2.1 Forest residuals availability as a primary energy source in the Murmansk region

In the selected region of Murmansk there are three forest economic regions. They are: Central, Western and Eastern, as presented below, Figure 21.

Figure 21 Map of the Murmansk region with forest economic zones indicated



Source: (Forestry committee, 2008).

In Figure 21, green zone is Western forest economic region, pink is Eastern and yellow is Central respectively. Below in the Table 8, the main characteristics of each zone are presented

Table 8 Forest economic zones highlights

Zone	Forest volume, cm	Out of tot %
Western	113,1	50%
Eastern	88,7	39%
Central	24,5	11%

Source: (Forestry committee, 2008)

It is stated in the Murmansk regions' "Forest plan" (Forestry committee, 2008), as of 2008 the total forest area available for commercial usage was 94 Th km^2. The majority of the forests in the Murmansk area are under protection, particularly 64.8%. And any commercial activity, including timber Harvesting, is restricted in that area.

Table 9 Total forests area and volume by the Designation

Designated use of forest	Area, Th sq km	Volume, mln cm
Protected forests	60,3	123,51
Commercial forest	34,3	102,6

Source: (Forestry committee, 2008)

Wood processing industry is not well developed in the selected region of Murmansk. Two main products generated in region are: round timber and sawn wood. (Forestry committee, 2008). For this thesis only harvested timber residuals will be reviewed as a primary source of energy. Data of the actual harvesting volumes in the Murmansk region, (in the Table 10 below) is available from the Federal statistical Agency of Russia (Federal Statistical Agency, 2015).

Table 10 Forest harvesting in Murmansk region (actual data)

Harvested timber [Th m3]	2009	2010	2011	2012	2013	2014
Murmansk region	84,64	94,3	126,9	117,22	100,02	126,08

Source: (Federal Statistical Agency, 2015)

Level of forest production is projected to increase till the level of 154 Th m^3 by 2018 (Forestry committee, 2008). The harvested volume will be extrapolated by the same % and under this approach the level of the harvested forest will reach the volume of 173 Th m^3 by 2020 and 310 173 Th m^3 by 2030, see below Table 11.

Table 11 Timber volume projection for Murmansk region

Harvested timber projection [Th m3]	2015	2020	2025	2030
Murmansk region	134	173	232	310

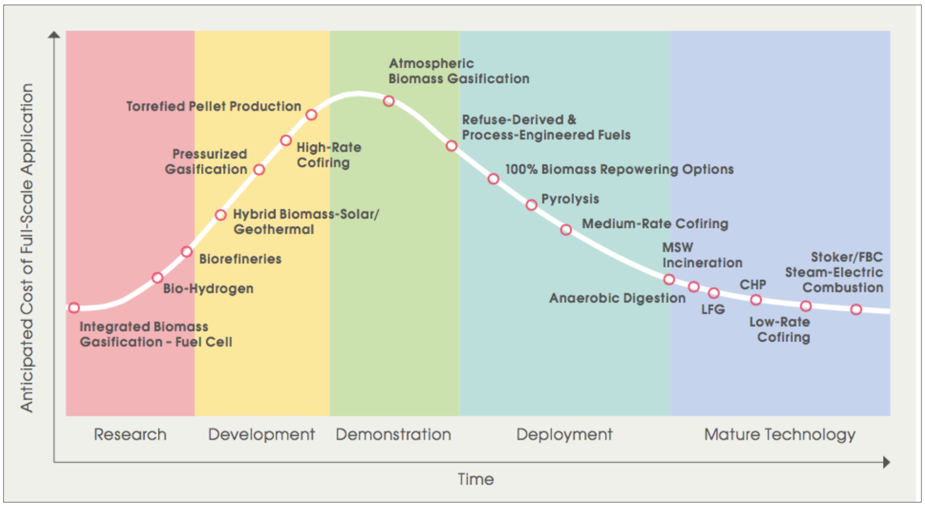
Source: Own assessment based on (Federal Statistical Agency, 2015)

With the given spruce specific density, as 500 kg/m^3 (Engineering tool box, 2010) available tonnage of the harvested forest is 150 Th ton in 2030, and out of that suitable residuals for further review are estimated as 30% of totally harvested forest or 45 Th ton.

4.2.1.1 Forest residuals technical potential of electricity generation

For forest residuals and peat briquettes conversion to energy (electricity and heating), the direct combustion was selected as a well developed and mature technology for electricity generation; as is shown below in Figure 22.

Figure 22 Learning curve for direct combustion



(IRENA, 2012)

The average global efficiency of fossil-fuelled power generation has remained stagnant for decades at 35% to 37%. (International Energy Agency (IEA), 2011). The level of 35% will be used for electricity generation calculations.

Forest residuals moisture content will be taken as 50%, as residuals are not specially treated before the usage, apart collection and drying naturally. In accordance with (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 1990), the energy content for wood with different moisture levels are as shown below in Table 12.

Table 12 Energy content for wood with different moisture level:

Fuel	As fired Gross calorific value (MJ/kg)	Typical burner efficiency (%)	Useable Net heating value (MJ/kg)
Wood at 0% m.c [1/]	19.8	80	15.8
10% m.c	17.8	78	13.9
20% m.c.	15.9	76	12.1
30% m.c.	14.5	74	10.7
40% m.c.	12.0	72	8.6
50% m.c.	10.0	67	6.7
Anthracite	31.4	83	26.1
Lignite	26.7	80	21.4
Heavy fuel oil	42.6	82.5	35.1
Light fuel oil	43.5	82.5	35.9
Butane	49.3	79.0	38.9
Propane	50.0	78.7	39.4

Source: (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 1990)

For further calculations the 6,7 MJ/kg will be considered, which is equivalent to 2,38 KWh/kg. Capacity factor for wood waste burning will be taken accordingly (IRENA, 2014); Results of the calculations are presented below in Table 13.

Table 13 Theoretical electricity generation from forest residuals

Given Data	Value	Unit
Energy source	Biomass	Forest residuals (FR)
Installed capacity	20000	[KW]
Conversion efficiency	35%	[%]
Capacity factor	0,90	
Energy content	2,38	[KWh/kg]
Source available in the region (FR)	45000000	[kg/year]

Calculated parameters	Value	Unit
Required biomass per hour	8403	[kg/h]
Required biomass per year	73613445	[kg/year]
Electricity output (20MW unit)	0,055	[TWh/y]
Theoretically possible generating facilities	0,61	[units]
Regional potential electricity output (FR)	0,034	[TWh/y]

Source: Own assessment

The totally available volume of timber is 45 Th ton/y. A 20 MW plant, can generate up to 0.055 TWh/y, of electricity, and requires 73 Th ton of feedstock per year. With the totally available volume of timber is 45 Th ton/y, the potential electricity generation is 0,034 TWh/y.

4.2.1.2 Forest residuals: Technical potential of heat generation:

As mentioned previously, the selected technology (Direct combustion) is a well established and commonly used technology for converting biomass into heat. The efficiency of the boiler is taken based on the data from the local heat generation plant in Murmansk (build capacity and generated heat in 2014), efficiency is set to be around 60% (Murmanskay heating station, 2015). As it was stated earlier, heat content of the forest residuals, with no pre treatment (moisture content of 50%), is 2,38 KWh/kg. The following potential output have been calculated, presented below in Table 14.

Table 14 Theoretical heat generation from forest residuals

Given Data	Value	Unit
Energy source	Biomass	Forest residuals (FR)
Installed capacity	20000	[KW]
Conversion efficiency	60%	[%]
Energy content	2,38	[KWh/kg]
Heating season length (280 days)	6720	hours
Source available in the region (FR)	45000000	[kg/year]

Calculated parameters	Value	Unit
Required biomass per hour	8403	[kg/h]
Required biomass per year	73613445	[kg/year]
Heat output (20MW unit)	0,081	[TWh/year]
Theoretically possible generating facilities	0,611	[units]
Regional potential heat output (FR)	0,049	[TWh/year]

Source: Own assessment

Possible heat generation from one facility with the capacity of 20 MW, based on biomass (wood/forest residuals) is 0.081 TWh/year. Yearly available volume of mentioned biomass in Murmansk region is 45 Th ton, thus potential annual heating generation is 0,049 TWh/y.
Forest residuals are not yet in use for electricity and heat generation in the Murmansk region. Moreover, the development of bioenergy is slow due to some critical obstacles such as lack of infrastructure for feedstock handling, treating and drying. Planning and construction of wood treatment infrastructure would require additional investments and besides investments devoted to the construction of the new biomass based facilities itself.
Optionally for the Murmansk region the total harvested forest can be considered as an energy source, this would potentially increase the technical potential of forestry biomass significantly. However, this is the subject of the additional research in order to ensure the sustainable forest harvesting in the Murmansk region and asses the monetary benefits of the harvested forest usage as an energy source, not the good for trading.

4.2.2 Peat: Availability as a primary energy source in the Murmansk area.

Peat is a fuel, which is a product of the partial decomposition of organic material. Peat is located in the wetland areas such as swamps. Around 45% of the global peat resources are concentrated in Russia. Peat resources is estimated to be around 175,65 bln ton and located on the area more than 500 Th km^2.

Peat as an energy source, has a number of long term disadvantages; Such as extensive (especially machined cutting and drainage) harvesting can ruin the integrity of the wetlands and its ability to recover (Northern Ireland Environment Link , 2011). Whilst, wetlands, in their natural state have number of benefits for environment; Its (wetlands) absorb the carbon dioxide and store it, and have a critical role in storing and purifying water. As it was stated before, peat is considered as semi renewable source of energy and yet it can be an alternative to the imported heavy oil, for electricity and heat generation in the Murmansk region. Peat briquettes as an energy source (for heating and electricity generation) was selected, due to its mode of production; Peat briquettes commonly produced on smaller scale by manual, semi-mechanical methods. Consequently, peat briquettes are the most efficient (less moisture content) and less damaging for the environment due to its production mode.

4.2.2.1 Peat availability in Murmansk region:

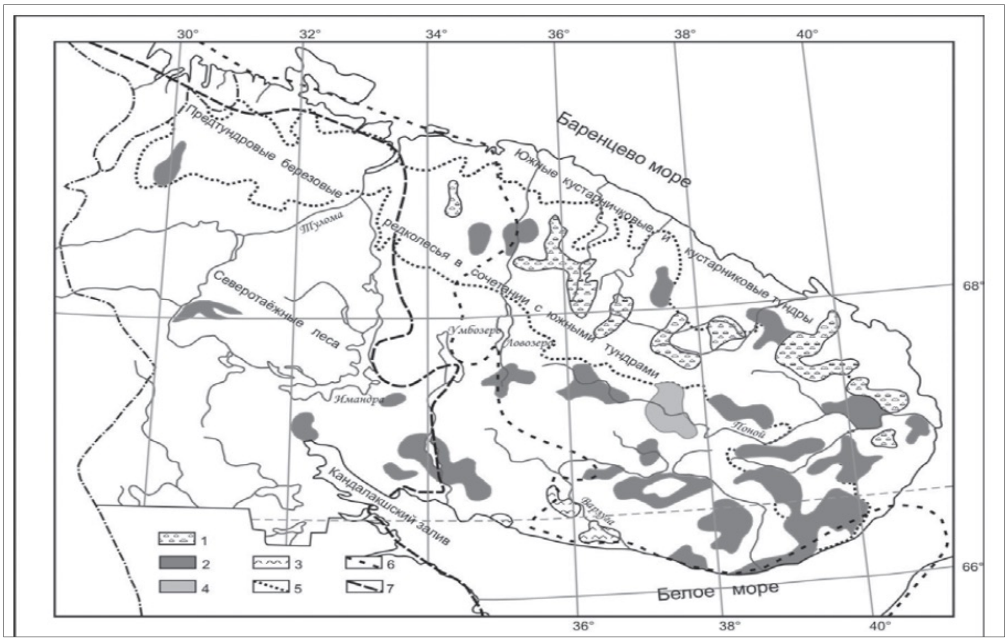
Peat is not involved in energy generation in the region, neither electricity nor heating. To figure out the available volume of the source in the region, the data from (Ruspeatland, 2015) was used. It is claimed in the source that a total of 204 Th ton a year of peat is available for treatment and other commercial usage; as is indicated below, in Table 15. The peat fields, located in the Murmansk region are presented on the map below, Figure 23.

Table 15 Peat resources in Murmansk region

Total area of the petlands in the Murmansk region (with required depth)	All exploration degree (P1 + P2 + P3 + A + B + C1 + C2)	Commercial resources	Resources avalible per year, considering the 50 years usage
[sq km]	**[mln tons]**	**[mln tons]**	**[mln tons per year]**
3 854,7	882,3	10,2	0,204

(Ruspeatland, 2015)

Figure 23 Map of peat fields in Murmansk regions



Source: (Evzerov, 2012).

As stated in the (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 1990) artificially dried compressed peat briquettes with a moisture content of 10-20%. It is assumed that the raw peat will be processed to the peat briquettes in the Murmansk region, as the most efficient energy source from peat and most convenient for further transportation. Considering the moisture content of raw peat, total weight, has to be 75% decreased in order to estimate the weight of peat in briquettes, which are artificially dried. That means that totally available peat in briquettes volume in the region is 31 Th ton a year.

4.2.2.2 Peat: Technical potential of electricity generation

The efficiency of electricity generation from peat will be the same level as for forest residuals, 35%. Heat content of the peat briquettes, will taken as 20 MJ/kg or 5,5 KWh/kg as presented below, in Table 16. The resulted calculations are displayed in Table 17.

Table 16 Combustion properties of different peat types

	Peat			Wood	Lignite
	Milled	Sod	Briquettes	Biomass	
Effective calorific value of dry matter (MJ/kg-mean)	18-22	18-22	18-22	18-19	20-24
Effective calorific value at operating moisture content (MJ/kg-mean)	7-12	11-14	17-18	12-13	11-14
Volatile substances (% dry matter-mean)	65-70	65-70	65-70	75-85	50-60
Bulk density at operating moisture content (kg/m^3)	300-400	300-400	700-800	320-420	650-800
Operating moisture content (%)	40-55	30-40	10-20	30-35	40-60

Source: (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 1990)

Table 17 Theoretical electricity generation from peat briquettes

Given Data	Value	Unit
Energy source	Biomass	Peat briquettes (PB)
Installed capacity	20000	[KW]
Conversion efficiency	35%	[%]
Capacity factor	0,90	
Energy content	5,5	[KWh/kg]
Source available in the region (PB)	31000000	[kg/year]

Calculated parameters	Value	Unit
Required biomass per hour	3636	[kg/h]
Required biomass per year	31854545	[kg/year]
Electricity output (20MW unit)	0,055	[TWh/year]
Theoretically possible generating facilities	0,97	[units]
Regional potential electricity output (PB)	0,054	[TWh/year]

Source: Own assessment

Considering the vast availability of peat in the Murmansk region, this source can be considered as an alternative for the imported heavy oil, especially for the rural areas, where peat fields are mainly located. Overall, it is theoretically possible to generate 0.054 TWh/y of electricity out of the yearly available peat volume in the region of Murmansk.

4.2.2.3 Peat: Technical potential of heating generation:

For the calculation of the theoretical heat generation from the peat briquettes, the same heat capacity has been taken as for the forest residuals; particularly 20 MW. Efficiency of the boiler is taken based on the data from the biggest heating plant in the region – Murmasnkay TEC. Based on its installed capacity and heat output in 2014, the efficiency is about 60% (Murmanskay heating station, 2015). Energy content of the peat briquettes is 5,5 KWh/kg. Derived calculations are shown below in Table 18.

Table 18 Theoretical heat generation from peat briquettes

Given Data	Value	Unit
Energy source	Biomass	Peat in briquettes (PB)
Installed capacity	20000	[KW]
Capacity factor	0,60	[%]
Heat content	5,5	[KWh/kg]
Heating season length (280 days)	6720	hours
Source available in the region (PB)	31000000	[kg/year]

Calculated parameters	Value	Unit
Required biomass per hour	3636	[kg/h]
Required biomass per year	31854545	[kg/year]
Heat output (20MW unit)	0,081	[TWh/year]
Theoretically possible generating facilities	0,97	[units]
Regional potential heat output (PB)	0,078	[TWh/year]

Source: Own assessment

Technically, it is possible to achieve a heating output of 0,081 TWh/y from one 20 MW facility based on peat briquettes (as an energy source), yet an available volume of peat briquettes in Murmansk region is 31 Th tons a year. Therefore, the theoretical potential of the heat generation from peat is 0,078 TWh/y.

4.2.3 Municipal Solid Waste (MSW): Availability as a primary energy source in the Murmansk area

In this part, the municipal solid waste availability as an energy source in the Murmansk region is appraised. It can be said that waste is a sustainable energy source in the sense of a reoccurring volume. MSW management system includes collection, recovery, and disposal of waste; mentioned actions are conducted by specialist entities and coordinated by local authorities. In accordance with (International Finance Corporation, 2011) volume of MSW in Russia is steadily growing and around 48 Mln tons produced in 2010; meaning around 330 kg per capita per year. For the further calculations, the level of the generated MSW per capita will be assumed as 380 kg. To estimate the projected volume of MSW in the Murmansk region, the average per capita volume is multiplied to the population (number of inhabitants in the region). MSW projected volume in the Murmansk region is presented in Table 19.

