CZECH TECHNICAL UNIVERSITY IN PRAGUE
FACULTY OF ELECTRICAL ENGINEERING
DEPARTMENT OF ECONOMICS, MANAGEMENT AND HUMANITIES

# “Power Supply of Long-Distance Gas Pipeline's Along the Line Consumers”

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## Declaration

I hereby declare that this master's thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – "On maintaining ethical principles when working on a university final project, CTU in Prague".

Date Signature

# Abstract

The present diploma thesis is devoted to the problem of long distance gas pipelines along the line customers' power supply. Different options of renewable system's configuration have been designed. Key economical indicators were evaluated for each of configurations. Using this information, system configurations comparison have been conducted in order to find optimal solution. Conclusions on the application of renewable sources of energy on long distance power lines were made.

**Keywords**: long distance pipelines, gas transportation, renewable energy, wind turbines, telemetry, remote measurement, remote valve control.

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# ZADÁNÍ DIPLOMOVÉ PRÁCE

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Pokyny pro vypracování:

- give overview of current situation and technical solutions
- overview the market of renewables in Russia and support scheme
- evaluate how expensive the current power supply scheme is, find flaws in it and create necessity for alternatives
- calculate key economical indices for alternative systems (NPV, IRR, payback period)
- compare variants and already existing system, make conclusions

Seznam odborné literatury:

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## Contents

## Abbreviations

| **English** | **Russian** | **Transcript** |
|---|---|---|
| ORC | | Organic Renken Cycle |
| OEC | | ORMAT Energy Converter |
| LPG | | Liquefied Petroleum Gas |
| NG | | Natural Gas |
| GDS | | Gas Distribution Stations |
| GOST | Gosudarstvenny Standard | State Standard |
| CCVT | | Closed Cycle Vapor Turbine |
| TPES | | Total Primary Energy Supply |
| OECD | | Organisation for Economic Co-operation and Development |
| IEA | | International Energy Agency |
| RAO “EES of Russia” | Rossiiskoe Aktsionernoe Obschestvo “Edinie Energosistemy Rossii” | Russian Stick Company “Unifed Energy Systems of Russia” |
| UES | | Unified Energy System |
| PUE | Pravila Ustrojstva Elektroustanovok | Rules on Electrical Installations |

# 1. Introduction

From the discovery of fire to that of the atom, the development of human societies has largely been based on the conquest of energy. In all countries, energy has gradually become one of the key factors of social and economic development, along with capital, labor and natural resources – it is now impossible to do without it. At the moment, power industry is a vast segment of modern global economy with the annual volume of trade on it that can be roughly estimated to 6 - 9 trillion of US dollars. World consumption of energy inputs was 12700 millions of tonnes oil equivalent in 2013 and growing at rate of approximately 2-3% a year [1]. The most used fossil fuels are oil, natural gas and coal. Traditionally oil is the dominant power source followed by coal and natural gas, but energy mix of different countries may vary.

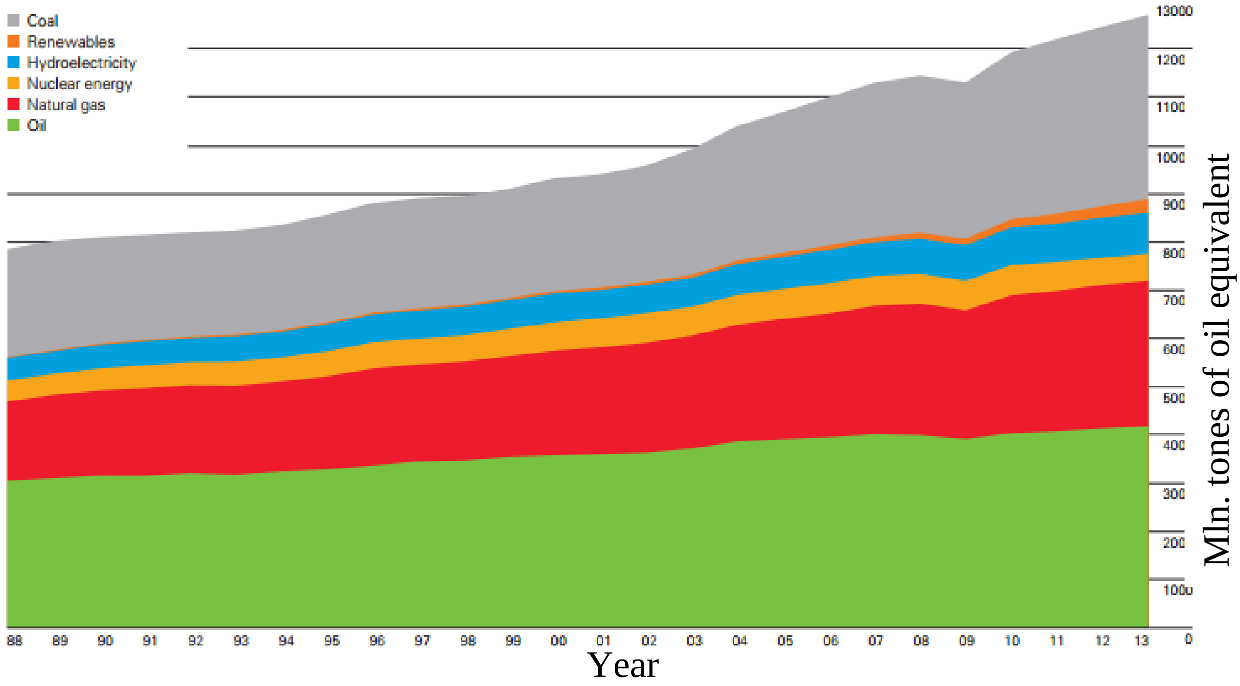



Figure 1. World Energy Consumption by Source [1]

Natural gas is expected to be the fastest growing primary energy source: its share in world energy demand will increase from 23 % in 2000 to 28 % in 2030, mostly at the expense of coal and nuclear energy. Gas is expected to overtake coal as fuel No. 2 by 2010 (Figure 3). Over the past decade, increasing gas use in power generation has been a key feature of the dynamics of the gas industry. [1]