Table 19 Forecasted volume of the MSW generation in Murmansk region

Generated MSW [Th Tons]	2020	2025	2030
Forecast of the MSW generation in the region (with 380 kg per year/per capita)	310	317	323

(International Finance Corporation, 2011)

4.2.3.1 MSW: Technical potential of electricity generation

The selected technology for the MSW conversion into energy (for both electricity and heating) is the Incineration. Incineration is the waste treatment systems, where waste materials converts into ash, flue gas, and heat. Incineration is burning the waste (including MSW) to boil the water, which after powers steam generators, producing electricity.

After incineration, the waste volume is typically reduced up to 95% (caricomenergy, 2015). One of the major benefits of the technology, is that the MSW is not require any pretreatment. Thus, the primary purpose of a waste-to-energy facility is to manage municipal solid waste; energy production (electricity and heating) can be considered as an extra benefit. In accordance with the US Energy Information Administration, municipal solid waste contains both biogenic and non-biogenic components. Nowadays, the proportion of the non biogenic waste has increased (EIA, 2012), as much as 50%, below Table 20. EIA states that non-biogenic material has a higher heat content, and consequently the average heat content of MSW will increase, making its' more efficient for producing energy (electricity and heating).

Table 20 Heat content of components of MSW

Biogenic	Heat content (MMBtu/ton)	Non-biogenic	Heat content (MMBtu/ton)
Newsprint	16	Rubber	26.9
Paper	6.7	PET (polyethylene terephthalate)	20.5
Containers and packaging	16.5	HDPE (high-density polyethylene)	19.5
Textiles	13.8	PVC	16.5
Wood	10	LDPE/LLDPE (low-density polyethylene)	24.1
Food waste	5.2	PP (polypropylene)	38
Yard trimmings	6	PS (polystyrene)	20.5
Leather	14.4	Other (plastic)	18.1
Average	11.1	Average	23

Source: (EIA, 2012),

The average MSWs heat content, with 50% of non biogenic in the mixture is 17 MMBtu/ton or 4.98 kWh/kg, which will be considered in further estimations. Potential electricity output from 20MW facility based on MSW, presented below in Table 21.

Table 21 Potential electricity generation from MSW in Murmansk region

Given Data	Value	Unit
Energy source	Biomass	Municipal Solid Waste (MSW)
Installed capacity	20000	[KW]
Conversion efficiency	35%	[%]
Capacity factor	0,90	
Energy content	4,98	[KWh/kg]
Source available in the region (MSW)	32300000	[kg/year]

Calculated parameters	Value	Unit
Required biomass per hour	4016	[kg/h]
Required biomass per year	35180723	[kg/year]
Electricity output (20MW unit)	0,055	TWh/y
Theoretically possible generating facilities	0,92	[units]
Regional potential electricity output (MSW)	0,051	TWh/y

Source: Own assessment

That type of waste treatment can reduce the volume of solid waste up to 90%, as mentioned before. Thus, the main target of the technology is garbage utilization, and energy output is a secondary product.

4.2.3.2 MSW: Technical potential of heat generation:

As mentioned above, the MSW energy content is 4,98 KWh/kg, this number will be used for further calculations. The efficiency is about 60% (Murmanskay heating station, 2015). Potential heating output, given below, in Table 22.

Table 22 Technical potential of heat generation from MSW

Description	Value	Unit
Energy source	Biomass	Municipal Solid Waste (MSW)
Installed capacity	20000	[KW]
Capacity factor	60%	[%]
Heat content	4,98	[KWh/kg]
Heating season length (280 days)	6720	hours
Source available in the region (MSW)	323000000	[kg/year]

Calculated parameters	Value	Unit
Required biomass per hour	4016	[kg/h]
Required biomass per year	26987952	[kg/year]
Heat output (20MW unit)	0,081	[TWh/year]
Theoretically possible generating facilities	11,97	[units]
Regional potential heat output (MSW)	0,965	[TWh/year]

Source: Own assessment

Considering the projected volume of the MSW more than 300 Th ton a year (in 2030 particularly 323 Th ton a year). the potential heating output of the 20 MW facility based on MSW will be 0,081 TWh/y. And total possible heat generation is 0,965 TWh/y. Municipal solid waste as an energy source has a few benefits; First of all, it is sustainable (with a steadily growing volume), secondly, usage of the MSW as an energy source can partially solve the utilization issues, particularly landfilling.

4.2.4 Biomass as an energy source in the Murmansk area (technical)

In terms of electricity generation, with the usage of locally available biomass (forest residuals, peat briquettes, MSW) and existing technologies it would be possible to generate overall 0,509 TWh/year, presented in Table 23. That amount of electricity would cover 3.10% total required electricity generation in the Murmansk region in 2030. Yet, the mentioned generation of electricity is only technical potential notwithstanding the economical feasibility, which is a subject of the analyses in the chapter 5 of this report.

Table 23 Biomass potential for electricity generation in Murmansk region

Source	Possible electricty generation	Share of regional demand 2030 (21,8 TWh/y)
	[TWh/y]	[%]
Forest residuals	0,113	0,52%
Peat briquests	0,054	0,25%
Municipal Solid Waste	0,509	2,34%
Total from local Energy sources	**0,676**	**3,10%**

Source: Own assessment

Based on the biomass (different types) availability projections and capabilities of the selected technologies, all of a lump it possible to generate 1,094 TWh/y of heating, see below Table 24. That level of generation could secure around 7% of the regional heat demand of 2030. And yet, the feasibility study will be performed in the chapter 5.

Table 24 Biomass potential for heating generation in Murmansk region

Source	Possible heat generation	Share of regional demand 2030 -15,47 TWh/y
	TWh/y	[%]
Forest residuals	0,049	0,32%
Peat briquettes	0,078	0,51%
Municipal Solid Waste	0,965	6,24%
Total from local energy sources	1,093	7,06%

Source: Own assessment

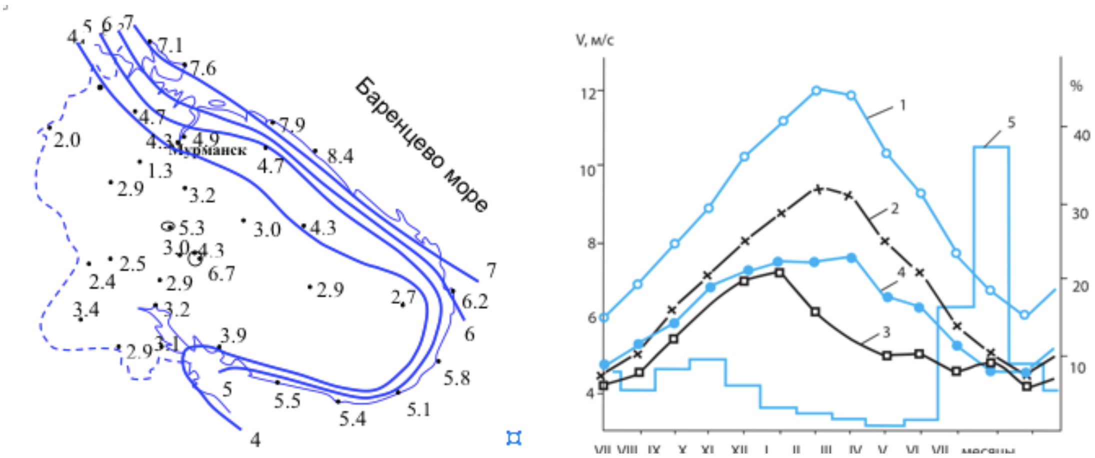
4.3 WIND

4.3.1 Wind: Availability as a primary energy source in the Murmansk region

Generally, the Murmansk region is considered to have high potential for wind energy, mainly due to its' geographical location, along the coastal line. Offshore wind speed is usually higher than the onshore one. However, the cost of the offshore wind farms construction is significantly greater than the onshore one. In accordance with (IRENA, 2012) capital expenditures for offshore wind farms almost twice higher vs onshore once (1850-2250 US$/KW vs 4000 US$/KW). Thus, only onshore wind as an energy source will be reviewed in this thesis.

For the wind energy potential calculations, data from the Kolskiy Scientific Centre was used. The highest wind speed registered in the coastal areas of the Murmansk region is more than 7 m/s and the record registered speed is 40 m/s (Minin V. A., Economical Aspects of small scale renewable energy development in remote locations, 2011). In the centrally located areas of the region, the average annual wind speed is not more than 5 m/s, measured on the height of 10 m. Detailed map with average wind speed measured in the Murmansk region and wind speed variations within the seasons, presented below, Figure 24. Presented data is a result of 10 years monitoring of the wind speeds from 37 stations located in the Murmansk region at the 10 meter height.

Figure 24 Average wind speed in Murmansk region, measured at 10 m height.



Source: (Minin V. , 2012)

To calculate wind energy potential in the region, apart the average wind speed, it is necessary estimate the appropriate area available and suitable for the wind parks construction. Information on the Murmansk region land usage is available in the report "Environmental condition and protection actions efficiency" (Ministry of Natural Resources and Environmental Protection of Murmansk region, 2015). Below in Table 25, the area usage allocation for of the Murmansk region is presented.

Table 25 Murmansk region land usage, 2014

Description	[Th sq km]
Total area of Murmansk region	144,9
Populated areas	0,611
Industrial area	4,575
Agricultural	28,57
Protected forests and other	3,228
Lakes	0,77
Forests	95,1
Avalible area	12,0

Source: (Ministry of Natural Resources and Environmental Protection of Murmansk region, 2015)

In addition, a further limiting factor as 40% is imposed, due to a low level of logistical access to the coastal lines due to poor infrastructural development in such areas. Thus, the total available land for the wind parks construction will be estimated to be 7,2 Th km^2.

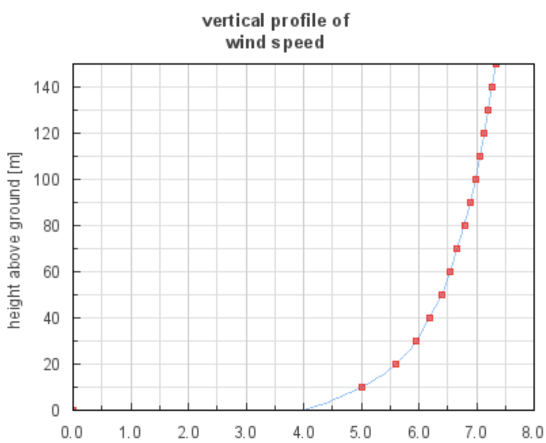
4.3.2 Wind: technical potential of electricity generation

The average wind speed for the region (taking into account fluctuations in districts and different seasons) is assumed as 5 m/s. In accordance with the mentioned research (Minin V. A., Economical Aspects of small scale renewable energy development in remote locations, 2011) the measurements were performed on the 10 meters height. However, up-to-date wind turbans are able to operate at the height 80 and more, in order to catch higher speed and generate more electricity.. For the selected region of Murmansk, there is no available data on the wind speed at such height (at 80-100 m), thus the wind profile calculator will be used (Wind data, 2014). Considering the average speed (as 5 m/s) at the height of 10, wind speed on the higher level if estimated, see in Table 26.

Table 26 Wind speed at the height 80-100 m

Result

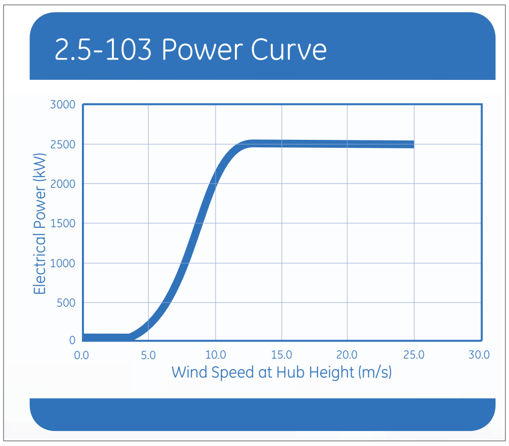
height above ground	wind speed
150 m	7.33 m/s
140 m	7.27 m/s
130 m	7.21 m/s
120 m	7.14 m/s
110 m	7.06 m/s
100 m	6.98 m/s
90 m	6.89 m/s
80 m	6.79 m/s
70 m	6.67 m/s
60 m	6.54 m/s
50 m	6.39 m/s
40 m	6.19 m/s
30 m	5.95 m/s
20 m	5.60 m/s
10 m	5.00 m/s



Source: (Wind data, 2014)

Henceforth, it will be assumed that wind turbine erected on the height of 80 m, and average wind speed at this point is 6.79 m/s. This number will be used for calculations of potential electricity generation from wind, in the Murmansk region. The type of selected wind turbine is 2.5 MW GE; the performance chart of which is presented below in Figure 25. The yearly average power output at a given speed is around 700 KW from one turbine.

Figure 25 GE wind turbine performance 2.5 MW



Source: GE Power & Water

According to the (Denholm, Hand, Jackson, & Ong, 2009) report, land requirements for the wind park, in terms of capacity per unit area, typically, ranges from 1.0 to 11.2 MW/km^2, and the average capacity density is 3.0 ± 1.7 MW/km^2, or 4,7 MW/km^2, if the maximum is taken. Thus, the required area for 20 MW wind park is 4.25 km^2 (if the highest density is considered). Results of the calculations are presented in Table 27.

Table 27 Technical potential of Electricity generation from wind in Murmansk region

Given Data	Value	Unit
Energy source		Wind
Capacity	20000	[KW]
Power output (one turbine)	700	[KW/unit]
Turbine power capacity	2500	[KW/unit]
Capacity factor	0,28	

Calculated parameters	Value	Unit
Suitable land ifor wind park construction	7,2	[Th km2]
Land required for one (20 MW) wind park	0,004	[Th km2]
Electricity output (20MW wind park)	0,049	[TWh/year]
Number of possible wind parks in the region	1694	[units]
Regional potential electricity output (Wind)	83,2	[TWh/year]

Source: Own assessment

The maximum recorded wind speeds reach up to 40 m/s, however, the average wind speed (measured at the height of 10 m) is assumed as 5 m/s. Estimated average speed at the height 80 m is 6,79 m/s. Based on the wind speed and the available, suitable territory for the winds parks construction, the total expected output can reach the level of 83,154 TWh/y. Which can cover more than 100% of Murmansk region electricity demand (21,8 TWh/y in 2030). Ultimately, decision on the wind park construction depends on the cost of the generated electricity, which is the subject of the chapter 5.

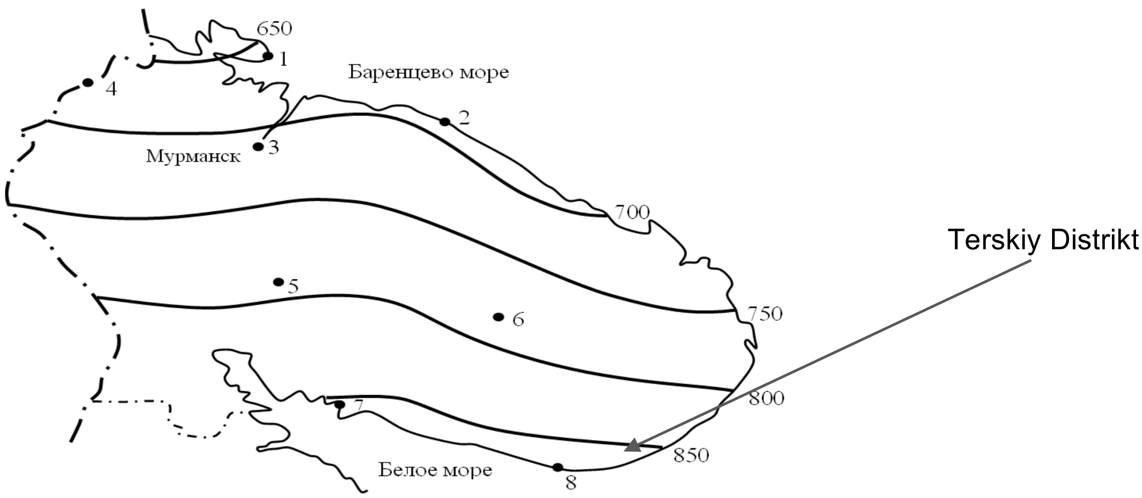
4.4 SOLAR

The biggest part of the Murmansk region is located below the polar circle line, there is polar night and polar day in the region. Consequently, the biggest obstacle of solar energy developing in the region is the low level of solar insolation. Seasonably, there is a monthly variation of daylight length, from zero hours in December to almost 24 hours in June and July (when the highest solar radiation is observed). The most promising candidates for solar energy are remote isolated consumers fully dependent on imported fuels.