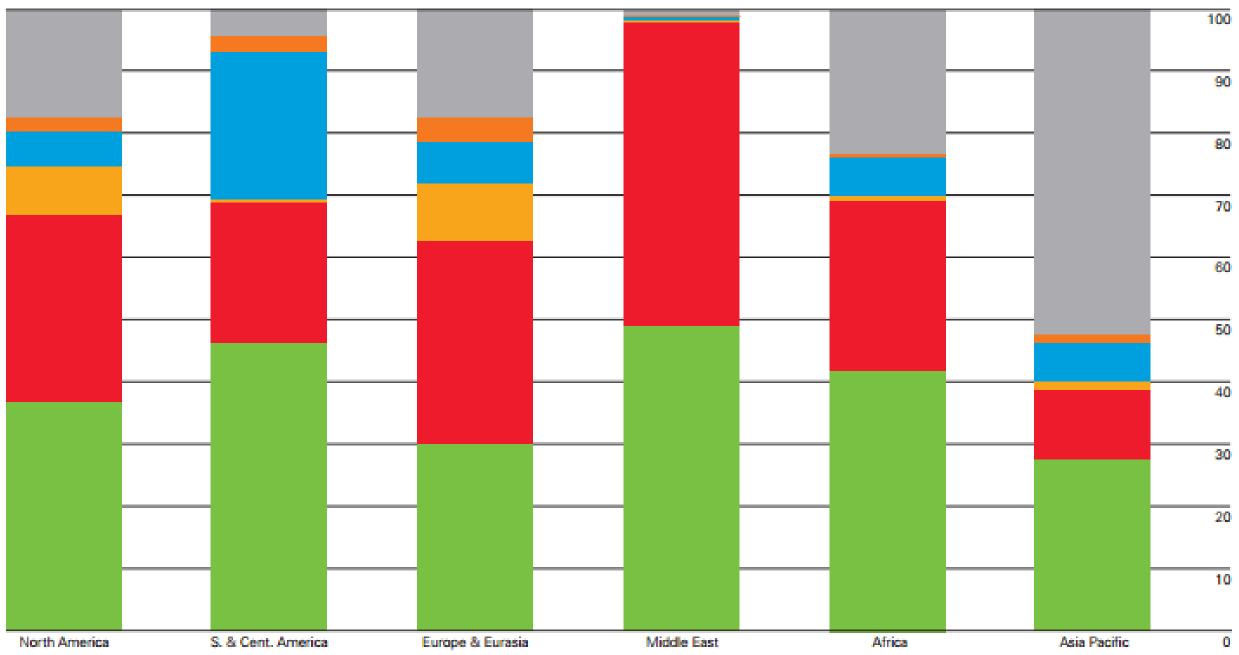


Figure 2. Regional Consumption Pattern by Regions (percentage) [1]

This explains high demand for the energy inputs in general and for natural gas in particular. Production of such natural resources as gas and oil is a complicated scientific, engineering and technical process, which involves geological exploration, evaluation of stock, legislation, pre-exploitation process, mining, processing, transporting, storing, etc. Needless to say, that oil and gas fields are usually located in remote areas. Reasons listed above determine high cost of energy inputs production.

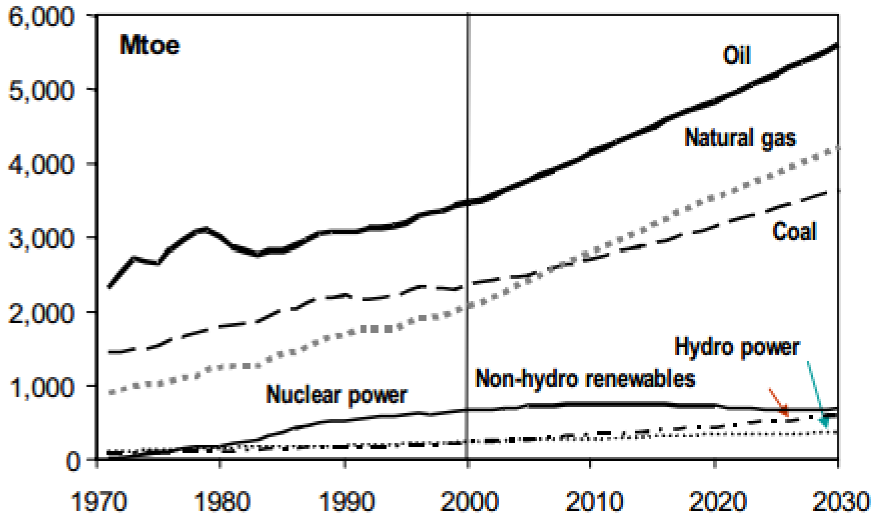


Figure 3. World Primary Energy Demand [2]

Companies of energy sector are constantly looking for new ways of how to increase efficiency of business and decrease expenses. Costs can be reduced in different stages and parts of business, and the following work is dedicated to economical optimization of transmission pipelines' electrical supply. Possibility to improve economic of gas transmission using renewable energy sources in general and wind turbines in particular will be researched.

## 2. Long-Distance Pipelines in Russia

At the moment, Russian Federation has one of the biggest oil and gas reserves in the world. High demand and price on these products makes it very attractive to produce and sell it. But unfortunately, oil fields are usually located in remote areas, which are extremely far from final consumers. This creates the problem of transporting gas and oil on long distances.

The most environmental friendly and economically rational way of transporting is using pipelines, which is being used in Russia for over 100 years. At the moment there are over 50 thousand kilometers of long distance pipelines and 200 thousand kilometers of big-inch pipelines, which are capable of transporting 600 millions of tons of oil and 800 billions of cubic meters of gas per year. The biggest of transporting pipelines are 'Surgut – Polotsk', 'Nizhnewartovsk – Kurgan – Kuibishev – Lisichansk', 'Druzhba – 1', 'Druzhba – 2' and currently being constructed pipeline of Yamburg direction. Moreover, recent Eastern part of the country projects were started at such regions as Kamchatka and Far East.

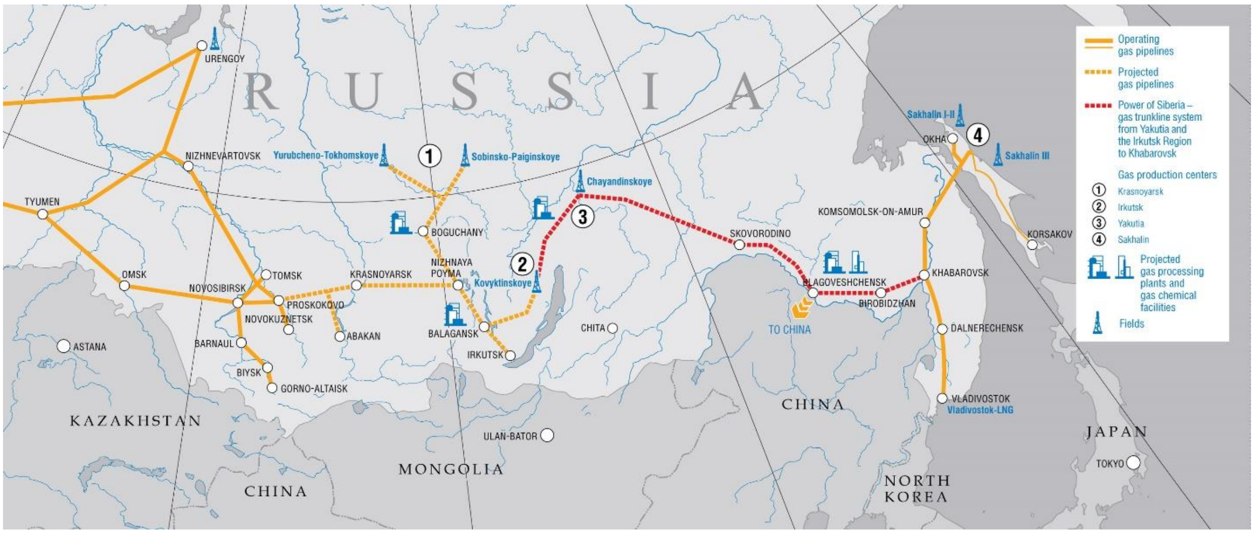


Figure 4 – Long-Distance Pipelines in Russian Federation [3]

Russian oil pipelines are governed by Transneft corporation and gas pipelines by Gazprom Corporation, whose primary functions are centralized control and management over supplies, resource accounting, and operating modes of oil transportation and emergency actions.

### 1.1. Linear Consumers' Electrical Load

Modular-packed Power Station is an autonomous system, which is intended to control valves on the pipeline, implement measurements and protection with the ability of remote control. Such tasks does not need much power, as it is mostly low-voltage electronic components and small engines, but it has excessive reliability requirements. Due to specifics of the application, such power stations should be able to operate without having maintenance for at least half a year by GAZPROM's regulations or, in real life for longer periods of time, as these stations are situated in remote and hard access areas. Basic block diagram of station's electrical scheme is presented in the Figure 5. In this scheme, base energy source is a gas burner, which is being backed-up by a diesel generator. As it was explained previously, transporting fuel to remote areas in amounts sufficient for a long-time operation is a costly business, that's why the company has decided to use gas drawn from pipe as an energy source. In my work, instead of ORMAT gas burner, wind turbines will be introduced.

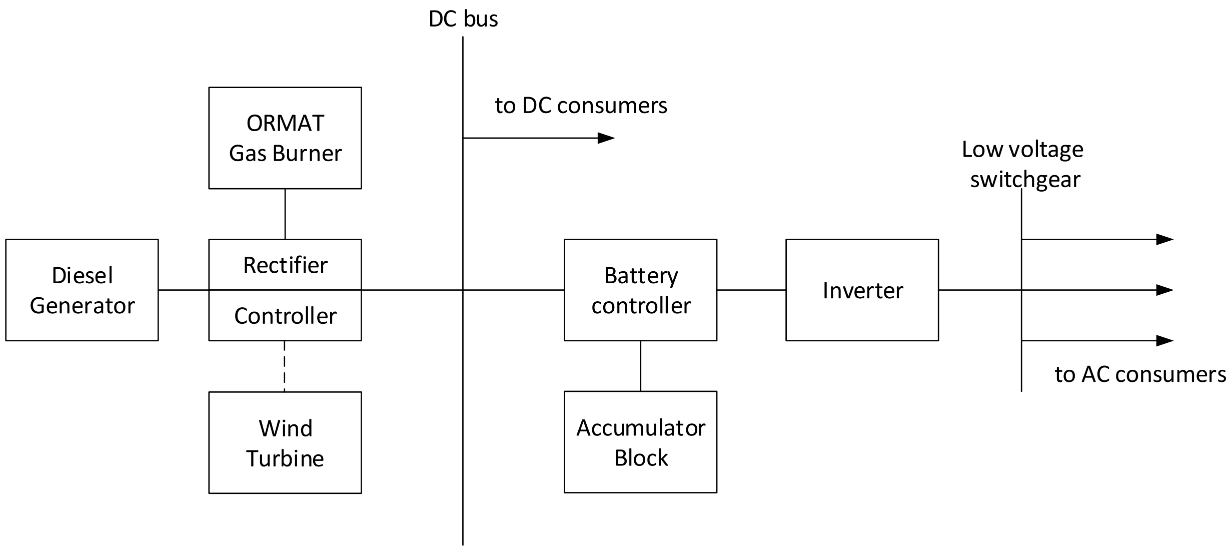



Figure 5. Structural scheme of autonomous consumer power supply

From the GAZPROM's inside document, 'List of Modular packed Power Station's Electrical Loads' (see Annex Table 1), the load of control station has been evaluated. Peak load of the station is 3.2 kW, which is all the installed equipment, including heating systems is operating at the same time. Average was estimated at the value of 1.2 kW, representing the situation of station's idle consumption, when heating and some basic measurement equipment is working. Due to specifics of the task, additional measurements and valve controls turn on in shuffled mode each 2-3 hours. Moreover, in consideration of load curve, season factor should be included. In summer time load is approximately 30% lower than in the winter, due to necessity of heating. Based on my intuition and said logic, the following load diagram of the station has been created (see Figure 6). Load table for a reference day of each month can be found in the Annex (Annex Table 2).

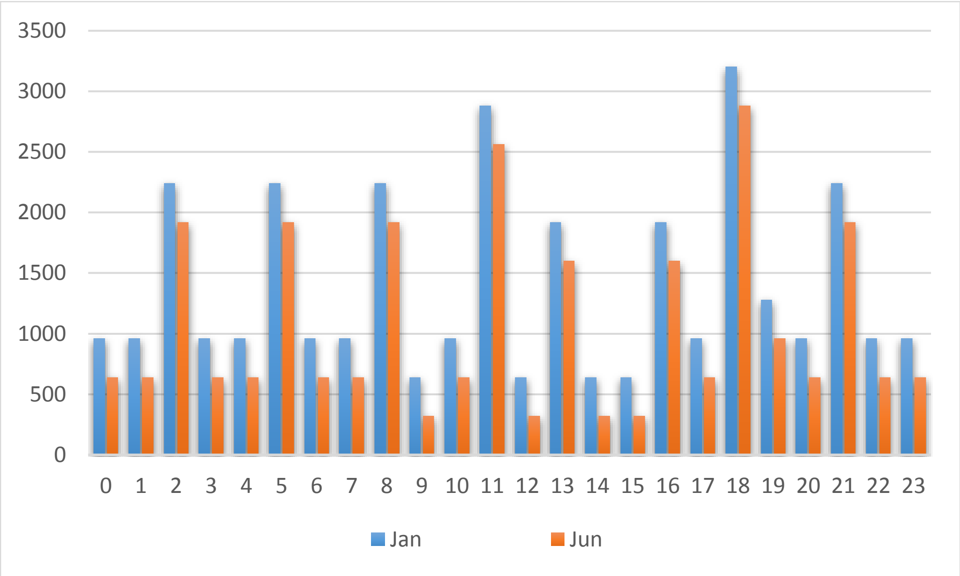


Figure 6. Load plot of a consumer station in January and in June

This load will be further used to compare it with the amount of energy generated with a wind turbine and the result will determine, whether it is necessary to use diesel generator/gas burner, to secure the load, therefore spend money on fuel, or use accumulation to store excess of energy if available.