4.4.1 Solar: availability as a primary energy source

Insolation level varies along the territory of Murmansk, from 2 to 8 Kwh/m^2/day, as indicated on Figure 26 below. (Minin V. A., Prospects of implementation of the renewable energy sources in the Murmansk region , 2013), South part of Murmansk region (and particularly the Terskiy region) has the highest potential for solar energy development. Potential electricity generation coming from the solar energy, will be calculated for one district of the Murmansk region (Terskiy), where the highest average insolation level as 7,5 Kwh/m^2/day or 2737 Kwh/m^2/year.

Figure 26 Average insolation level in Murmansk region KWh/sqm/year



Source: (Minin V. A., Prospects of implementation of the renewable energy sources in the Murmansk region , 2013)

The total area of the Terskiy district is 19 Th km^2; Area usage allocation (of Terskiy district) presented below, in Table 28, (Terskiy district administration, 2013) . Based on the data in the aforementioned table, the total area available for solar plant installation is around 0.46 Th km ^{2}.

Table 28 Terskiy region land usage, 2013

Description	[Th sq km]
Total area of Terskiy region	19,31
Populated areas	0,02
Industrial area	0,16
Agricultural	0,16
Protected forests and other	0,01
Lakes and forests	18,51
Avalible area	0,46

Source: (Terskiy district administration, 2013)

4.4.2 Solar: Technical potential of electricity generation

In case of solar energy, the selected technology for electricity generation is PV panels. Solar photovoltaic panels convert sunlight directly into electricity. This type of solar cells is most competitive in the market due to their low cost and highest commercially available efficiency. In order to understand the energetic performance (potential electricity generated); the level of the produced electricity will be calculated, with the following formula in accordance with (photovoltaic-software, 2014)

$$E=A*r*H*PR$$

[E] Generated electricity, KWh

[A] Total solar panel area, m^2

[r] Solar panel yield, %

[H] Annual average solar radiation on tilted panels, KWh/m^2/ year

[PR] Performance ratio (varies from 0.5 to 0.9), %

Potential electricity, generated from 20MW PV facility, in Terskiy district of Murmansk region is presented below, in Table 29.

Table 29 Potential electricity generation from 20 MW PV plant

Description	Value	Unit
Installed capacity	20	[MW]
Solar insolation average per year	7,5	[kWh/km2/d]
PV power output	240	[kW]
Required number of PV	66679	[units]
PV area	1,61	[m2]
Total required area for 20MW PV field	107353	[m2]
Solar panel yield	14,9%	[%]
Performance ratio	75%	[%]
Electricty output from 1MW facility	0,018	[TWh/y]
Area avaliable and suitable for PV field	460000	[m2]
Possible number of 20MW PV fields	4,28	[units]
Total potential electricity output	0,077	[TWh/y]

Source: Own assessment

The total possible generated electricity is 0,018 TWh/y from one 20 MW PV field. However, considering the afore-mentioned land usage allocation of Terskiy region (see Table 28), totally available and suitable territory for PV fields construction is 0,46 Th km^2, thus the overall potential output of electricity is 0,077 TWh/y (considering 4,28 units 20 MW facilities).

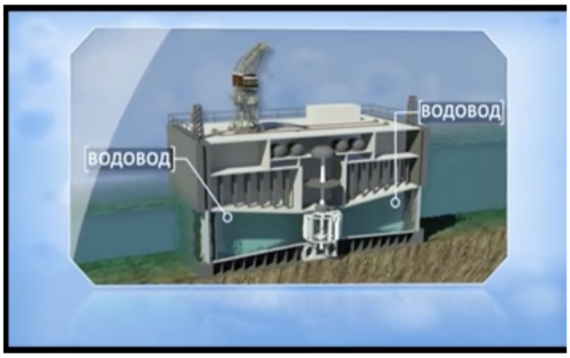
Besides the low level of insolation in the Murmansk region, there are additional obstacles against the solar energy development in the Murmansk region. Such as fluctuations in solar insolation; specifically, the polar nights (with 0 insolation) and polar days (with almost 24 hours of daylight). The estimated cost of the electricity and feasibility study of the PV field construction, is the subject of analyses of the chapter 5 of this thesis.

4.5 TIDAL:

Tides are the result of the gravity, the rise and fall of water levels (in some cases more than 12 m) creates potential energy. In order to capture this energy, it is necessary to have a barrage or other barrier; the power generates through turbines located in the barrage. Accordingly (IRENA, 2014), currently existing tidal energy generation projects are as follows: in France (240 MW), Canada (20 MW), China (5 MW), Russia (0.4 MW) and South Korea (254 MW). The biggest advantage of tidal energy is its' stability and predictability (unlike some other renewable energy sources such as wind and solar energy).

"Kislogubskay" tidal electrical station, located in the Murmansk region, in Figure 27, commissioned in 1968, and has a total capacity of 0,4 MW. In 1992 the station was preserved due to a lack of investments; later on in 2004 it was brought back to operations.

Figure 27 Kislogubskay tidal electricity station



Source: RusHydro

To estimate the potential energy from tides in the Murmansk region, it is necessary to analyze, difference in tides levels (heights difference) and surface water areas (or area of the barrier). To identify required parameters, data from RusHydro report (RusHydro, 2009), was used. There, the coast and gulfs of Murmansk region were surveyed in order to select the most applicable locations for a tidal stations; Totally 53 gulfs/bays were analyzed, the map of he survey is presented below in Figure 28.

Figure 28 Gulfs/bays of Murmansk region coastline examined for tidal potential

Source: (RusHydro, 2009)

Out of the analyzed areas, the most appropriate locations have been selected. The selection criteria were: Maximum tidal height (more than 3 meters), Watershed area (more than 4 km^2), Sea depth from the lowest possible point in the water (more than 8 m). The most appropriate areas are represented below in Table 30.

Table 30 Selected areas for the tidal generating stations construction

Bay name	Sea	Max tide height [m]	Average tide heigh [m]	Area of the enclosed basin [sqkm]
Bay Dolgay	Barents	4,2	2,54	4,5
Bay Drozdovka	Barents	4,5	3,33	3,9
Bay Iventseva	Barents	4,5	3,33	21,8
Bay Gremiha	Barents	5	3,7	3,1
River delta Ioganka	Barents	5	3,7	3,1
Bay Lubovskay (far)	White	5,8	4,35	56,5
Bay Lubovskay (close)	White	5,8	4,35	49

Source: (RusHydro, 2009)

To calculate the potential energy of tides, the article from the Applied Energy magazine was used, particularly (Junqiang Xia, 2012). In the mentioned article it is stated, that potential energy contained in a volume of water can be depicted with the formula:

$$E \ = 0.5 * \rho * g * A * \Delta h^2$$

E- potential energy over a tidal cycle, GW

ρ- sea water density 1025, t/m3 (Average meaning);

g- gravity

A-Horizontal area of the enclosed basin, km2

Δh- mean tidal range in the basin (m)

For the coastal regions, where tidal power generation is economically attractive, the tidal regime generally consists of two floods and two ebb tides, with a semi-diurnal period of 12.42 hours. At low tide level, the potential energy is zero. (Junqiang Xia, 2012) Thus, the total mean potential power can be represented with the formula below. The tidal energy potential is displayed below in Table 31.

$$\overline{P} = \tfrac{24}{12.42} E_p \,/\, 86400 = 0.11263 (A_b \cdot \Delta h_b^2)$$

Source: (Junqiang Xia, 2012)

Table 31 Tidal energy potential in Murmansk region

Bay name	Sea	Max tide height [m]	Average tide heigh [m]	Area of the enclosed basin [sqkm]	Potential energy [MW]
Bay Dolgay	Barents	4,2	2,54	4,5	3,3
Bay Drozdovka	Barents	4,5	3,33	3,9	4,9
Bay Iventseva	Barents	4,5	3,33	21,8	27,2
Bay Gremiha	Barents	5	3,7	3,1	4,8
River delta Ioganka	Barents	5	3,7	3,1	4,8
Bay Lubovskay (far)	White	5,8	4,35	56,5	120,4
Bay Lubovskay (close)	White	5,8	4,35	49	104,4
					269,8

Source: Own assessment

4.5.1 Tidal: technical potential of electricity generation

There are two types of technologies of electricity generation from tidal, the barrage and the turbines. In the case of the barrage, the energy is created due to water running from higher level to lower level (the same concept as a dam). In the case of turbines, the kinetic energy of the movement of the tides rotate the fences similar to a wind turbine.

As for the Murmansk region, the barrage technique with vertical axis turbines selected. Accordingly to (IRENA, 2014), out of the existing tidal energy generation projects, more than 70% of them use turbines with vertical axis. Electricity generation form tidal characterized by low values of power conversion efficiency of - η %, usually ranging from 20 to 40% with an average of 33%. The potential annual tidal energy output from a barrage can be approximately calculated as shown in the equation below:

$E = 0.987 * A * \Delta h^2 * \eta$, where:

E- GWh

A-Horizontal area of the enclosed basin, km^2

Δh- mean tidal range in the basin, m

η- Efficiency, 33%

Out of the total potential areas, RusHydro specialists selected three the most applicable, presented in below in Table 32. Selection parameters were: Technological (if the existing designs is possible to use there), operational (required period for construction) and financial.

Table 32 Tidal electricity output in Murmansk region:

Name	Length	Installed capacity	Potential electricty generation	Projected construction length
	[m]	[MW]	[TWh/y]	[Years]
Bay Dolgay	1200	12	0,0238	2-3
Bay Ivanovskay	500	66	0,157	5-6
Bay Lumbovsky (far)	6450	320	0,912	7-8
	Total	**398**	**1,0928**	

(RusHydro, 2009)

Technical potential of electricity generation from the energy of tide in the Murmansk region is on the level of 1.092 TWh/y. Electricity output is 1.09 TWh/y from the three most promising locations. The cost of the station construction and potential cost of the electricity, will be calculated in chapter 5.

4.6 Hydro

4.6.1 Hydro: Availability in Murmansk region

Hydro energy is already well developed in the Murmansk region, almost 40% of electricity generated in the region is coming from hydro stations. As a main source of information to evaluate hydro energy potential in the Murmansk region, the research "Potential of the micro hydro power stations in the far north regions of Russia" was used (V.A. Minin, 2005). Hydropower is a renewable energy source based on the natural water cycle. In general, hydro energy sources are abundant in the Murmansk region. Water in rivers comes from melted snow, thus, rivers have a high level during spring and lower level during the autumn and winter seasons. A map of the rivers in the Murmansk region is shown below, in Figure 29.

Figure 29 Rivers in the Murmansk region

(Konovalova, 2005)

There are more than 107 Th lakes with a total surface area of 8 Th km^2 , 10 water storing facilities, and 21 Th rivers with a total length of 60 Th km (V.A. Minin, 2005). Most of the rivers 19,5 thousand (or 95.1%) are less than 10 km long. 15 rivers (or 4%) in the Murmansk region are longer than 100 km. 4 % of rivers are longer than 200 km. Hydrographic characteristics of the most promising rivers for the generation of hydro energy are presented below, in Table 33.

Table 33 Hydrographic characteristics of the selected rivers

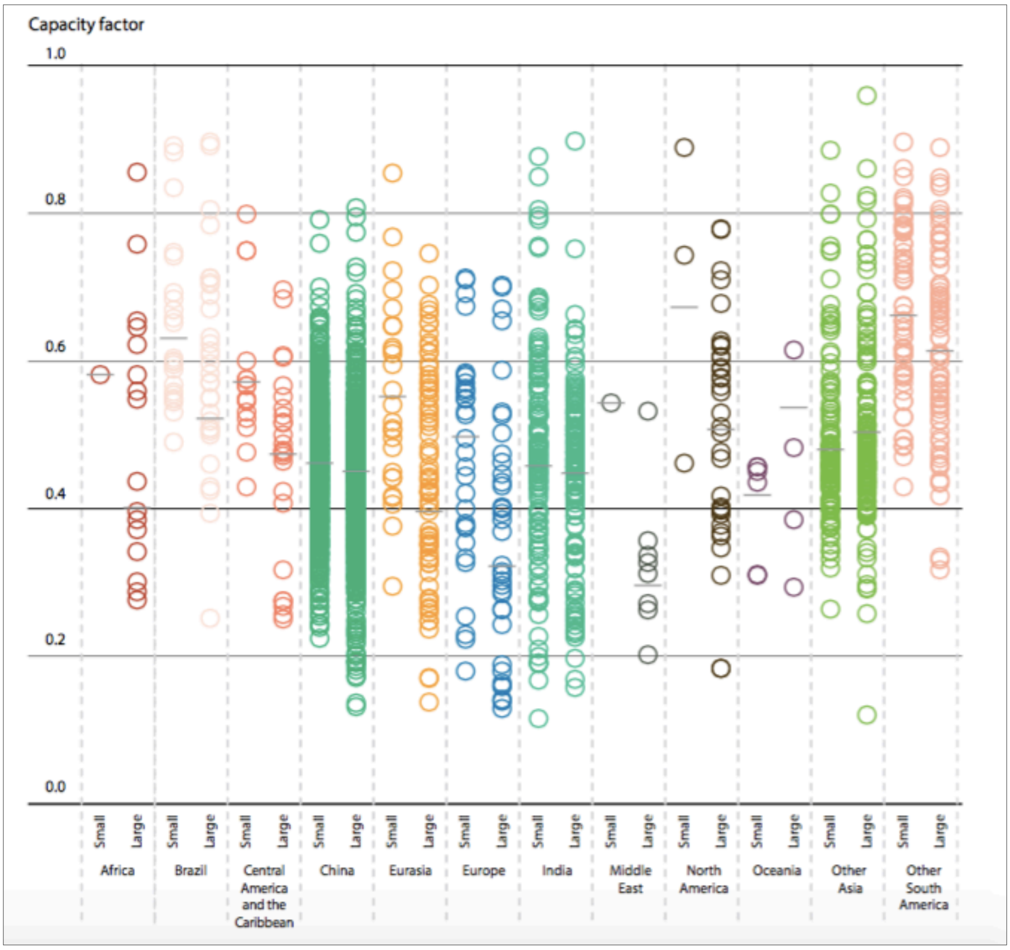
River	Length	Water hight	Average water flow rate
	[km]	[m]	[m3/s]
Rynda	97,6	285	18,5
Harlovka	126	260	32,5
ay Lisitca	118	290	30,2
Indel	23	37,2	7,87
Hlebnay	29	111	3
Umba	125	151,6	81
Kica	37	54,3	3,18
Acha	80	131,2	12,6
Pacha	26	54,3	1,36

(Konovalova, 2005)

4.6.2 Hydro: technical potential of electricity generation

Weighted average capacity factors for both small and large hydropower projects are around 0,5 presented below, in Figure 30. For this report, an average for small Hydropower in Eurasia will be taken as 0,6.

Figure 30 Weighted average capacity factors for small/large hydro stations



Source: (IRENA, 2015)

To calculate potential generation of the electricity, the following formula was used:

$$P_{th}[W] = \mu\ [\%] * \rho\ \left[\frac{kg}{m3}\right] * q\left[\frac{m3}{s}\right] * g\left[\frac{m}{s2}\right] * h[m]$$

$\mu\ [\%]$- Efficiency

$\rho\ \left[\frac{kg}{m3}\right] - dencity\ of\ water$

$q\left[\frac{m3}{s}\right] - flow\ rate$

Potential generation of electricity from hydropower stations in the Murmansk region, displayed the below, in Table 34.

Table 34 Theoretical potential of electricity generation from hydro sources

Rivers	Length	Water high	Average flow rate	Build capacity	Potential electricity output
	[km]	[m]	[m3/s]	[MW]	[Bln KWh]
Rynda	97,6	285	18,5	28	0,135
Harlovka	126	260	32,5	46	0,217
Lisitca	118	290	30,2	47	0,225
Indel	23	37,2	7,87	2	0,008
Hlebnay	29	111	3	2	0,009
Umba	125	151,6	81	66	0,315
Kica	37	54,3	3,18	1	0,004
Acha	80	131,2	12,6	9	0,042
Pacha	26	54,3	1,36	0,40	0,002
Total				201	0,9560
Average	74	153	21	17	0,083

Source: Own assessment

Potential electricity generation from hydro stations in the Murmansk region is 0.95 TWh/y. Cost of generated electricity, will be analyzed henceforth in chapter 5.

4.7 Renewable energy’s technical potential in the Murmansk region:

4.7.1 Electricity technical potential:

From the derived results on the technical potential of electricity generation in the Murmansk region, it is possible to conclude that the most promising renewable sources for electricity generation (in terms of volume of the electricity generation) is wind potential electricity generation 83 TWh/y, which represents more than 100% of the Murmansk region need in electricity in 2030. Hydroenergy with 0.95 TWh/y, and tidal energy with 1,09 TWh/y both represent around 10% of regional electricity demand of 2030, overall results presented in Table 35.

The least promising energy sources (in terms of volume of generated electricity) are electricity generation based on peat briquettes with overall output 0.05 TWh/y Solar energy with 0.077 TWh/y. Most of the local energy sources is in rural locations and require additional investments for new infrastructure, which makes the prospect of utilizing renewable energy resources less attractive. Currently, Murmansk’s region is electricity saturated, due to the nuclear station. However, a deficit of electricity may occur, starting from 2018, when the scheduled decommission of the nuclear reactors will take place.