A power station is supposed to have some amount of accumulation capacity, required to keep the station working and heated for 24 hours in case of power outage (no gas in the pipeline and low level of diesel fuel) or severe accidents. For the reference, capacity has been set to 600 Amp-hours.

## 1.2. Current Solution

Transportation of gas and oil using long-distance pipelines is a complex technical process, in which large amount of intermediate stations are involved. These stations are needed to monitor and keep the pressure inside the pipes at required level, remote valves control, probing of gas/oil parameters using telemetry. Power supply of such intermediate stations is an important engineering problem.

The primary linear (along the line) consumers of long-distance pipelines are[4]:

- Electrochemical protection means;
- Controllable points of linear remote controlled mechanization;
- Technological linking equipment;
- Means of control and automation;
- Gas distribution stations;
- Nodes of gas reduction (letting down);
- Nodes of cleaning equipment;
- Connection nodes and others.

By Russian legislation ‘Rules on Electrical Installations’ (PUE) [5], electrical consumers can be divided into several groups by its’ reliability requirements. Those groups are:

- 1st category – electrical consumers, interruption of which power supply may lead to danger to peoples’ lives, significant economic damage, damage to an expencive piece of equipment or break complex technological process. Power consumers with extreme importance of reliability of power supply can be put into special group;
- 2nd category – eletrical consumers, interruption of which power supply may lead to mass underproduction or big equipment and workpower downtime, and to disturbance of normal living activity of significant amount of people;
- 3rd category are all other consumers.

Consumers of 1st category should be supplied from two independent mutually backing up power sources with interruption of power supply time limited to time of automatic switch between sources. Special group of power supply should have one additional source. 2nd category consumers should also rely on two independent power sources. The difference between 1st and 2nd categories is the time of supply's interruption – 2nd category consumers can be interrupted for a time enough for operative personal actions or dispatch switching between sources, when for the 1st category, switching should be made strictly automatically.

According to internal standard of Gazprom corporation CTO 2-6.2-1-149-2007 'Reliability categorization of electrical power consumers' [6, 7, 8], most of the equipment can be categorized as 2nd category, but special consideration must be made for consumers of 1st category, which are controllable points of linear telemechanics.

When designing long-distance pipelines' linear consumers power supply scheme following aspects should be taken into account:

1. Significant length of pipelines
2. Dispersion of consumers along the length of the pipelines and their low power (2 to 10 kW)
3. Remoteness from existing external power sources such as overhead lies etc.

Considering these aspects, power supply of along-the-line customers, where connection to the existing distribution networks is impossible, is being done using diesel generators or ORC (organic Renkin cycle) plant. Such systems with nominal power from hundreds of watts to several kilowatts are designed to operate in severe climate conditions almost without maintenance. Amongst applications of such energy converters powering of cathode protection and telemetry systems can be found. ORC plants are widely used in Russia and earned a good reputation. As an example an energy converter ORMAT model 40AG-48-ARC for arctic climate produced in Israel and which is being used by Gazprom corporation.

ORMAT Energy Converter is a turbine generator with closed steam cycle. It is a fully complected independent source of energy for remote unmaintained site, working under Renkin cycle.

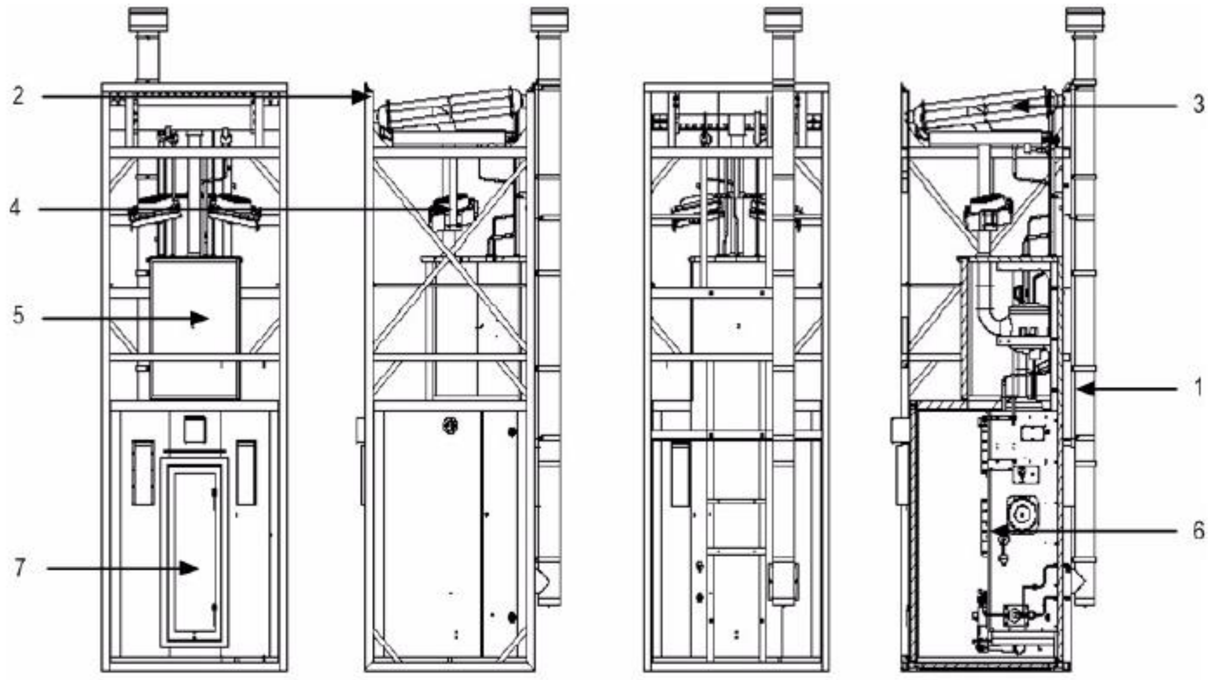



Figure 7 – OEC General View [9]

(1 – exhaust pipe, 2 – lifting loop 4 pc., 3 – condenser, 4 – condensate ventilator, 5 – turbine generator, 6 – steam generator, 7 – door)

System is implemented in a form of container in which fuel burning system, steam generator, turbine generator, air-cooled condenser and rack cabinet of distributive and control equipment can be found. The general view of OEC is presented in the picture 2. OEC is a source of direct (rectified and filtered) current designed for continuous or variable load and requires minimal maintenance. Energy converter burns supplied fuel (gas for example) and converts acquired heat energy into steam energy of low pressured organic fuel, which in its order, is being converted into rotational energy of a turbine and generator, which are mounted on the same axle. Dump steam exiting the turbine is caught in the condenser with air-cooling. Condensed liquid is being supplied back to steam generator.

ORMAT Energy Converter has following technical characteristics presented in the table 1.

Table 1 - ORMAT 40AG-48-ARC Specifications [9]

| | | |
|---|---|---|
| Output power | 4000 | W |
| Output voltage | 110 | V DC |
| Output current | 36,4 | A |
| Fuel consumption under 100% load | 24±0,1 | $m^3$/h of liquefied petroleum gas (LPG) |
| | 7,2±0,2 | $m^3$/h of natural gas (NG) |
| Working outside temperatures | From -50 up to +37 | $^oC$ |

At the moment companies start to use such autonomous plants backed up with diesel generators to supply long-distance pipelines' linear consumers. Advantages of such solutions are simplicity in exploiting, no need of frequent maintenance and transporting fuel to remote areas. Power supply system is constructed from blocks which allows to scale the system in accordance with needs and simplifies initial setup time and maintenance.

The basic layout of Closed Cycle Vapor Turbogenerator (CCVT), showing the components that participate in the thermodynamic cycle are shown in Picture 6.

The system is comprised of the following components:

- A Vapor Generator, where the heat provided by the fuel vaporizes the organic liquid. Various types of fuels can be used for combustion;
- A Turbine, where the vapors expand and turn the turbine thus producing shaft power to drive the generator, which has a common shaft with the turbine;
- A Condenser, where the heat is rejected and the vapors condense into liquid that returns to the Vapor Generator by gravity. The condenser is of natural draft type. Fans may be employed in extreme conditions.

The system is hermetically sealed and operates under vacuum. An organic fluid that is suitable for this application is used as the motive fluid. Over a period of time, impurities in the motive fluid may separate out of the fluid while in the vapor state.

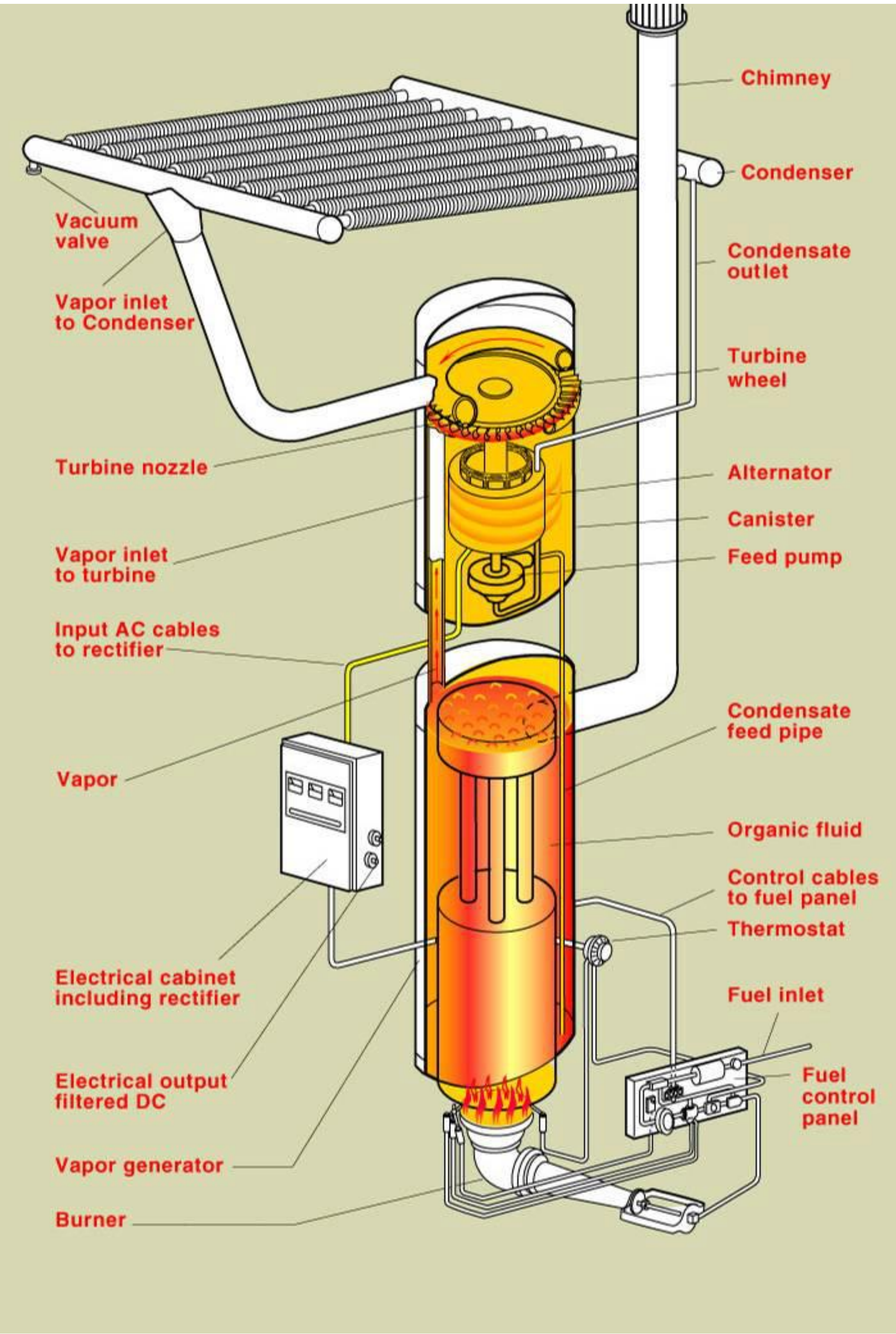



Figure 8. CCVT components [9]

### 1.3. Disadvantages of Current Solution

Despite of problem of long distance pipelines' linear consumers power supply can be considered as already solved, some issues exist. Main disadvantage is that intermediate stations are remote not only from existing electrical networks, but also from settlements (villages or cities). Because of that, diesel fuel delivered to the consumption points has relatively high cost, which as the final result has a negative impact on the price of the energy, produced by the station. In order to minimize costs, diesel generator time of work should be minimized, but in this case amount of gas drawn from the pipeline will increase. At the certain price for a gas this might become extremely expensive for a company, which creates necessity to look for alternative variants of solving the power supply problem. One of such solution can be installation of renewable energy sources.