Table 35 Electricity from renewable sources technical potential in Murmansk region

Source	Possible electricity generation	Share of regional demand 2030 (21,8 TWh/y)
	[TWh/y]	[%]
Forest residuals	0,11	0,52%
Peat briquests	0,05	0,25%
Municipal Solid Waste	0,51	2,34%
Wind	83,15	382%
Solar	0,08	0,35%
Hydro	0,95	4,36%
Tidal	1,09	5,01%
Total electricity from local Energy sources	**85,95**	**13%**

Source: Own assessment

4.7.2 Heating technical potential:

Based on the performed calculations for potential heating generation in Murmansk region, from the selected energy sources (biomass, several types); it can be conducted that biomass can potentially cover 7,06% of regional heat demand in 2030; with the major contributor from MSW, which can deliver up to 6,24% of totally required heating in 2030. Results are presented in Table 36. All of the currently used energy sources for heating generation is imported, such as heavy oil or coal, which cause adverse environmental issues, due to CO_2 emissions while transportation and the burning of the fossil fuels (heating oil/coal).

Table 36 Heat generation from renewable sources technical potential in region

Source	Possible generation	Out of regional demand 2030 - 15,47 TWh/y
	TWh/y	[%]
Forest residuals	0,049	0,32%
Peat briquettes	0,078	0,51%
Municipal Solid Waste	0,965	6,24%
Total from local energy sources	1,093	7,06%

Source: Own assessment

5. Economical assessment of locally available energy sources

In this chapter, the feasibility of potential renewable energy projects will be evaluated. To better estimate the cost of the potentially generated energy, for both electricity and heat generation, the long run marginal cost (LRMC) will be calculated. Doing so, it will be possible to compare the cost of generating energy from the locally available renewable energy source with the energy projected costs in the Murmansk region, the latter of which was discussed in the previous chapter 3.

The definition of the LRMC of electricity and heating is defined as the price of electricity/heat required for a project, where revenues would equal costs, and a return on the capital invested equal to the discount rate.

The following formulas will be used to calculate the LRMC:

FORMULA 1

$$LRMC = \frac{Annuity\ of\ cost}{Annually\ generated\ electricity}$$

FORMULA 2

$$Annuity\ (cost) = NPV(cost) * Capital\ Recovery\ Factor\ (CRF)$$

FORMULA 3

$$CRF = \frac{[i * (1 + i)^{n}]}{[(1 + i)^{n-1}]}$$

Where: n-investment horizon, which will be taken as 15 years for all the projects and i- discount rate.

Discount rate is an interest rate used to determine the present value of future cash flows (Investopedia, 2014). Discount rate for Russia was fixed in 2012 by Central bank of the level of 8,25% (Central Bank of Russia, 2012). Considering current economical situation on the global scale (particularly, low oil prices) and economical situation in Russia, the discount rate will be taken as 10%, in order to cover some risks.

FORMULA 4

$$NPV\ (cost) = \sum Discounted\ Costs$$

Furthermore, for the calculation of the LRMC, it will be necessary to identify a few parameters such as the CAPEX, O&M, and other costs (explained below). As a bench mark for these parameters, the resource that will be used is the IRENA research «Renewable energy technologies: cost analyses series» (IRENA, 2015) To calculate the LRMC the following parameters needs to be considered:

✓ CAPEX (Equipment costs and other initial capital costs).

The total investment cost – capital expenditure (CAPEX) – consists of the equipment, the fuel handling and preparation machinery, the engineering and construction costs, and the planning costs (IRENA, 2012). Basically, CAPEX is the major expenses, which needs to be made in order to complete the construction of heat/electricity generating facility. The measurement unit of the CAPEX is US$/KW. For each renewable energy source a CAPEX will be individually reviewed and assigned.

✓ Feedstock costs:

This means the cost of the energy source. This cost will include the treatment and transportation (when applicable). The feed stock cost will be identified for each energy source separately. For some of these source, the feedstock cost will be 0 (such as wind or solar), while for others (such as biomass; peat particularly) it can be up to 40% of the generated electricity/heating cost, this is due to the expenses on the raw source treatment such as drying or the transportation costs, and warehousing costs.

✓ O&M (Operations and maintains costs).

Fixed O&M cost, includes expenses on labor, scheduled maintenances, routine component/equipment replacement (for boilers, feedstock handling equipment, etc.), insurance, etc. Usually this parameter is taken as a % per year of the total CAPEX; the level of the % depends on the technology being used, and so the cost (or %) of such will be identified individually for each technology. Again, as a benchmark, the IRENA reports will be used as the main informational source of the level of O&M.

Once all the parameters are given values, and the LRMC is calculated for energy sources for both electricity generation and heating generation, a conclusion can be made about whether the project is economically feasible, also the NPV will be calculated to further indicate whether the projects are economically feasible.

<u>Two cases will be considered in feasibility study</u>

- Basic case: with investment horizon as of 15 years, and discount rate of 10% (which is higher than 8,25%, the officially set by Russian Central Bank). The basic case will be calculated, with consideration of the related risks, higher discount rate and shorter (than life time) investment horizon.
- For the second case the discount rate will be taken on the level of 8,25% and investment horizon period as the lifetime of the technology. In this case the tariffs projection for the period beyond 2030 for heating/electricity has to be estimated, thus the indexation level will be applied.

Additionally, it is necessary to mentioned, recent law introduced by Russian Government. As of May 28th 2013, a Decree (No. 861-r) was issued On "Amendments to Guidelines for State Policies in Increasing the Effectiveness of Use of Renewable Energy Sources for the Period until 2020". The strategy outlines steps taken by state authorities to promote further use of renewable energy sources and establishes targets for electricity generation using renewable energy sources; in particular, its' target is to install create 6,000 MW of new capacity using renewable energy sources by 2020. The capacity subsidies are individual for each energy source and will be paid on the monthly basis.

Abovementioned capacity subsidies, will be considered for wind as wind is the most promising energy source of the region and capable to cover more than 100% of regional electricity need.

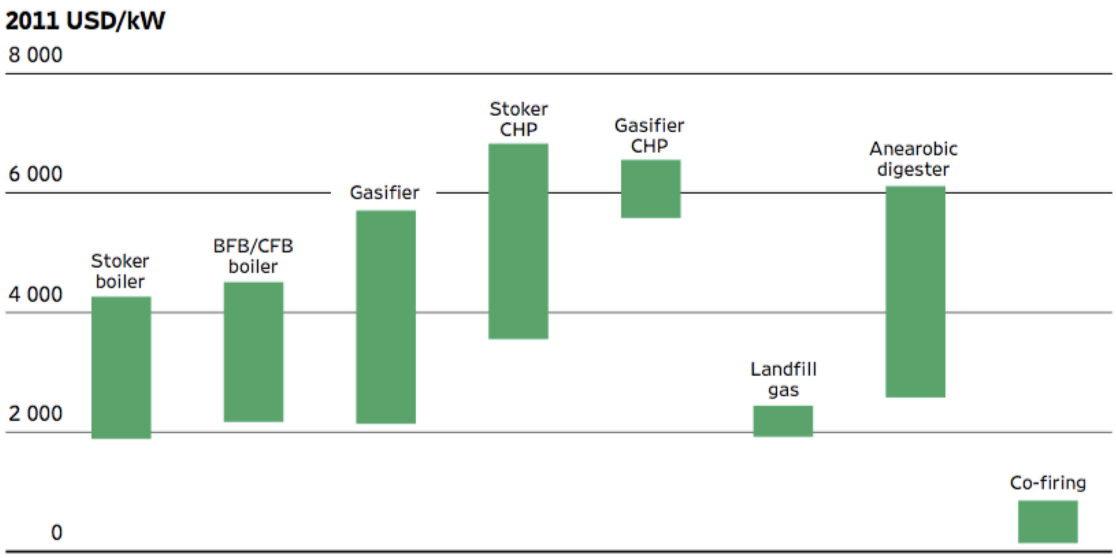
5.1.1 Biomass Electricity generation costs

CAPEX

The cost and efficiency of biomass power generation equipment varies significantly by technology. Equipment cost depends on the nature of the feedstock, and level of feedstock pre treatment onsite. The technology selected for biomass conversion to the energy is direct as well established and available on a wide range of scales; from a few MW to 100 MW or more.

In Figure 31, CAPEX range presented, for various technologies. Accordingly (IRENA, 2015) Biomass power plants in developing countries may have noticeable lower than in developed countries, that is due to lower local content costs and the cheaper equipment allowed by less strict environmental regulations. The range of capital costs may vary between USD 500/kW and USD 5000/kW in developing countries. Capex for combustion will be taken on the level as 650 US$/KW, which represents co-firing in a fossil-based power plan.

Figure 31 CAPEX for biomass based power plants



Source: (IRENA, 2015)

O&M:

Fixed O&M costs for biomass power plants typically range from 2% to 6% of the CAPEX, per year as of (IRENA, 2015) . For calculations, the Fixed O&M cost will be taken as 2% per year of the capital expenditures. Additionally, the indexation factor will be applied as of 2% to estimate annual increase in O&M costs.

Area required for the plant construction:

This parameter is necessary to determine in order to estimate the cost of land rental. In the Murmansk region, the land cost varies for different regions. To simplify the the cost of the land near the Murmansk city will be used (as Murmansk in the biggest city of the region and consequently the highest demand in both heating and electricity). According to a local (http://murmansk.irr.ru) the average cost of land rental is about 1,4 US$/m^2/year. Indexation factor for annual cost increase is considered on the level of 2%.

Feedstock biomass:

Cost of biomass feedstock mainly depends on the level of pre treatment of the biomass as an energy source; from simple collection and transportation, to artificial drying and packing. To estimate the biomass cost as a feedstock, data from a various sources including local newspapers has been reviewed and related costs were identified and benchmarked. Afterwards, costs are adjusted individually as per local specifics (when applicable).

5.1.1.1 Forest residual electricity generation cost:

Forest and wood processing residues may appear to be an attractive energy source from technical point of view. However, collection and handling costs must be considered as well as transportation costs.

To estimate the cost of forest residuals as a feedstock a few local (regional) suppliers were checked; Such as below commercials from the local web sources:

1. http://birzha-othodov.ru/catalog/struzhki-opilki/656/, where the price of forest residuals starts from 100 rub (around 2 US$) per 10 cub/m, which is equivalent of 3,5 tons),
2. and [http://arkhangelsk.dorus.ru/industry/timber-industry/prodam-othody-derevoobrabotki_7017270.html], where it is stated that 0,35 tons would cost 20 rub or (0,4 US$).

Both on the ex-works terms (logistic expenses is not included) and both for raw, not pretreated forest residuals different sizes and high moisture content. Based on the presented above information, the cost of the forest residuals as a feedstock will be fixed on the level of 2 US$/ton. Other expenses will be added to the basic cost, expenses such as handling and transportation and storing of the feedstock; as shown below in Table 37. Assumption made based on the average price range in the Murmansk region.

Table 37 Timber feedstock cost

• Cost of the Timber itself	2 [US$/ton]
• Handling and transportation (within the region)	2 [US$/ton]
• Storing the wood residues	1 [US$/ton]
Total cost of the wood residues	5 [US$/ton]

Source: Own assessment

In additional to the above, the cost indexation factor added as of 2% annual increase per year; Area required for plant itself and storage facility, will be taken as 25 Th m^2, for 20 MW generating facility as per (PPC renewables, 2012). Below are the resulted numbers in Table 38.

Table 38 Electricity generation feasibility from Forest residuals

Forest residuals (WR)		
Given data	Unit	Value
Installed capacity	20000	[KW]
Electricity output	0,055	[TWh/year]
CAPEX	$ 650	[US$/KW]

Given data	Unit	Value
O&M	10%	[%]
Land rental	$ 1,40	[US$/m²/year]
Required area	25000	[m²]
Cost of the feedstock (WR)	0,005	[US$/kg]
Required biomass	73613445	[kg/year]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario parameters		
Investment Horizon	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	50	[US$/MWh]
NPV	$ 536 833	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	44,4	[US$/MWh]
NPV	$ 5 248 291	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Electricity tariff [US$/Mwh]	Electricity sale	Discounted Costs
				2%	2%	2%			
0	2020	$ (13 000 000)	$ (13 000 000)						$ (13 000 000)
1	2021	$ 1 347 040	$ 1 481 744	$ (1 300 000)	$ (35 000)	($ 368 067)	$ 44,1	$ 2 448 677	$ (879 030)
2	2022	$ 1 197 138	$ 1 448 538	$ (1 326 000)	$ (35 700)	($ 375 429)	$ 43,9	$ 2 434 809	$ (815 100)
3	2023	$ 1 146 422	$ 1 525 887	$ (1 352 520)	$ (36 414)	($ 382 937)	$ 45,6	$ 2 531 884	$ (755 820)
4	2024	$ 1 101 529	$ 1 612 749	$ (1 379 570)	$ (37 142)	($ 390 596)	$ 47,6	$ 2 638 865	$ (700 852)
5	2025	$ 1 132 572	$ 1 824 018	$ (1 407 162)	$ (37 885)	($ 398 408)	$ 51,8	$ 2 870 658	$ (649 881)
6	2026	$ 1 043 721	$ 1 849 016	$ (1 435 305)	$ (38 643)	($ 406 376)	$ 52,6	$ 2 916 588	$ (602 617)
7	2027	$ 961 828	$ 1 874 330	$ (1 464 011)	$ (39 416)	($ 414 503)	$ 53,4	$ 2 963 253	$ (558 790)
8	2028	$ 886 347	$ 1 899 964	$ (1 493 291)	$ (40 204)	($ 422 794)	$ 54,3	$ 3 010 666	$ (518 151)
9	2029	$ 816 778	$ 1 925 920	$ (1 523 157)	$ (41 008)	($ 431 249)	$ 55,1	$ 3 058 836	$ (480 467)
10	2030	$ 752 132	$ 1 950 838	$ (1 553 620)	$ (41 828)	($ 439 874)	$ 56,0	$ 3 106 412	$ (445 524)
11	2031	$ 708 320	$ 2 020 919	$ (1 584 693)	$ (42 665)	($ 448 672)	$ 57,7	$ 3 199 604	$ (413 122)
12	2032	$ 667 000	$ 2 093 333	$ (1 616 387)	$ (43 518)	($ 457 645)	$ 59,4	$ 3 295 593	$ (383 077)
13	2033	$ 628 037	$ 2 168 156	$ (1 648 714)	$ (44 388)	($ 466 798)	$ 61,2	$ 3 394 460	$ (355 217)
14	2034	$ 591 301	$ 2 245 463	$ (1 681 689)	$ (45 276)	($ 476 134)	$ 63,0	$ 3 496 294	$ (329 383)
15	2035	$ 556 667	$ 2 325 336	$ (1 715 322)	$ (46 182)	($ 485 657)	$ 64,9	$ 3 601 183	$ (305 428)
	NPV	**536 833**					**Revenue:**	**$ 44 967 783**	
	Ann	**70 580**						**NPV of Cost**	$ (21 192 457)
								Annuity of Costs	$ (2 786 252)

Source: Own assessment

Based on the calculated numbers the conclusion can be made, that electricity generating project (with installed capacity of 20 MW) and based on the forest residuals is economically feasible, as NPV is positive in both cases basic and optional.

5.1.1.2 Peat electricity generation cost:

As aforementioned in the 7.1.1.1, the majority of the costs are similar for peat and forest residuals, with the exception of feedstock costs. In Russia, the cost of peat, particularly peat briquettes is around 6000 rub/ton or around 100-120 US$/ton; this is according to a local trading source (http://helpczech.ru/teplo/doma/pellety-iz-torfa-v-karelii-tsena). As a benchmark cost, 110 US$/ton will be used; below in Table 39 below, the results of the cost calculations are presented.