### 1.4. Proposed Variant

Russia has substantial and diverse renewable energy resources — wind, geothermal, hydro, biomass and solar. Practically all regions have at least one or two forms of renewable energy that are commercially exploitable, while some regions are rich in all forms of renewable energy resources (Habarovskiy kray, Primorskiy kray and Amurskaya oblast). Russian experts estimate that the amount of renewable energy that is economically recoverable is more than 270 million tonnes of coal equivalent (Mtce) per year, including

- 115 Mtce/y of geothermal energy,
- 65.2 Mtce/y of small hydropower,
- 35 Mtce/y of biomass,
- 12.5 Mtce/y of solar,
- 10 Mtce/y of wind and
- 36 Mtce/y of low potential heat [10].

According to the new Energy Strategy of Russia, adopted in May 2009 [11], the economic potential of renewables has grown significantly in recent years because the prices for fossil fuels have increased while the cost of renewable energy technologies has dropped.

In consideration of renewable energy sources, specific nature of Siberia and Far East geographic should be taken into account. Significant disadvantage in usage of hydro energetics is the fact that during winter time most rivers in that area freeze, which in combination with shorter light day in the summer and therefore increased power demand makes small hydro plants inapplicable. Moreover, at Far East and Siberia regions plains prevail with lower energetic rush of water so required amount of energy can't be harnessed

Application of geothermal stations is also problematic, due to necessity to drill 3-5 km shafts and temperatures are quite low (except for Kamchatka region with high volcanic activity).

Solar panels installation in such a northern territory is obviously unfavorable because of low efficiency of modern panels, and relatively small amount of solar energy. Another issue is polar night phenomena when solar panels are completely worthless. Optimal variant would be to use wind turbines if wind potential of region allows that.

Except for the technical and economical reasons, another argument to turn to renewable energy sources is to use it as a publicity stunt. GAZPROM corporation is one of the largest companies in the Russian Federation and has to review it's public image. Being a resource extractor, known to dig the earth and change the landscapes, it is really important to present company in a right way and form a positive image amongst population. Implementation of renewable energy projects can be used as a demonstration of corporation's care for the environment. This factor should be also considered when taking decision on project's fulfillment.

## 2. Renewables Market in Russia

### 2.1. Overview

Russia currently uses very little of its huge renewable energy potential. According to official Russian statistics, renewable energy without large hydro over 25 MW accounted for 1% in year 2008 and 17% with it taken into account. Heat produced by renewable sources can be evaluated at level of 3% or 2000 million of Gcal [12].

Russia's energy mix is dominated by natural gas, which accounts for 45% of Total Primary Energy Supply (TPES), and 37% of electricity generation inputs [13]. Electricity and heat tariffs and domestic gas prices are state-controlled, and often kept artificially low. When the cost of using renewable energy is compared with the distorted price of the conventional energy market, it is not surprising that renewable energy is often not competitive.

Table 2 – Russia's energy mix [13]

| | 2005 | 2008 |
|---|---|---|
| Oil | 21,5% | 22,9% |
| Gas | 45,7% | 44,4% |
| Coal | 17,2% | 16,9% |

There are several reasons why the use of renewable energy in Russia is still far behind Europe. First and foremost it is so because of the low cost of traditional and locally available energy sources. Russia is in possession of huge oil and gas reserves, which are easily accessible and make the production of fuel and energy very cheap. In order to keep the energy prices on the Russian market low, the Russian government imposes high export duties on all commodities. Russian officials have explained occasionally that they consider the huge energy reserves and consequently low energy prices to be a sort of compensation for the substantial disadvantages Russian businesses encounter, because of the severity of its climate and the remoteness of its locations. The rise of energy prices would not only cause significant hardship to many families, which are already struggling to make ends meet,but would also lead to numerous dismissals. Many plants, especially in the metallurgical field would have to close down, because their main asset, the low energy prices, would be void. It goes without saying that the Russian government perfectly understands these causalities and will certainly not raise the prices substantially, fearing social unrest.

Another reason for the underdevelopment of renewable energy in Russia is the inconsistent legal base. There are only scarce government subsidies and tax incentives, and - contrary to the claims of the country's leader - no renewable portfolio standard.

Furthermore, among the population there is a weak awareness of environmental questions in general and renewable energy advantages in particular. For most of the Russian people renewable energy development is only a whim of the elite, which has no other problems to care about.

The latter two facts also cause a low share of private investment in renewable energy projects, which along with modest state funding makes the financing of these projects very difficult [14].

Over the last decades Russian energy sector faced several reforms, which aim was privatization, demonopolization and liberalization of an energy market. As International Energy Agency (IEA) states in its report, achievements to date have been impressive by international standards, however the outcome remains uncertain.

Ultimately, a competitive wholesale market structure is best achieved through diversity of ownership. Although the very successful 2008 privatization brought several new entrants and greater diversity of generation ownership, government-owned enterprises continue to own or control over 60% of total generation assets. A trend toward consolidation of ownership within government-owned entities is also beginning to emerge. Government ownership is not a problem of itself, so long as government-owned enterprises are operated on an arm's-length basis subject to normal corporate governance requirements, regulation and commercial practices. Several stakeholders suggested that scope may exist to improve the operational and investment performance of government-owned enterprises. IEA experience suggests that increasing the level and diversity of private ownership can result in substantial efficiency improvements [15].

Currently in Russia there are plenty applications where renewable energy sources have a competitive advantage over conventional energy sources. There will be more of such applications in the future when domestic gas prices increase. The combination of Russia's rich renewable energy resources and modern, existing renewable energy technologies suggests that investment in renewable energy in Russia could generate large economic benefits. The Mechanisms of the Kyoto Protocol are particularly well-suited to foreign investment in this domain.

Globally, markets for grid-connected renewables, particularly wind, geothermal, small hydro and bio fuels, are growing rapidly due to investments in OECD and other countries. As a result of economies of scale, technology improvements and more efficient production techniques, costs have declined to a point where in many locations (in Russia and elsewhere) these systems can be cost-competitive with conventional energy technologies [16], for example numerous wind farms in Germany and the USA prove that. Off-grid applications are also moving towards becoming cost-competitive with traditional off grid systems, but relatively high maintenance costs are a sufficient downside of renewable energy. But in case, when the variable costs of a traditional off-grid source, such as diesel generator are high due to high cost of the fuel (at remote areas), renewable energy source systems may gain an advantage.

Although Russia as a nation is an energy exporter, most Russian regions produce less energy than they need, so they have to import it from the few energy-rich regions such as Western Siberia. Some of Russia's fossil-fuel-deficient regions face frequent disruptions in fuel supplies due to rugged weather and transportation conditions and to suppliers' preferences for export markets. Given long distances between regions, transportation costs can dramatically increase the total cost of fuel. Indeed, some remote territories such as Kamchatka, Republic Tyva and Republic Altai spend more than half of their budgets on fuel [17].

Federal Law No. 35-FZ dated 26 March 2003 "On the Electric Power Industry" (hereafter, the "Federal Electricity Law") [18], as amended in 2007, requires the Russian government to adopt strategic national targets for the development of renewable energy [19]. It also provides for support mechanisms for electricity generation from renewable energy. To fulfil its obligation, on 8 January 2009 the government adopted Resolution No. 1-r "On the Main Areas of Government Policy to Raise the Energy Efficiency of Electric Power from renewable Energy Sources for the Period to 2020". In accordance with this resolution and also the updated Energy Strategy to 2030, 4.5 per cent of all electricity produced and consumed in 2020 should be generated from renewable energy sources.

Resolution No. 1-r also includes provisional targets of 1.5 per cent for 2010 and 2.5 per cent by 2015. According to government estimates in the Energy Strategy to 2030, reaching the 4.5 per cent target would require up to 25 gigawatts of new installed renewable energy capacity by 2020 (excluding large hydro) [19]. The Energy Strategy to 2030 stipulates that the share of renewables must remain at least 4.5 per cent in the period from 2020 to 2030, generating 80-100 billion kilowatt-hours per year. According to more recent analysis by the Russian Energy Forecasting Agency, reaching the target would require 14.7 gigawatts of new installed renewable energy capacity [20]. IFC has estimated that reaching the 4.5 per cent target would displace more than 36 million tons of carbon dioxide per year.

Many other countries, including all of the EU members, have adopted specific targets for renewable energy to account for a certain proportion of total energy demand and/or electricity consumption (or generation). All the EU members have also adopted targets for renewables in the heating and transport sectors. Countries that adopt such targets usually develop a detailed renewable energy strategy, or action plan, outlining how the country will achieve the target. Although such action plans are not a key prerequisite for successful renewable energy deployment, they are generally very useful because they:

i) provide a long-term vision for investors and enhance policy credibility;
ii) help the government to track progress in meeting the national target.

If renewable energy targets are not supported by effective measures, the risk of non-compliance is high. If targets are neither mandatory nor properly enforced, their raison d’être is undermined, damaging investors’ confidence in the government’s policy commitments. In Russia, Resolution No. 1-r does not explicitly state that the renewable energy targets are mandatory: it simply says that the Ministry of Energy should adopt additional “indicative” targets in order to monitor achievement of the general objectives. The target of 1,5 per cent by 2010 has not been met. The updated General Scheme for the Development of the Electricity Sector, currently at government approval stage, assumes that, with the current legal and regulatory framework, the 45 per cent target will not be met by 2020. According to the Energy Forecasting Agency, only about 0,3 – 0,4 gigawatts of new renewable energy capacity will be installed by 2020. The Agency assumes that the 4.5 per cent target might be met by 2030 [21]. But even in 2030, only 6,1 gigawatts of the new renewable energy capacity are projected to come online in the Agency’s “reference scenario” and 14,1 gigawatts in its “maximum growth” scenario. Postponing the target to 2030 would make it more expensive to meet. The delay in adopting the incentive schemes necessary to reach the target would affect investor confidence, thus increasing the cost of investment in renewable energy sources because of a “risk premium”. Moreover, postponing the target would also affect the total investment required: in 2030, more capacity/more electricity is expected to be produced and consumed [22].

### 3.1. Support Scheme

In November 2007 Russian Federal Electricity Law – the primary legislative act devoted to the regulation of the Russian electrical energy market – faced long awaited changes, which were aimed to modify legal frame work in order to introduce renewable energy sources support by adding extra charge to the wholesale price of energy. This scheme never came to life, due to assumed law and technical problems and probable influence on consumers' end price of electricity.

In 2011 the Federal Law was modified again, with the introduction of additional support mechanisms: assistance for renewable energy sources was considered to be applied through the market of power. This scheme intended to ensure attractiveness and feasibility of RES projects investments by the means of contracting agreements of sale and purchase (Agreements for the Delivery of Renewable Energy Capacity), to supply power to the grid with investors of such project. Statement No. 449 is a next step in the process of development of legal basis of renewable energy sources support by the means of payment for power.

Contracting mechanism of RES power provision is similar to contractual scheme used previously during in context of privatization of former monopoly RAO 'EES of Russia'. As a part of investment program financing, investors, who have bought generating equipment in the privatization process, signed long-term contracts of electrical power (capacity) delegation.

Russian approach of supporting RES on the basis of electrical power payment significantly differs from schemes of renewables development applied in other countries. Renewable energy generation support in a form of feed-in tariffs, additional charges, certificates, usually coincides with the volume of RES energy production (volume is expressed in MWh). In contrary, Russian support scheme is based on power generation delegation or to the ability of generating unit to produce electrical power, i.e. readiness of a station to produce electrical energy expressed in MW or MW per month.

Apart from the fact, that Russian approach is new for the industry and thus investors are not familiar with it, it also raises regulative problems, connected with varying output of renewable power sources. By which way RES stations' operators are going to prove the ability of their units to produce certain amount of electrical energy? This question remains crucial, as the payment for delegated power depends on at what measure station satisfies all the requirements of readiness of power production. In case if the unit does not correspond to some of the requirements, payment can be significantly reduced by several coefficients.