Table 39 Electricity generation feasibility from peat briquettes

BIOMASS Peat briquettes (PB) electricity		
Given data	Unit	Value
Installed capacity	20000	[KW]
Electricity output	0,055	[TWh/year]
CAPEX	$ 650	[USD/KW]

Given data	Unit	Value
O&M	10%	[%]
Land rental	$ 1,40	[US$/m^2/year]
Required area	25000	[m^2]
Cost of the feedstock (PB)	0,110	[US$/kg]
Required biomass	35180723	[kg/year]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario parameters		
Investment Horizon	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	111,9	[US$/MWh]
NPV	$ (25 469 117)	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	100,02	[US$/MWh]
NPV	$ (24 451 629)	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Electricity tariff [US$/Mwh]	Electricity sale	Discounted Costs
				2%	2%	2%			
0	2020	$ (13 000 000)	$ (13 000 000)						$ (13 000 000)
1	2021	$ (1 443 272)	$ (1 587 600)	$ (130 000)	$ (35 000)	$ (3 869 880)	$ 44,14	$ 2 447 280	$ (3 668 072)
2	2022	$ (1 390 212)	$ (1 682 157)	$ (132 600)	$ (35 700)	$ (3 947 277)	$ 43,89	$ 2 433 420	$ (3 401 303)
3	2023	$ (1 252 779)	$ (1 667 449)	$ (135 252)	$ (36 414)	$ (4 026 223)	$ 45,64	$ 2 530 440	$ (3 153 936)
4	2024	$ (1 123 206)	$ (1 644 486)	$ (137 957)	$ (37 142)	$ (4 106 747)	$ 47,57	$ 2 637 360	$ (2 924 559)
5	2025	$ (930 428)	$ (1 498 463)	$ (140 716)	$ (37 885)	$ (4 188 882)	$ 51,75	$ 2 869 020	$ (2 711 864)
6	2026	$ (869 238)	$ (1 539 909)	$ (143 531)	$ (38 643)	$ (4 272 660)	$ 52,58	$ 2 914 924	$ (2 514 637)
7	2027	$ (812 004)	$ (1 582 367)	$ (146 401)	$ (39 416)	$ (4 358 113)	$ 53,42	$ 2 961 563	$ (2 331 754)
8	2028	$ (758 476)	$ (1 625 860)	$ (149 329)	$ (40 204)	$ (4 445 275)	$ 54,27	$ 3 008 948	$ (2 162 172)
9	2029	$ (708 418)	$ (1 670 413)	$ (152 316)	$ (41 008)	$ (4 534 181)	$ 55,14	$ 3 057 091	$ (2 004 923)
10	2030	$ (662 138)	$ (1 717 415)	$ (155 362)	$ (41 828)	$ (4 624 864)	$ 56,00	$ 3 104 640	$ (1 859 111)
11	2031	$ (603 101)	$ (1 720 716)	$ (158 469)	$ (42 665)	$ (4 717 362)	$ 57,68	$ 3 197 779	$ (1 723 903)
12	2032	$ (549 050)	$ (1 723 153)	$ (161 639)	$ (43 518)	$ (4 811 709)	$ 59,41	$ 3 293 713	$ (1 598 528)
13	2033	$ (499 578)	$ (1 724 679)	$ (164 871)	$ (44 388)	$ (4 907 943)	$ 61,19	$ 3 392 524	$ (1 482 271)
14	2034	$ (454 312)	$ (1 725 247)	$ (168 169)	$ (45 276)	$ (5 006 102)	$ 63,03	$ 3 494 300	$ (1 374 470)
15	2035	$ (412 906)	$ (1 724 809)	$ (171 532)	$ (46 182)	$ (5 106 224)	$ 64,92	$ 3 599 129	$ (1 274 508)
	NPV	(25 469 117)					Revenue:	$ 44 942 131	
	Ann	(3 348 521)						NPV of Cost	$ (47 186 012)
								Annuity of Costs	$ (6 203 723)

Source: Own assessment

Electricity generation from peat briquettes, located in the Murmansk region is not feasible. The calculated LRMC is 111 US$/MWh and NPV is -25,6 Mln US$ in basic scenario. The reason causing negative NPV is most probable high cost of the feedstock (peat briquettes). However, the cost of the peat briquettes can be potentially decreased with the development of the infrastructure.

5.1.1.3 Municipal solid waste electricity generation cost.

The cost of the combustion technology for the Municipal solid waste is higher than that for other types of biomass; this is mainly due to the system of filters which are required due to the hazardous emissions. Waste incineration involves high investment costs of both CAPEX and O&M. Investment costs for Waste-to-Energy plants, vary from country to country, however for Europe it can be considered on the level of 400 – 700 eur/ton capacity (Cewep, 2010). The maximum will be taken is consideration as 700 eur/ton or 745 usd/ton, which is equivalent of 8259 US$/KW. Suggested O&M expenses, of MSW facilities, is 79 US$/ton per year (or 10% of CAPEX), in accordance to the example given in the report (ICF International, 2014).
Feedstock, cost is estimated 0, as local municipality (of Murmansk region) is responsible for waste collection, transportation and following disposal. MSW electricity generating results, presented in Table 40.

Table 40 Electricity generation feasibility from MSW

BIOMASS MSW Electricity		
Given data	Unit	Value
Installed capacity	20000	[KW]
Electricity output	0,055	[TWh/year]
CAPEX	$ 8 259	[USD/KW]

Given data	Unit	Value
O&M	10%	[%]
Land rental	$ 1,40	[US$/m²/year]
Required area	25000	[m²]
Cost of the feedstock (MSW)		[US$/kg]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario paramters		
Investment Horizon	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	723,9	[US$/MWh]
NPV	$ (283 698 034)	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	653,53	[US$/MWh]
NPV	$ (320 398 283)	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Electricity tariff [US$/Mwh]	Electricity sale	Discounted Costs
				2%	2%				
0	2020	$ (165 180 000)	$ (165 180 000)						$ (165 180 000)
1	2021	$ (12 822 112)	$ (14 104 323)	$ (16 518 000)	$ (35 000)	$ -	$ 44,14	$ 2 448 677	$ (15 048 182)
2	2022	$ (11 941 530)	$ (14 449 251)	$ (16 848 360)	$ (35 700)	$ -	$ 43,89	$ 2 434 809	$ (13 953 769)
3	2023	$ (11 036 707)	$ (14 689 857)	$ (17 185 327)	$ (36 414)	$ -	$ 45,64	$ 2 531 884	$ (12 938 949)
4	2024	$ (10 195 554)	$ (14 927 311)	$ (17 529 034)	$ (37 142)	$ -	$ 47,57	$ 2 638 865	$ (11 997 935)
5	2025	$ (9 342 905)	$ (15 046 842)	$ (17 879 614)	$ (37 885)	$ -	$ 51,75	$ 2 870 658	$ (11 125 358)
6	2026	$ (8 669 903)	$ (15 359 261)	$ (18 237 207)	$ (38 643)	$ -	$ 52,58	$ 2 916 588	$ (10 316 241)
7	2027	$ (8 045 351)	$ (15 678 113)	$ (18 601 951)	$ (39 416)	$ -	$ 53,42	$ 2 963 253	$ (9 565 969)
8	2028	$ (7 465 764)	$ (16 003 528)	$ (18 973 990)	$ (40 204)	$ -	$ 54,27	$ 3 010 666	$ (8 870 262)
9	2029	$ (6 927 907)	$ (16 335 642)	$ (19 353 470)	$ (41 008)	$ -	$ 55,14	$ 3 058 836	$ (8 225 152)
10	2030	$ (6 429 303)	$ (16 675 955)	$ (19 740 539)	$ (41 828)	$ -	$ 56,00	$ 3 106 412	$ (7 626 959)
11	2031	$ (5 950 829)	$ (16 978 410)	$ (20 135 350)	$ (42 665)	$ -	$ 57,68	$ 3 199 604	$ (7 072 271)
12	2032	$ (5 507 847)	$ (17 285 982)	$ (20 538 057)	$ (43 518)	$ -	$ 59,41	$ 3 295 593	$ (6 557 924)
13	2033	$ (5 097 730)	$ (17 598 746)	$ (20 948 818)	$ (44 388)	$ -	$ 61,19	$ 3 394 460	$ (6 080 984)
14	2034	$ (4 718 047)	$ (17 916 776)	$ (21 367 794)	$ (45 276)	$ -	$ 63,03	$ 3 496 294	$ (5 638 731)
15	2035	$ (4 366 547)	$ (18 240 149)	$ (21 795 150)	$ (46 182)	$ -	$ 64,92	$ 3 601 183	$ (5 228 641)
	NPV	(283 698 034)					Revenue:	$ 44 967 783	
	Ann	(37 298 852)						NPV of Cost	$ (305 427 324)
								Annuity of Costs	$ (40 155 684)

Source: Own assessment

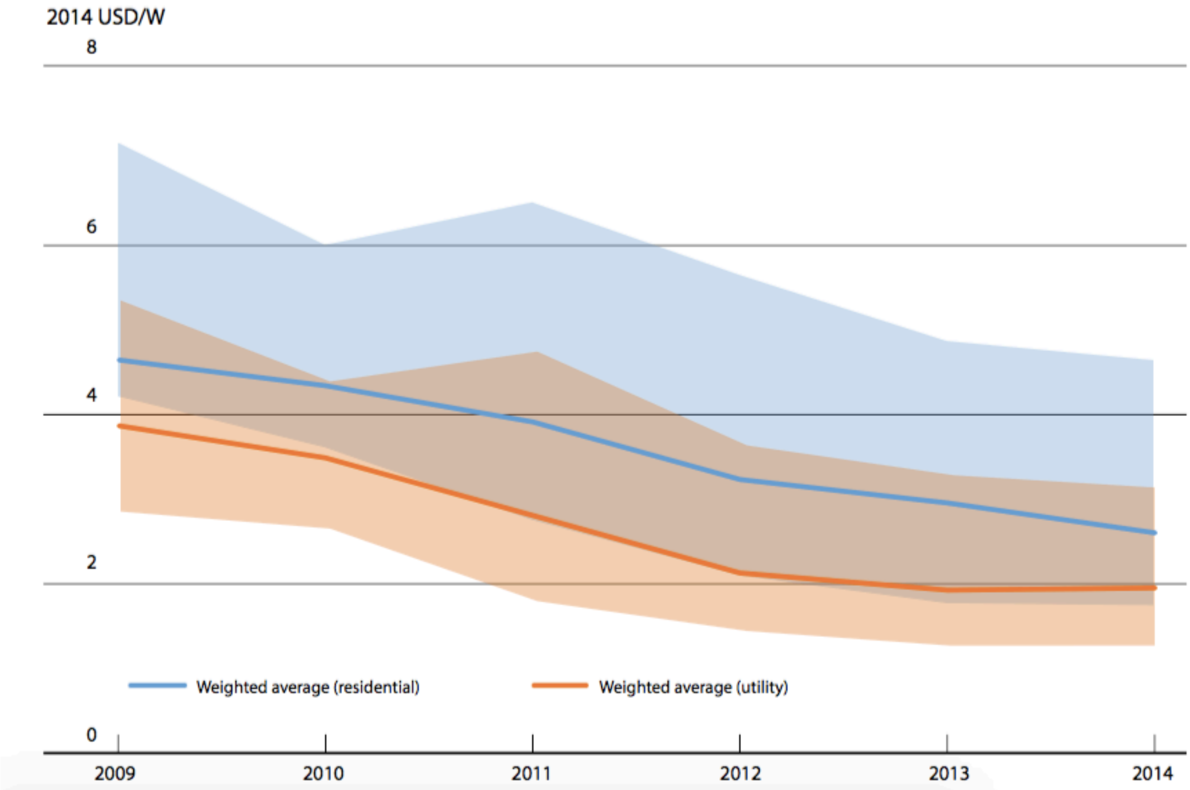
MSW based electricity generation project in the Murmansk region is not feasible as the NPV is negative in both cases basic scenario (15 years investments horizon and 10% discount rate) and optional one (20 years investments horizon and 8.25%) discount rate. Considering the current abundance of electricity in the Murmansk region, and low prices for landfilling; electricity generation from waste is not feasible economically, however it may have changed in case of nuclear reactors decommissioning will be in accordance with schedule.

5.2 Solar: Electricity generation cost

To understand the LRMC of electricity generation from PV plant in the Murmansk region, several basic parameters have to be identified. In accordance with (IRENA, 2012), the structure of the PV generation plant consists of the following:

First of all, capital cost or CAPEX: which includes PV module cost and balance of system cost (associated structural costs, such as site preparations and electrical system cost). The average PV electricity generation facility's CAPEXs is presented below in Figure 32. Additional components of the costs are: discount rate, O&M, level of solar radiation and efficiency of the solar cells.

Figure 32 PV utility scale installation cost



Source: (IRENA, 2015)

For the evaluation of the solar energy (electricity generation) potential in the Murmansk region, the simplest PV panels selected. the considered; without turning mechanism and locally produced (this to be eligible for the premium capacity payment from the Russian Government). CAPEX will be taken below weighted average (Figure 33) as 1800 US$/KW for solar PV utility scale construction in the Murmansk region. locally produced PV (Russian PV plant) panels were selected and particularly, panels made by "Ryazanskiy sintered metal powder plant". The specifications of the PV panels are:

- ✓ Peak power 240 kw
- ✓ Rated Voltage 29.1 V
- ✓ Cell/Model efficiency 14.9%
- ✓ Total area 1.61 sq. m
- ✓ Dimensions 1640 mm x 980 mm x 36 mm
- ✓ Weights 21.5 kg

For a PV facility with a capacity of 20MW, 84 units of PV panels will be required, as each of panel have the dimensions of 1640 mm x 980 mm or 1.61 Sq. m; the total required area is 107 Th m^2. Feasibility study results of the 20MW PV facility on the Murmansk region, are presented below in Table 41.

Table 41 Electricity generation feasibility from Solar

Solar Energy		
Given data	Unit	Value
Build capacity	20000	[KW]
Generated electricity	0,018	[TWh/year]
CAPEX	$ 1 800	[USD/KW]

Given data	Unit	Value
O&M	5%	[%]
Land rental	$ 1,40	[US$/m^2/year]
Required area	107353	[m^2]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario parameters		
Investment Horizon	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	383,6	[US$/MWh]
NPV	$ (45 473 167)	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	286,44	[US$/MWh]
NPV	$ (40 279 261)	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Electricity tariff [US$/Mwh]	Electricity sale	Discounted Costs
				2%	2%				
0	2020	$ (36 000 000)	$ (36 000 000)						$ (36 000 000)
1	2021	$ (1 050 657)	$ (1 155 723)	$ (1 800 000)	$ (150 294)	$ -	$ 44,14	$ 794 571	$ (1 772 995)
2	2022	$ (991 098)	$ (1 199 229)	$ (1 836 000)	$ (153 300)	$ -	$ 43,89	$ 790 071	$ (1 644 050)
3	2023	$ (907 224)	$ (1 207 515)	$ (1 872 720)	$ (156 366)	$ -	$ 45,64	$ 821 571	$ (1 524 482)
4	2024	$ (828 756)	$ (1 213 382)	$ (1 910 174)	$ (159 493)	$ -	$ 47,57	$ 856 286	$ (1 413 611)
5	2025	$ (732 415)	$ (1 179 561)	$ (1 948 378)	$ (162 683)	$ -	$ 51,75	$ 931 500	$ (1 310 803)
6	2026	$ (681 251)	$ (1 206 878)	$ (1 987 345)	$ (165 937)	$ -	$ 52,58	$ 946 404	$ (1 215 472)
7	2027	$ (633 648)	$ (1 234 802)	$ (2 027 092)	$ (169 256)	$ -	$ 53,42	$ 961 546	$ (1 127 074)
8	2028	$ (589 359)	$ (1 263 344)	$ (2 067 634)	$ (172 641)	$ -	$ 54,27	$ 976 931	$ (1 045 105)
9	2029	$ (548 154)	$ (1 292 518)	$ (2 108 987)	$ (176 094)	$ -	$ 55,14	$ 992 562	$ (969 097)
10	2030	$ -509 990	$ (1 322 782)	$ (2 151 167)	$ (179 615)	$ -	$ 56,00	$ 1 008 000	$ (898 617)
11	2031	$ -469 367	$ (1 339 158)	$ (2 194 190)	$ (183 208)	$ -	$ 57,68	$ 1 038 240	$ (833 263)
12	2032	$ -431 923	$ (1 355 559)	$ (2 238 074)	$ (186 872)	$ -	$ 59,41	$ 1 069 387	$ (772 662)
13	2033	$ -397 413	$ (1 371 976)	$ (2 282 835)	$ (190 609)	$ -	$ 61,19	$ 1 101 469	$ (716 469)
14	2034	$ -365 609	$ (1 388 401)	$ (2 328 492)	$ (194 422)	$ -	$ 63,03	$ 1 134 513	$ (664 362)
15	2035	$ -336 304	$ (1 404 824)	$ (2 375 062)	$ (198 310)	$ -	$ 64,92	$ 1 168 548	$ (616 045)
	NPV	(45 473 167)					Revenue:	$ 14 591 601	
	Ann	(5 978 529)						NPV of Cost	$ (52 524 107)
								Annuity of Costs	$ (6 905 543)

Source: Own assessment

20 MW solar energy facility construction for electricity generation in the Murmansk region is not economically feasible; as shown above, in Table 43 (NPV is negative – 45 mln US$, and LRCM 383 US$/MWh). That is due to the several factors, such as low level of insolation in the region and low generation of the electricity, consequently insufficient level of revenue from electricity sale. Moreover, as mentioned before, the peak of electricity consumption is during winter months and at the same time, there will be a polar night, with no insolation at all.

5.3 Tidal: Electricity generation cost

For the Tidal energy cost estimation, the main source used was IRENA «Tidal Energy, Technological brief» (IRENA, 2014). Tidal generating stations has been commercially applied, since the late 1960s,). Most of the installed facilities are still operative. In order to calculate the cost of the generation, the tidal station in "Bay Ivanovskay' will be taken as an example (of the technical parameters) for further calculations. Parameters of tidal station in the Murmansk region are presented below in Table 42.

Table 42 Bay Ivanovskay technical parameters

Name	Length	Installed capacity	Potential electricty generation	Projected construction length
	[m]	[MW]	[TWh/y]	[Years]
Bay Dolgay	1200	12	0,0238	2-3
Bay Ivanovskay	500	66	0,157	5-6
Bay Lumbovsky (far)	6450	320	0,912	7-8
	Total	**398**	**1,0928**	

Source: Own assessment

As stated below in Table 43, CAPEX for the planned facility in Russia is 377 US$/KW. For the theoretical case, the O&M will be estimated as 5% of CAPEX per year. The cost of tidal energy is zero. Calculation results are presented below in Table 44.

Table 43 Actual costs of the tidal energy facilities:

Barrage	Country	Capacity (MW)	Power generation (GWh)	Construction costs (million USD)	Construction costs per kW (USD/kW)
Operating					
La Rance	France	240	540	817[1]	340
Sihwa Lake	Korea	254	552	298	117
Proposed/planned					
Gulf of Kutch	India	50	100	162	324
Wyre barrage	UK	61.4	131	328	534
Garorim Bay	Korea	520	950	800	154
Mersey barrage	UK	700	1340	5741	820
Incheon	Korea	1320	2410	3772	286
Dalupiri Blue	Philippines	2200	4000	3034	138
Severn barrage	UK	8640	15600	36085	418
Penzhina Bay	Russia	87000	200000	328066	377

Source: (IRENA, 2014)

Table 44 Electricity generation from tidal economical feasibility

Hydropower		
Given data	Unit	Value
Installed capacity	17000	[KW]
Electricity output	0,083	[TWh/year]
CAPEX	$ 2 000	[US$/KW]

Given data	Unit	Value
O&M	1%	[%]
Land rental	$ 1,40	[US$/m^2/year]
Required area	10000	[m^2]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario parameters		
Investment Horizo	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	58,61	[US$/MWh]
NPV	$ (4 486 642)	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	47,43	[US$/MWh]
NPV	$ 5 466 418	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Electricity tariff [USD/MWh]	Electricity sale	Discounted Costs
				2%	2%				
0	2020	$ (34 000 000)	$ (34 000 000)						$ (34 000 000)
1	2021	$ 3 008 961	$ 3 309 857	$ (340 000)	$ (14 000)	$ -	$ 44,14	$ 3 663 857	$ (321 818)
2	2022	$ 2 712 419	$ 3 282 027	$ (346 800)	$ (14 280)	$ -	$ 43,89	$ 3 643 107	$ (298 413)
3	2023	$ 2 569 538	$ 3 420 056	$ (353 736)	$ (14 566)	$ -	$ 45,64	$ 3 788 357	$ (276 710)
4	2024	$ 2 440 244	$ 3 572 761	$ (360 811)	$ (14 857)	$ -	$ 47,57	$ 3 948 429	$ (256 586)
5	2025	$ 2 429 087	$ 3 912 069	$ (368 027)	$ (15 154)	$ -	$ 51,75	$ 4 295 250	$ (237 925)
6	2026	$ 2 242 728	$ 3 973 129	$ (375 387)	$ (15 457)	$ -	$ 52,58	$ 4 363 974	$ (220 622)
7	2027	$ 2 070 663	$ 4 035 136	$ (382 895)	$ (15 766)	$ -	$ 53,42	$ 4 433 798	$ (204 576)
8	2028	$ 1 911 796	$ 4 098 104	$ (390 553)	$ (16 082)	$ -	$ 54,27	$ 4 504 738	$ (189 698)
9	2029	$ 1 765 114	$ 4 162 047	$ (398 364)	$ (16 403)	$ -	$ 55,14	$ 4 576 814	$ (175 902)
10	2030	$ 1 628 896	$ 4 224 937	$ (406 331)	$ (16 731)	$ -	$ 56,00	$ 4 648 000	$ (163 109)
11	2031	$ 1 526 722	$ 4 355 916	$ (414 458)	$ (17 066)	$ -	$ 57,68	$ 4 787 440	$ (151 247)
12	2032	$ 1 430 942	$ 4 490 909	$ (422 747)	$ (17 407)	$ -	$ 59,41	$ 4 931 063	$ (140 247)
13	2033	$ 1 341 157	$ 4 630 038	$ (431 202)	$ (17 755)	$ -	$ 61,19	$ 5 078 995	$ (130 047)
14	2034	$ 1 256 993	$ 4 773 428	$ (439 826)	$ (18 110)	$ -	$ 63,03	$ 5 231 365	$ (120 589)
15	2035	$ 1 178 099	$ 4 921 210	$ (448 623)	$ (18 473)	$ -	$ 64,92	$ 5 388 306	$ (111 819)
	NPV	**(4 486 642)**					**Revenue:**	$ 67 283 493	
	Ann	**(589 876)**						**NPV of Cost**	$ (36 999 308)
								Annuity of Costs	$ (4 864 439)

Source: Own assessment

Results, shown in Table 44 above, are confirming the feasibility of the tidal based electricity generating power stations in the Murmansk region. NPV is positive in the optional case (20 years investment horizon and 8.25% discount rate) and LRMC is 47,43 US$/MWh.

5.4 Wind: Electricity generation cost

Based on the information from IRENA, cost analyses series (IRENA, 2012), in 2010, the lowest CAPEX price for onshore wind farms was between 1 300 to 1 400 US$/kW. In China and Denmark, however, the average cost varied from 1 800 to 2 200 US$/KW, as per Table 45.

Table 45 Wind parks costs in different locations:

	Installed cost (2010 USD/kW)	Capacity factor (%)	Operations and maintenance (USD/kWh)	LCOE* (USD/kWh)
Onshore				
China/India	1 300 to 1 450	20 to 30	n.a.	0.06 to 0.11
Europe	1 850 to 2 100	25 to 35	0.013 to 0.025	0.08 to 0.14
North America	2 000 to 2 200	30 to 45	0.005 to 0.015	0.07 to 0.11
Offshore				
Europe	4 000 to 4 500	40 to 50	0.027 to 0.048	0.14 to 0.19

Source: (IRENA, 2012)

A CAPEX value for the wind electricity generation facilities in the Murmansk region will be taken as 2000 US$/KW. As per (IRENA, 2012), the O&M costs for onshore wind to electricity generation facilities typically range between 0.01 US$/kWh and 0.025 US$/kWh. Due to no experience in the maintenance of these facilities, the cost for O&M will be taken as 0.02 US$/KWh. Results of the feasibility study, presented in Table 46.

Table 46 Electricity generation from wind (economical feasibility);

Wind		
Given data	Unit	Value
Installed capacity	20000	[KW]
Electricity output	0,049	[TWh/year]
CAPEX	$ 2 000	[US$/KW]

Given data	Unit	Value
O&M	0,020	[%]
Land rental	$ 1,40	[US$/m^2/year]
Required area	4000	[m^2]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario parameters		
Investment Horizo	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (Case 1)		
LRMC (basic)	129,5	[US$/MWh]
NPV	$ (29 137 722)	[US$]

Optional scenario results (Case 2)		
LRMC (Optional)	107,79	[US$/MWh]
NPV	$ (25 322 590)	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Electricity tariff [US$/MWh]	Electricity sale	Discounted Costs
				2%	2%	0%			
0	2020	$ (40 000 000)	$ (40 000 000)						$ (40 000 000)
1	2021	$1 072 207	$1 179 428	$ (981 680)	$ (5 600)	$ -	$ 44,14	$ 2 166 708	$ (897 527)
2	2022	$948 274	$1 147 411	$ (1 001 314)	$ (5 712)	$ -	$ 43,89	$ 2 154 437	$ (832 253)
3	2023	$911 471	$1 213 168	$ (1 021 340)	$ (5 826)	$ -	$ 45,64	$ 2 240 334	$ (771 725)
4	2024	$879 234	$1 287 287	$ (1 041 767)	$ (5 943)	$ -	$ 47,57	$ 2 334 996	$ (715 600)
5	2025	$913 644	$1 471 433	$ (1 062 602)	$ (6 062)	$ -	$ 51,75	$ 2 540 097	$ (663 556)
6	2026	$841 462	$1 490 702	$ (1 083 854)	$ (6 183)	$ -	$ 52,58	$ 2 580 739	$ (615 297)
7	2027	$774 968	$1 510 193	$ (1 105 531)	$ (6 307)	$ -	$ 53,42	$ 2 622 030	$ (570 549)
8	2028	$713 714	$1 529 908	$ (1 127 642)	$ (6 433)	$ -	$ 54,27	$ 2 663 983	$ (529 054)
9	2029	$657 288	$1 549 851	$ (1 150 195)	$ (6 561)	$ -	$ 55,14	$ 2 706 607	$ (490 577)
10	2030	$604 845	$1 568 813	$ (1 173 198)	$ (6 693)	$ -	$ 56,00	$ 2 748 704	$ (454 899)
11	2031	$570 491	$1 627 676	$ (1 196 662)	$ (6 826)	$ -	$ 57,68	$ 2 831 165	$ (421 815)
12	2032	$538 021	$1 688 541	$ (1 220 596)	$ (6 963)	$ -	$ 59,41	$ 2 916 100	$ (391 138)
13	2033	$507 339	$1 751 473	$ (1 245 008)	$ (7 102)	$ -	$ 61,19	$ 3 003 583	$ (362 692)
14	2034	$478 351	$1 816 539	$ (1 269 908)	$ (7 244)	$ -	$ 63,03	$ 3 093 691	$ (336 314)
15	2035	$450 968	$1 883 806	$ (1 295 306)	$ (7 389)	$ -	$ 64,92	$ 3 186 501	$ (311 855)
	NPV	(29 137 722)					Revenue:	$ 39 789 674	
	Ann	(3 830 846)						NPV of Cost	$ (48 364 851)
								Annuity of Costs	$ (6 358 710)

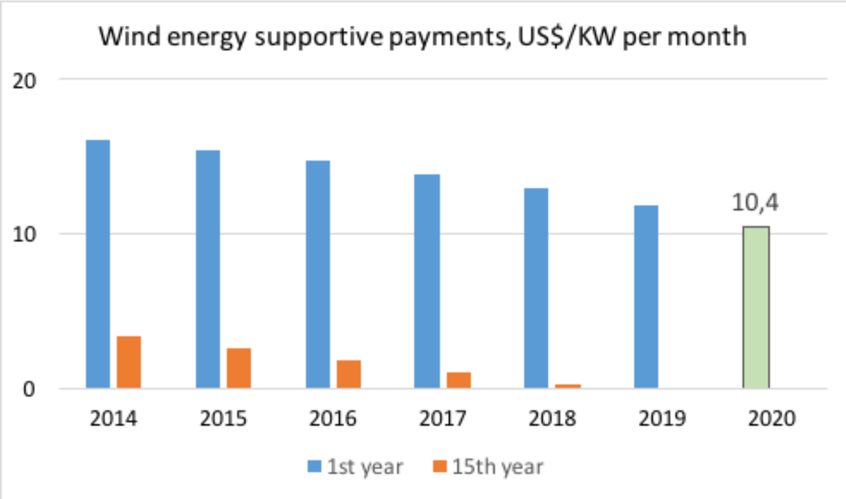
Source: Own assessment

The highest wind speed in the region is on the coastal, low populated areas. The construction of the 20 MW wind electricity facility is not economically feasible, according to the table above Table 46, the LRMC is 129 US$/MWh and the NPV is negative in both cases.

5.4.1 Wind energy potential, considering premium payments for capacity.

As was mentioned before in 2013 the new legislation act have been implemented (Goverment of Russian Federation , 2013). That enactment introduces the premium monthly payments for capacity, applicable for wind/solar/hydro based renewable energy. The premium payment size demands on the year of project launching, size and the structure of the payment as below, in Figure 33.

Figure 33 Capacity subsidies for wind energy



Source: (IFC World Bank, Association of renewable Energy , 2013)

In the Figure above only first year of operations is shown and year 15, however the payment size will be decreasing gradually through the period of 15 years. For the particular case of the report (launching of the projects is foreseen in 2020), the premium capacity payment on the first year is 10,4 US$/KW per month and by the year 15 that amount will reach 0. Estimated payments for each year of the operations from 1st to 15th, introduced in the table below, see below Table 47.

Table 47 Premium capacity payment decrease rate for the wind energy

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Capacity supportive payments projection, US$/KW per month	10,4	8,8	7,4	6,2	5,2	4,4	3,7	3,1	2,6	2,2	1,8	1,5	1,3	1,1	0,0

Source: Own assessment based on (IFC World Bank, Association of renewable Energy , 2013)

In order to check the feasibility of wind projects in the Murmansk region the following assumptions have been made: First of all, that all capacity will be eligible for premium payments; secondly that wind projects will start their operations in 2020, as for the moment, 2020 is the last year of subsidies validity.

As the law was introduced in 2013 and payments were given in rubles. At the moment of 2013, the Rub/US$ exchange rate was 34, and in recent year the Russian currency fluctuating heavily, thus the current exchange rate considered in calculations (65 rub/US$). The result of the feasibility study of 20MW wind park (considering the capacity subsidies payment) presented in Table 48 below.

Table 48 Wind energy feasibility assessment, with consideration of premium capacity payments

Wind		
Given data	Unit	Value
Installed capacity	20000	[MW]
Electricity output	0,049	[TWh/year]
CAPEX	$ 2 000	[USD/KW]

Given data	Unit	Value
O&M	0,020	[usd/KWh]
Land rental	$ 1,40	[USD/sq m/year]
Required area	4250	[sq m]

Optional scenario parameters		
Investment Horizon	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

With capacity subsidies results (scenario 4)		
LRMC (basic)	34,1	[USD/MWh]
NPV	$9 548 320	[USD]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Capacity subsidies	Electricity tariff [USD/Kwh]	Electricity sale	Discounted Costs
				2%	2%		3%		
0	2020	$(40 000 000)	$ (40 000 000)						$ (40 000 000)
1	2021	$3 031 798	$3 281 921	$ (981 680)	$ (5 950)	$ 2 102 843	$ 44,1	$ 2 166 708	($ 1 030 220)
2	2022	$2 899 026	$3 397 096	$ (1 001 314)	$ (6 069)	($ 2 250 042)	$ 43,9	$ 2 154 437	($ 1 060 465)
3	2023	$2 854 084	$3 620 349	$ (1 021 340)	$ (6 190)	($ 2 407 545)	$ 45,6	$ 2 240 334	($ 1 087 928)
4	2024	$2 813 272	$3 862 988	$ (1 041 767)	$ (6 314)	($ 2 576 073)	$ 47,6	$ 2 334 996	($ 1 112 781)
5	2025	$2 844 063	$4 227 453	$ (1 062 602)	$ (6 440)	($ 2 756 398)	$ 51,8	$ 2 540 097	($ 1 135 186)
6	2026	$2 759 195	$4 439 661	$ (1 083 854)	$ (6 569)	($ 2 949 346)	$ 52,6	$ 2 580 739	($ 1 155 298)
7	2027	$2 678 626	$4 665 599	$ (1 105 531)	$ (6 701)	($ 3 155 800)	$ 53,4	$ 2 622 030	($ 1 173 259)
8	2028	$2 602 095	$4 906 213	$ (1 127 642)	$ (6 835)	($ 3 376 706)	$ 54,3	$ 2 663 983	($ 1 189 206)
9	2029	$2 529 358	$5 162 517	$ (1 150 195)	$ (6 971)	($ 3 613 076)	$ 55,1	$ 2 706 607	($ 1 203 265)
10	2030	$2 459 639	$5 434 386	$ (1 173 198)	$ (7 111)	($ 3 865 991)	$ 56,0	$ 2 748 704	($ 1 215 558)
11	2031	$2 409 941	$5 763 860	$ (1 196 662)	$ (7 253)	($ 4 136 611)	$ 57,7	$ 2 831 165	($ 1 226 196)
12	2032	$2 361 622	$6 114 280	$ (1 220 596)	$ (7 398)	($ 4 426 173)	$ 59,4	$ 2 916 100	($ 1 235 287)
13	2033	$2 314 640	$6 487 035	$ (1 245 008)	$ (7 546)	($ 4 736 005)	$ 61,2	$ 3 003 583	($ 1 242 931)
14	2034	$2 268 954	$6 883 612	$ (1 269 908)	$ (7 697)	($ 5 067 526)	$ 63,0	$ 3 093 691	($ 1 249 222)
15	2035	$2 224 524	$7 305 597	$ (1 295 306)	$ (7 851)	($ 5 422 253)	$ 64,9	$ 3 186 501	($ 1 254 248)
16	2036	$2 181 312	$7 754 687	$ (1 321 212)	$ (8 008)	($ 5 801 810)	$ 66,9	$ 3 282 096	($ 1 258 093)
17	2037	$2 139 279	$8 232 692	$ (1 347 636)	$ (8 168)	($ 6 207 937)	$ 68,9	$ 3 380 559	($ 1 260 835)
18	2038	$2 098 389	$8 741 548	$ (1 374 589)	$ (8 331)	($ 6 642 493)	$ 70,9	$ 3 481 976	($ 1 262 549)
19	2039	$2 058 606	$9 283 324	$ (1 402 081)	$ (8 498)	($ 7 107 467)	$ 73,1	$ 3 586 435	($ 1 263 303)
20	2040	$2 019 895	$9 860 228	$ (1 430 122)	$ (8 668)	($ 7 604 990)	$ 75,3	$ 3 694 028	($ 1 263 163)
	NPV	**9 548 320**	$79 425 045	$(23 852 242)	$ (144 569)	($ 86 207 087)	**Revenue:**	**$ 57 214 770**	
	Ann	**990 680**						**NPV of Cost**	$ (16 121 009)
								Annuity of Costs	$ (1 672 625)

Source: Own assessment

The results, presented in table 49, above, showing that 20MW wind farm, located in the Murmansk region is feasible. NPV is positive 9 Mln US$ and LRMC is 34,1 US$/MWh, which is lower than projected tariff for electricity in 2030 (56 US$/MWh). In Table 49, highlights of the several options of the wind electricity generation feasibility are presented. As mentioned above the only feasibly option is the project, where subsidies considered as well as longer investment period and lower discount rate.

Table 49 20 MW onshore wind farm feasibility in Murmansk region

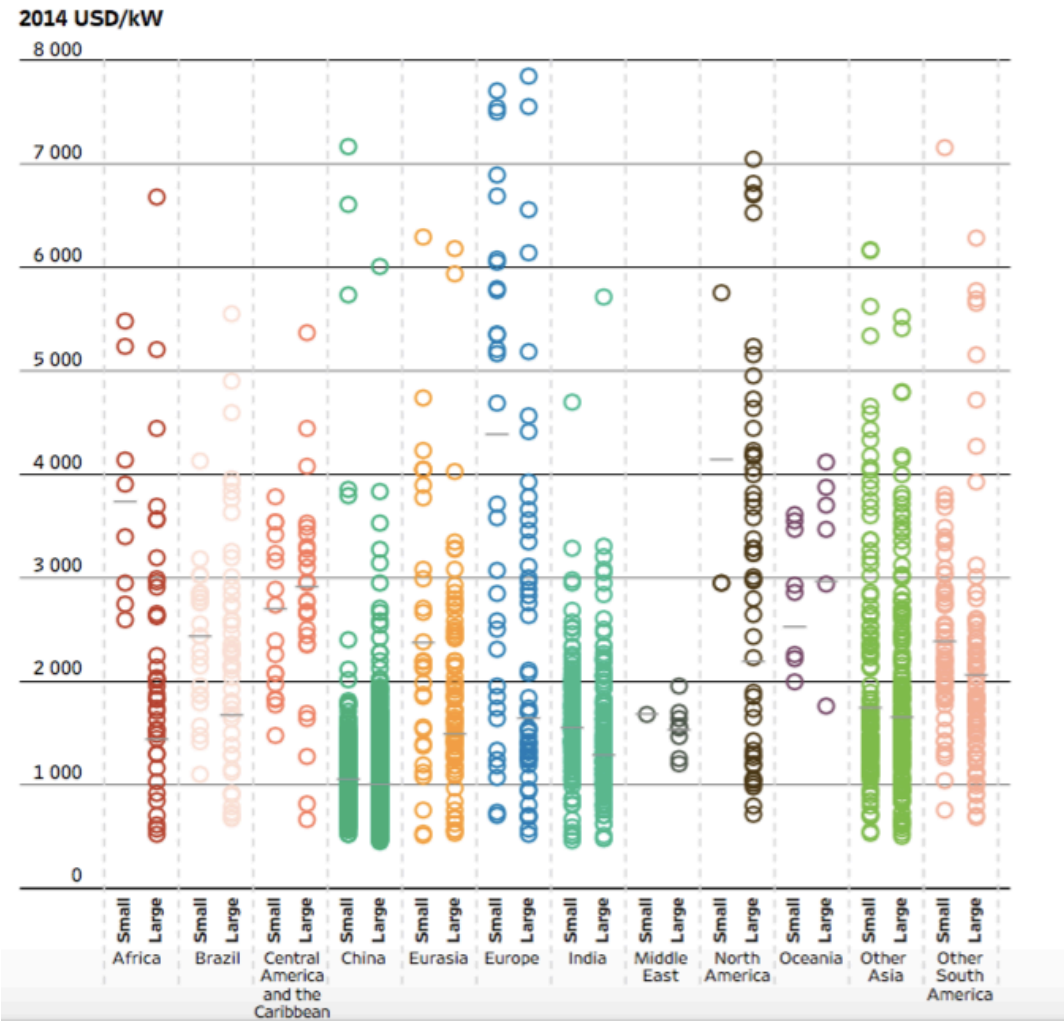
Case #	CAPEX	Investment horizon	Discount rate	CRF	Capacity subsidies	NPV		LCRM
	[US$/KW]	[year]	[%]	0,131	[yes/no]	+/-	[US$]	[US$/MWh]
Case 1	$ 2 000	15	10%	0,131	no	Negative	$ (29 137 722)	$ 129,55
Case 2	$ 2 000	20	8,25%	0,104	no	Negative	$ (25 322 590)	$ 107,79
Case 3	$ 2 000	15	10%	0,131	yes	Negative	$ (21 292 725)	$ 84,74
Case 4	$ 2 000	20	8,25%	0,104	yes	Positive	$9 548 320	$ 34,08

Source: Own assessment

5.5 Hydro: Electricity generation cost

For the hydro to electricity cost evaluation, IRENA research «Renewable Power Generation cost 2014» (IRENA, 2015) was used as the main information source. Electricity generation from hydro energy is a mature technology, technically proved and been used for decades. Hydropower is a capital intensive technology with high development and construction costs, which are mainly due to preparation works required (such as feasibility assessments, planning, design and engineering). Additionally, in case of remote or isolated locations, the construction costs can take almost a half of total projects expenses, due to difficulties in accessing the area.
CAPEX for large-scale hydropower projects typically varies from 1000 to 3500 US$/kW (IRENA, 2015). In line with the below presented data in Figure 34, the cost of the installation for small hydropower stations selected on the level of 2000 US$/KW.

Figure 34 Average installed cost for small/large hydropower projects



Source: (IRENA, 2015)

Hydropower stations usually have low operations and maintenance (O&M) costs, ranging from 1% to 4% (IRENA, 2015). In case of the Murmansk region, it can be said that, there are available experienced labor as well as engineering stuff, due to presents of the hydropower in the region for a few decades. the O&M costs will taken the lowest possible, or 1%, out of the (IRENA, 2015) recommended range.

Out of the total list of the potential hydropower stations in the Murmansk region, the average one was calculated; In order to use its (average electricity generating hydropower station in the Murmansk region) technical parameters, such as capacity and generation, for feasibility calculation. The list of the potential stations and the benchmarked average station as below in table 50. Feasibility checking results, presented below in Table 51.

Table 50 Hydropower Station in Murmansk Region with average parameters

Rivers	Length	Water high	Average flow rate	Build capacity	Potential electricity output
	[km]	[m]	[m3/s]	[MW]	[Bln KWh]
Rynda	97,6	285	18,5	28	0,135
Harlovka	126	260	32,5	46	0,217
Lisitca	118	290	30,2	47	0,225
Indel	23	37,2	7,87	2	0,008
Hlebnay	29	111	3	2	0,009
Umba	125	151,6	81	66	0,315
Kica	37	54,3	3,18	1	0,004
Acha	80	131,2	12,6	9	0,042
Pacha	26	54,3	1,36	0,40	0,002
Total				201	0,9560
Average	74	153	21	17	0,083

Source: Own assessment

Table 51 17 MW hydropower station in the Murmansk region, feasibility study

Hydropower		
Given data	Unit	Value
Installed capacity	17000	[KW]
Electricity output	0,083	[TWh/year]
CAPEX	$ 2 000	[US$/KW]

Given data	Unit	Value
O&M	1%	[%]
Land rental	$ 1,40	[US$/m^2/year]
Required area	10000	[m^2]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario parameters		
Investment Horizo	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	58,61	[US$/MWh]
NPV	$ (4 486 642)	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	47,43	[US$/MWh]
NPV	$ 5 466 418	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Electricity tariff [USD/MWh]	Electricity sale	Discounted Costs
				2%	2%				
0	2020	$ (34 000 000)	$ (34 000 000)						$ (34 000 000)
1	2021	$ 3 008 961	$ 3 309 857	$ (340 000)	$ (14 000)	$ -	$ 44,14	$ 3 663 857	$ (321 818)
2	2022	$ 2 712 419	$ 3 282 027	$ (346 800)	$ (14 280)	$ -	$ 43,89	$ 3 643 107	$ (298 413)
3	2023	$ 2 569 538	$ 3 420 056	$ (353 736)	$ (14 566)	$ -	$ 45,64	$ 3 788 357	$ (276 710)
4	2024	$ 2 440 244	$ 3 572 761	$ (360 811)	$ (14 857)	$ -	$ 47,57	$ 3 948 429	$ (256 586)
5	2025	$ 2 429 087	$ 3 912 069	$ (368 027)	$ (15 154)	$ -	$ 51,75	$ 4 295 250	$ (237 925)
6	2026	$ 2 242 728	$ 3 973 129	$ (375 387)	$ (15 457)	$ -	$ 52,58	$ 4 363 974	$ (220 622)
7	2027	$ 2 070 663	$ 4 035 136	$ (382 895)	$ (15 766)	$ -	$ 53,42	$ 4 433 798	$ (204 576)
8	2028	$ 1 911 796	$ 4 098 104	$ (390 553)	$ (16 082)	$ -	$ 54,27	$ 4 504 738	$ (189 698)
9	2029	$ 1 765 114	$ 4 162 047	$ (398 364)	$ (16 403)	$ -	$ 55,14	$ 4 576 814	$ (175 902)
10	2030	$ 1 628 896	$ 4 224 937	$ (406 331)	$ (16 731)	$ -	$ 56,00	$ 4 648 000	$ (163 109)
11	2031	$ 1 526 722	$ 4 355 916	$ (414 458)	$ (17 066)	$ -	$ 57,68	$ 4 787 440	$ (151 247)
12	2032	$ 1 430 942	$ 4 490 909	$ (422 747)	$ (17 407)	$ -	$ 59,41	$ 4 931 063	$ (140 247)
13	2033	$ 1 341 157	$ 4 630 038	$ (431 202)	$ (17 755)	$ -	$ 61,19	$ 5 078 995	$ (130 047)
14	2034	$ 1 256 993	$ 4 773 428	$ (439 826)	$ (18 110)	$ -	$ 63,03	$ 5 231 365	$ (120 589)
15	2035	$ 1 178 099	$ 4 921 210	$ (448 623)	$ (18 473)	$ -	$ 64,92	$ 5 388 306	$ (111 819)
	NPV	**(4 486 642)**					**Revenue:**	$ 67 283 493	
	Ann	**(589 876)**						**NPV of Cost**	$ (36 999 308)
								Annuity of Costs	$ (4 864 439)

Source: Own assessment

In accordance with presented results, hydro electricity generation is economically feasible only in alternative case, meaning in case of longer investment horizon (up to 20 years) and lower discount rate- 8.25%. Hydropower is currently being used in the region to provide around 40% of total electricity demand.

6. Cost of heating generation from renewable energy sources.

First of all, it is necessary to mention that heat generation in this report is only considered to come from the biomass (several types: forest residuals; peat briquettes and MSW). To measure the feasibility of heating generation facilities, the same methodology applied as for the electricity generation (identification of LRMC and NPV). Also, the same parameters as for the electricity will be used to understand above mentioned LRCM and NPV. The parameters are: CAPEX (Equipment costs and other initial capital costs), O&M (Operations and maintenance costs), and Feedstock cost.

6.1 Biomass heating generation cost:

As a guideline for the biomass heating cost (CAPEX) the NREL data was used (NREL, 2013). As is stated on the web page, the mean installed cost as of 2013 was 600 US$/KW, with a standard deviation of +/- 361 US$/KW. For the purpose of this report, CAPEX will be taken as 650 US$/KW; this cost slightly higher than the average, and this is to take into account logistical issues. The O&M will be taken as 10% of CAPEX.

6.1.1.1 Forest residuals: heating generation cost:

To calculate the cost of heating generation from Timber, LRMC with the only difference with the other biomass sources in feedstock cost, which is 5 US$/ton for forest residuals. Based on the mentioned above parameters the following results were achieved Table 52.

Table 52 Forest residuals heat generation feasibility

BIOMASS: Wood/forest residuals (WR) heating		
Given data	Unit	Value
Installed capacity	20000	[KW]
Heating output	0,081	[TWh/year]
CAPEX	$ 650	[US$/KW]

Given data	Unit	Value
O&M	10%	[%]
Land rental	$ 1,40	[US$/m²/year]
Required area	25000	[m²]
Cost of feedstock	0,005	[US$/kg]
Required feedstock	73613445	[kg/year]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario parameters		
Investment Horizon	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	44,72	[US$/MWh]
NPV	$ (5 076 875)	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	41,11	[US$/MWh]
NPV	$ (2 583 240)	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Heating tariffs [USD/MWh]	Heat supply	Discounted Costs
				2%	2%	2%	3%		
0	2020	$ (13 000 000)	$ (13 000 000)						$ (13 000 000)
1	2021	$ 955 056	$ 1 050 562	$ (1 300 000)	$ (35 000)	$ (368 067)	$ 34	$ 2 753 629	$ (1 548 243)
2	2022	$ 862 840	$ 1 044 037	$ (1 326 000)	$ (35 700)	$ (375 429)	$ 34	$ 2 781 165	$ (1 435 643)
3	2023	$ 779 193	$ 1 037 106	$ (1 352 520)	$ (36 414)	$ (382 937)	$ 35	$ 2 808 977	$ (1 331 233)
4	2024	$ 703 339	$ 1 029 758	$ (1 379 570)	$ (37 142)	$ (390 596)	$ 35	$ 2 837 067	$ (1 234 416)
5	2025	$ 634 571	$ 1 021 983	$ (1 407 162)	$ (37 885)	$ (398 408)	$ 36	$ 2 865 437	$ (1 144 640)
6	2026	$ 572 246	$ 1 013 768	$ (1 435 305)	$ (38 643)	$ (406 376)	$ 36	$ 2 894 092	$ (1 061 394)
7	2027	$ 515 776	$ 1 005 102	$ (1 464 011)	$ (39 416)	$ (414 503)	$ 36	$ 2 923 033	$ (984 202)
8	2028	$ 464 629	$ 995 974	$ (1 493 291)	$ (40 204)	$ (422 794)	$ 37	$ 2 952 263	$ (912 623)
9	2029	$ 418 318	$ 986 371	$ (1 523 157)	$ (41 008)	$ (431 249)	$ 37	$ 2 981 786	$ (846 251)
10	2030	$ 376 398	$ 976 280	$ (1 553 620)	$ (41 828)	$ (439 874)	$ 37	$ 3 011 603	$ (784 705)
11	2031	$ 359 579	$ 1 025 922	$ (1 584 693)	$ (42 665)	$ (448 672)	$ 38	$ 3 101 951	$ (727 636)
12	2032	$ 343 312	$ 1 077 460	$ (1 616 387)	$ (43 518)	$ (457 645)	$ 40	$ 3 195 010	$ (674 717)
13	2033	$ 327 599	$ 1 130 959	$ (1 648 714)	$ (44 388)	$ (466 798)	$ 41	$ 3 290 860	$ (625 646)
14	2034	$ 312 439	$ 1 186 487	$ (1 681 689)	$ (45 276)	$ (476 134)	$ 42	$ 3 389 586	$ (580 145)
15	2035	$ 297 831	$ 1 244 113	$ (1 715 322)	$ (46 182)	$ (485 657)	$ 43	$ 3 491 274	$ (537 952)
	NPV	**(5 076 875)**					Revenue:	$ 45 277 733	
	Ann	**(667 476)**						NPV of Cost	$ (27 429 446)
								Annuity of Costs	$ (3 606 253)

Source: Own assessment

Heating generation project with the installed capacity of 20 MW and based on the locally available forest residuals is not economically feasible in both cases basic and alternative. As NPV is negative.

6.1.1.2 Peat briquettes: heat generation cost:

In case of peat briquettes, CAPEX for heating generation project will be considered the same as for the wood/forest residual (650 US$/KW), as well as O&M cost (10% of CAPEX per year). The only difference is the cost of the energy source itself, which is sizably higher in case of peat briquettes; on the level of 110 US$/ton. Feasibility results of 20 MW heating generation station, based on peat briquettes, presented in Table 53.

Table 53 Heat generation cost using Peat Briquettes

BIOMASS: Peat briquettes (PB) heating		
Given data	Unit	Value
Installed capacity	20000	[KW]
Heating output	0,081	[TWh/year]
CAPEX	$ 650	[US$/KW]

Given data	Unit	Value
O&M	10%	[%]
Land rental	$ 1,40	[US$/m²/year]
Required area	25000	[m²]
Cost of feedstock	0,110	[US$/kg]
Required feedstock	31854545	[kg/year]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario paramters		
Investment Horizon	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	88,04	[US$/MWh]
NPV	$ (31 646 450)	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	86,02	[US$/MWh]
NPV	$ (37 484 893)	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Heating tariffs [USD/MWh]	Heating supply	Discounted Costs
				2%	2%	2%	3%		
0	2020	$ (13 000 000)	$ (13 000 000)						$ (13 000 000)
1	2021	$ (1 895 792)	$ (2 085 371)	$ (1 300 000)	$ (35 000)	$ (3 504 000)	$ 34	$ 2 753 629	$ (4 399 091)
2	2022	$ (1 780 673)	$ (2 154 615)	$ (1 326 000)	$ (35 700)	$ (3 574 080)	$ 34	$ 2 781 165	$ (4 079 157)
3	2023	$ (1 672 065)	$ (2 225 519)	$ (1 352 520)	$ (36 414)	$ (3 645 562)	$ 35	$ 2 808 977	$ (3 782 491)
4	2024	$ (1 569 646)	$ (2 298 119)	$ (1 379 570)	$ (37 142)	$ (3 718 473)	$ 35	$ 2 837 067	$ (3 507 401)
5	2025	$ (1 473 106)	$ (2 372 452)	$ (1 407 162)	$ (37 885)	$ (3 792 842)	$ 36	$ 2 865 437	$ (3 252 317)
6	2026	$ (1 382 146)	$ (2 448 555)	$ (1 435 305)	$ (38 643)	$ (3 868 699)	$ 36	$ 2 894 092	$ (3 015 785)
7	2027	$ (1 296 477)	$ (2 526 467)	$ (1 464 011)	$ (39 416)	$ (3 946 073)	$ 36	$ 2 923 033	$ (2 796 455)
8	2028	$ (1 215 824)	$ (2 606 227)	$ (1 493 291)	$ (40 204)	$ (4 024 995)	$ 37	$ 2 952 263	$ (2 593 077)
9	2029	$ (1 139 921)	$ (2 687 874)	$ (1 523 157)	$ (41 008)	$ (4 105 494)	$ 37	$ 2 981 786	$ (2 404 489)
10	2030	$ (1 068 514)	$ (2 771 450)	$ (1 553 620)	$ (41 828)	$ (4 187 604)	$ 37	$ 3 011 603	$ (2 229 617)
11	2031	$ (980 248)	$ (2 796 763)	$ (1 584 693)	$ (42 665)	$ (4 271 356)	$ 38	$ 3 101 951	$ (2 067 463)
12	2032	$ (899 074)	$ (2 821 678)	$ (1 616 387)	$ (43 518)	$ (4 356 784)	$ 40	$ 3 195 010	$ (1 917 102)
13	2033	$ (824 432)	$ (2 846 162)	$ (1 648 714)	$ (44 388)	$ (4 443 919)	$ 41	$ 3 290 860	$ (1 777 677)
14	2034	$ (755 807)	$ (2 870 176)	$ (1 681 689)	$ (45 276)	$ (4 532 798)	$ 42	$ 3 389 586	$ (1 648 391)
15	2035	$ (692 725)	$ (2 893 684)	$ (1 715 322)	$ (46 182)	$ (4 623 454)	$ 43	$ 3 491 274	$ (1 528 508)
	NPV	**(31 646 450)**					Revenue:	$ 45 277 733	
	Ann	**(4 160 678)**						NPV of Cost	$ (53 999 022)
								Annuity of Costs	$ (7 099 455)

Source: Own assessment

Heat generation from peat briquettes is not feasible, with LRMC being as 88 US$/MWh (in basic case and negative NPV - 31mln US$.

6.1.1.3 Municipal Solid Waste heat generation cost:

Municipal solid waste as an energy source has a few benefits: first of all, it is sustainable (with a growing supply as the population increases). Secondly, utilizing MSW as an energy source can partially solve environmental issues, such as landfilling. Below, feasibility is the calculations Table 54.

Table 54 Heat generation from MSW, feasibility study

BIOMASS: Municipal solid waste (MSW) heating		
Given data	Unit	Value
Installed capacity	20000	[KW]
Heating output	0,081	[TWh/year]
CAPEX	$ 8 259	[USD/KW]

Given data	Unit	Value
O&M	10%	[%]
Land rental	$ 1,40	[US$/m^2/year]
Required area	25000	[m^2]
Cost of feedstock	0,000	[US$/kg]

Basic scenario parameters		
Investment Horizon	15	[year]
Discount rate	10%	[%]
CRF	0,131	[factor]

Optional scenario parameters		
Investment Horizon	20	[year]
Discount rate	8,25%	[%]
CRF	0,104	[factor]

Basic scenario results (case 1)		
LRMC (basic)	497,96	[US$/MWh]
NPV	$ (283 074 753)	[US$]

Optional scenario results (case 2)		
LRMC (Optional)	449,56	[US$/MWh]
NPV	$ (319 940 223)	[US$]

DATA	DATA	CALC	CALC	EXPENSES	EXPENSES	EXPENSES	DATA	INCOME	CALC
Year count	Year number	Discounted CF	Nominal CF	O&M	Land rental	Cost of the feedstock	Heating tariffs [USD/MWh]	Heat supply	Discounted Costs
				2%	2%		3%		
0	2020	$ (165 180 000)	$ (165 180 000)						$ (165 180 000)
1	2021	$ (12 544 883)	$ (13 799 371)	$ (16 518 000)	$ (35 000)	$ -	$ 34	$ 2 753 629	$ (15 048 182)
2	2022	$ (11 655 285)	$ (14 102 895)	$ (16 848 360)	$ (35 700)	$ -	$ 34	$ 2 781 165	$ (13 953 769)
3	2023	$ (10 828 523)	$ (14 412 764)	$ (17 185 327)	$ (36 414)	$ -	$ 35	$ 2 808 977	$ (12 938 949)
4	2024	$ (10 060 180)	$ (14 729 109)	$ (17 529 034)	$ (37 142)	$ -	$ 35	$ 2 837 067	$ (11 997 935)
5	2025	$ (9 346 146)	$ (15 052 062)	$ (17 879 614)	$ (37 885)	$ -	$ 36	$ 2 865 437	$ (11 125 358)
6	2026	$ (8 682 601)	$ (15 381 758)	$ (18 237 207)	$ (38 643)	$ -	$ 36	$ 2 894 092	$ (10 316 241)
7	2027	$ (8 065 991)	$ (15 718 334)	$ (18 601 951)	$ (39 416)	$ -	$ 36	$ 2 923 033	$ (9 565 969)
8	2028	$ (7 493 009)	$ (16 061 931)	$ (18 973 990)	$ (40 204)	$ -	$ 37	$ 2 952 263	$ (8 870 262)
9	2029	$ (6 960 584)	$ (16 412 692)	$ (19 353 470)	$ (41 008)	$ -	$ 37	$ 2 981 786	$ (8 225 152)
10	2030	$ (6 465 855)	$ (16 770 764)	$ (19 740 539)	$ (41 828)	$ -	$ 37	$ 3 011 603	$ (7 626 959)
11	2031	$ (5 985 056)	$ (17 076 063)	$ (20 135 350)	$ (42 665)	$ -	$ 38	$ 3 101 951	$ (7 072 271)
12	2032	$ (5 539 895)	$ (17 386 565)	$ (20 538 057)	$ (43 518)	$ -	$ 40	$ 3 195 010	$ (6 557 924)
13	2033	$ (5 127 739)	$ (17 702 346)	$ (20 948 818)	$ (44 388)	$ -	$ 41	$ 3 290 860	$ (6 080 984)
14	2034	$ (4 746 147)	$ (18 023 484)	$ (21 367 794)	$ (45 276)	$ -	$ 42	$ 3 389 586	$ (5 638 731)
15	2035	$ (4 392 858)	$ (18 350 058)	$ (21 795 150)	$ (46 182)	$ -	$ 43	$ 3 491 274	$ (5 228 641)
	NPV	(283 074 753)					Revenue:	$ 45 277 733	
	Ann	(37 216 907)						NPV of Cost	$ (305 427 324)
								Annuity of Costs	$ (40 155 684)

Source: Own assessment

The project, incineration plant, with installed capacity of 20MW, is not economically feasible with projected negative NPV -283 mln US$ and high LRMC cost 497 US$/MWh.

7.Conclusions and recommendations

Derived results: Electricity:

Murmansk region is currently electricity abundant due to nuclear power station (which is providing 60% of total electricity), however the situation may change noticeably in case of the nuclear reactors decommissioning as its scheduled (starting from 2018). After that point the Murmansk region most probably will face the electricity deficit. The region has very limited time to make adjustments and implement alternative generating facilities, as before first stage of decommissioning only two years left; thus actions have to be taken immediately. In case of sources selection for electricity generation, time is required for facility construction, facility construction. This is an extra factor to be considered in decision making.

The forecasted economic growth and development of the Murmansk region is only possible if the the energy system will be sustainable and well developed, thus it is crucial to ensure the generation of the electricity at acceptable cost. Otherwise the development of the region seems problematic. However, for electricity generation, derived results are very promising. And after the brief analyses some of the renewable sources are feasible, such as wind, hydro and tidal.

Technically, wind itself can provide 83 TWh/y, which is a few times higher than the regional demand in 2030 (21.8 TWh/y). Hydro energy, which is already being used in the region (40% out of the current electricity generation), can be extended to some level and add around 5% to the local energy mix by 2030, results are presented below in Table 55.

Table 55 Electricity generation potential by energy sources

Source	Possible electricity generation	Share of regional demand 2030 (21,8 TWh/y)
	[TWh/y]	[%]
Forest residuals	0,11	0,52%
Peat briquests	0,05	0,25%
Municipal Solid Waste	0,51	2,34%
Wind	83,15	382%
Solar	0,08	0,35%
Hydro	0,95	4,36%
Tidal	1,09	5,01%
Total electricity from local Energy sources	**85,95**	**13%**

Source: own assessment (excluding wind energy)

Abovementioned results for electricity generation, can give a guideline on the further actions, and that these several sources (Wind, hydro, tidal) have to be deeply analyzed for further usage. In Table 56, the feasibility study results for electricity generating projects are provided.

Table 56 Electricity generation feasibility

Source	Electricity output from 1 facility , TWh/y	Electricity potential in the region, TWh/y	Additional conditions	NPV	NPV, US$	LRMC, US$/MWh
Wood/forest residuals	0,06	0,034	Case 1 (15 years, 10% discount rate)	Positive	$ 536 833	50,2
			Case 2 (20 years, 8,25% discount rate)	Positive	$ 5 248 291	44,4
Peat briquettes	0,06	0,054	Case 1 (15 years, 10% discount rate)	Negative	$ (25 469 117)	111,9
			Case 2 (20 years, 8,25% discount rate)	Negative	$ (24 451 629)	100,0
MSW	0,06	0,509	Case 1 (15 years, 10% discount rate)	Negative	$ (283 698 034)	723,9
			Case 2 (20 years, 8,25% discount rate)	Negative	$ (320 398 283)	653,5
Solar (PV field)	0,02	0,077	Case 1 (15 years, 10% discount rate)	Negative	$ (45 473 167)	383,6
			Case 2 (20 years, 8,25% discount rate)	Negative	$ (40 279 261)	286,4
Wind	0,049	83,000	Case 1 (15 years, 10% discount rate)	Negative	$ (29 137 722)	129,5
			Case 2 (20 years, 8,25% discount rate)	Negative	$ (25 322 590)	107,8
			Case 3 (15 years, 10% discount rate, subsidies)	Negative	$ (21 292 725)	84,7
			Case 4 (20 years, 8,25% discount rate, subsidies)	Positive	$ 9 548 320	63,4
Tidal	0,16	1,092	Case 1 (15 years, 10% discount rate)	Positive	$ 25 839 840	29,9
			Case 2 (20 years, 8,25% discount rate)	Positive	$ 43 065 919	25,8
Hydro	0,0956	0,956	Case 1 (15 years, 10% discount rate)	Negative	$ (4 486 642)	58,6
			Case 2 (20 years, 8,25% discount rate)	Positive	$ 5 466 418	47,4

Source: own assessment

Derived results: Heating:

In additional to the electricity generation projects development, heating generation is crucial to ensure the quality of living in the region. Harsh climate and nine months of heating period, both have led to the strong dependence on the imported heating oil (around 80%). Government of Russia is providing subsidies to the local Murmansk authorities to purchase necessary volume of heating oil yearly, to secure the heating period. Considering this, the heating generation projects has to be developed in parallel with the existing system, which will increase the financial pressure on the regional budget (as the heating oil still will be purchased annually to ensure the heat supply). Overall, it can be concluded, that the Murmansk region is very rich with the biomass resources (different types), yet if we consider forest residuals for example, that type of the biomass can provide less than 1% of the required heating, see Table 57.

locally available biomass (Forest residuals/ peat briquettes/MSW) overall can cover only 7% of regional heat demand in 2030. Forest harvesting as well as wood processing industry is surprisingly poor developed (in comparison to the area and the volume of the available commercial forests in the Murmansk region (94 Th km^2, or 102 mln m^3)); which is maybe due to ecological limitations of harvesting. However, it could be beneficial for the region if the the usage of the biomass as an energy source (particularly for heating) will be extended.

Table 57 Heat generation technical potential

Source	Possible heat generation	Share of regional demand 2030 -15,47 TWh/y
	TWh/y	[%]
Forest residuals	0,049	0,32%
Peat briquettes	0,078	0,51%
Municipal Solid Waste	0,965	6,24%
Total from local energy sources	1,093	7,06%

Source: own assessment

For heat generation non of the projects are feasible with the selected sources, technologies and estimated cost projection for heat supply (as per Table 58). However, it can be different if instead the conventional combustion technology, the cogeneration will be used to convert biomass to the heat and electricity, which is more efficient (around 75-80%). Moreover, the projects could be feasible in case of the subsidies from the Government side for some limited period in order to ensure the launching of the projects.

In general, to release the dependence on the imported fuels (heating oil and coal) it could be a solution to focus on the further research and analyses of biomass based heating generation plants (particularly forest residuals). Additional opportunity to increase the heat generation volume from biomass is to devote all harvested forest to the energy generation (instead of exporting as a raw material and importing heavy oil), yet that is a subject for the separate analyses. Other option, for improving the situation with the heating in the Murmansk region, is to focus on the efficiency, such as to implement proper measurement system and to control the consumption, improve the quality of houses thermo isolation and to repair/change heat transmitting lines. All these actions are targeted to minimize the losses and potential decrease the required generation.

Table 58 Heat generation projects feasibility

Source	Heat output from 1 facility , TWh/y	Heat potential in the region, TWh/y	Additional conditions	NPV	NPV, US$	LRMC, US$/MWh
Wood/forest residuals (WFR)	0,081	0,049	Case 1 (15 years, 10% discount rate)	Negative	$ (5 076 875)	44,72
			Case 2 (20 years, 8,25% discount rate)	Negative	$ (2 583 240)	41,11
Peat briquettes (PB)	0,081	0,078	Case 1 (15 years, 10% discount rate)	Negative	$ (31 646 450)	88,04
			Case 2 (20 years, 8,25% discount rate)	Negative	$ (37 484 893)	86,02
Municipal solid waste (MSW)	0,08	0,11	Case 1 (15 years, 10% discount rate)	Negative	$ (283 074 753)	497,96
			Case 2 (20 years, 8,25% discount rate)	Negative	$ (319 940 223)	449,56

Source: own assessment

General conclusion:

One of the challenges, which appeared during the working on thesis is the information sources availability and quality of the information about the renewable sources of energy in the Murmansk region. However even with the rough estimations made in some cases, to asses the availability of the source in the region, still the solid conclusion can be done regarding the type of the most promising energy source for the Murmansk region (both heating and electricity).

The other uncertainty happened during work, is the fluctuations of the Russian currency (ruble), which is an issue in regards of the tariffs projections, as the exchange rate more than doubled in comparison with 2011 (when the forecast was prepared).

The weak point of the thesis, is that CO2 emissions are not considered, and not included in the scope of the thesis; however, that is important factor to study in order to decide on the project feasibility in the ecological aspect. To suggest the proper energy mix for the Murmansk region, it would be beneficial to compare emissions level of the different energy sources the suggested renewable and current fossil fuels.

However, in spite the mentioned uncertainties, derived results confirmed the feasibility of some of the projects; For the Murmansk region particularly, these projects are: Hydro, tidal and wind in case of electricity generation, these sources I would recommend to analyze further on.

The main obstacle of the further development of the Murmansk region's energy system (for both heating and electricity generation and supply) is lack of investments and particularly private, which is due to the market condition overall (Russia is considered to be unstable and risky for investments) and regulated tariffs as well. Moreover, the construction of the new generating facilities has to be started simultaneously with the infrastructure development (i.e. logistic access development, treatment facilities construction in case of biomass, grids and etc), that would lead to more financial pressure.

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