Federal Electricity Law assigns the problem of main regulatory terms development for Agreements for the Delivery of Renewable Energy Capacity, which will be signed with RES investors, on Russian Federation government. Statement No. 449 sets special rules of power supply into the system for renewables, as traditional rules do not correspond to source specific nature. It is important to mention, that Russian government should develop contract terms in a way to meet strategic target of RES generation share, which was set to the level of 4,5% by year 2020, but was later corrected to more realistic 2,5%. Statement No. 449 introduced system of competitive selection of investment projects, designed for different renewable source (wind, solar, small hydro). Investors, whose RES projects would be chosen, will have right to implement their project with subsidies and mandatory agreement with United Energy System [22].

The Federal Law Introducing the Capacity-Based Scheme does not provide any indication as to how the government will adopt the list of installations that are entitled to support. The government could announce a tender for specific projects at specific locations. The list could then be approved on the basis of bids submitted by investors. Alternatively, investors could independently take the initiative to bid for projects that they identify themselves. Looking at the "classic" Agreements for the Delivery of Capacity, it can be expected that the government will unilaterally determine the location, the amount of capacity, and the type of projects in advance. Indeed, the private investors that purchased the TGKs and OGKs from RAO UES must implement the investment programmes that are determined centrally by the state. The Agreements for the Delivery of Capacity formalize this obligation [22]

Capacity remuneration mechanisms can, if well designed, provide an alternative to the existing electricity output-based support schemes. By remunerating the installed capacity of renewable energy installations or their availability, capacity mechanisms could remove the current incentive to deliver as much electricity as possible to the grid even in periods of low demand. Capacity-based support schemes could therefore facilitate the integration of wind energy to the grid and the management of wind flows. Furthermore, from a financial perspective, supporting wind energy through capacity payments could reduce investor’s exposure to the risks of low wind periods and provide strong guarantees of recovery of their large investment costs. Russia’s plans to introduce a capacity-based support scheme highlight the complex interaction between renewable energy and capacity markets.

The Russian capacity-based approach to support renewable energy illustrates the fact that, despite their apparent antagonism, renewable energy support policies and capacity mechanisms share a common objective: to attract investments in electricity production. The fundamental difference between renewable energy schemes and capacity mechanisms relates to the different energy policy objectives for which they were initially designed. Renewable energy policies aim to decarbonize the fuel mix of the electricity sector and to reduce the dependency on fossil fuels. They aim to replace part of the electricity produced from fossil fuels by electricity produced from renewable energy sources. Support schemes have therefore primarily been based on the electricity output of renewable energy installations. Capacity mechanisms, on the other hand, aim to ensure long-term supply-demand adequacy and at the same time guarantee the short-term operational reliability of the system. They have therefore often been based on the availability of installations to produce electricity [23].

### 3.2. Wind potential of Russian Federation

Russia has used its high wind resource for many hundreds of years, mainly mechanically for water pumping. However, despite an enormous potential, commercial, large-scale utilization has never occurred and development has generally been restricted to agricultural uses in areas where a grid connection was infeasible. The areas of greatest resource are the regions where the population density is less than 1 person per $km^2$.

The coastal areas of the Pacific and Arctic Oceans, the vast steppes and the mountains are the areas of highest potential. In 1935 the wind resource was estimated at 18 000 TWh for the USSR as a whole. More recently, estimates suggest that the European part of Russia has a gross wind energy resource of 29 600 TWh/yr (37%) and the Siberian and Far East part, 50 400 TWh/yr (63%). The technical resource for each is reported to be 2 308 and 3 910 TWh/yr, respectively. By the most recent estimates, Russia has a total potential of 80,000 TWh/yr for wind energy, 6,218 TWh/yr of which is economically feasible [24].

Most of this potential is found in the southern steppes and the seacoasts of the country, although in many of these areas the population density is less than 1 person per square km. This low population density means that there is little existing electricity infrastructure currently in place, which hinders development of these resources. [25].

Wind energy is the most dynamically developing renewable energy sector in Russia. During the recent years it has surpassed even hydro energy in terms of numbers of newly installed power facilities. After the closure of RAO EES, Rushydro now also manages the development of the sector and the main wind park projects. Currently about 10 big and 1600 small wind parks are installed in Russia [26]. The country has excellent potential for wind power generation. An attempt to utilize just 25 percent of its total potential would yield some 175,000 MW of power. The highest wind energy potential is concentrated along seacoasts, in the vast territories of steppes and in the mountains [27]. Russia has a long history of small-scale wind turbines located in agricultural areas with low population density. As connection to the main energy grid is difficult there, small energy suppliers are in high demand. However, large-scale commercial wind energy production has been having a difficult stand so far in Russia.

Russia has no major domestic producers of windmills that can compete with the major international players in this sector. There are some manufacturers for small windmills, but not for facilities with big capacities [28]. It should be noted, that the most of the equipment used nowadays cannot be applied in severe climate conditions of Russian Federation. The RES equipment should be able to operate in temperature range from -60 to +40 $^{o}$C, which means that some sort of key node heating should be introduced. Moreover, some adjustments to the construction should be made, such as short and hard pylon for wind generator instead of long and flexible one. Currently, experimental technical solutions for high power wind turbines are being developed and tested by several Russian construction bureaus [29].

Applications of renewable energy technologies in Russia can be divided in two groups: off-grid and grid connected. With Russia’s renewable energy resource base, and given the technologies that already exist in the global marketplace, small investments, combined with sound policy changes, could generate large economic returns. Grid connected appliances are not being investigated in the present work as irrelevant.

Off-grid systems have proven to be very cost-effective in many OECD and developing countries. In Russian areas not connected to centralized electricity supply renewable energy systems can replace or supplement existing traditional systems cost-effectively as done in other countries such as Canada, the USA, Norway, and Sweden.

In Russia, some 20 million people live in regions that are not connected to the centralized grid administered by the Unified Energy Systems (UES). While half of them are connected to smaller, autonomous power grids, about 10 million are served by stand-alone generation systems using either diesel fuel or gasoline. Nearly half of these diesel and gasoline systems are reported to be no longer operating because of fuel delivery problems or/and high fuel costs. Most stand-alone systems are used in the far northern regions of Russia, in the Far East and in Siberia. Every year 6-8 million tonnes of liquid fuel (diesel, black oil) and 20-25 million tonnes of coal are sent to these territories [30]. Remote northern and Far Eastern areas, not connected to oil and gas pipelines, get their fuel by rail or road and sometimes by helicopter. Such supplies are very unreliable and expensive. The cost of transporting these fuels is not borne by the users of these systems. Removing these energy subsidies could make renewable energy a viable alternative [31]. Because of the sheer size of Russia, wind or hybrid wind-diesel systems, biomass-fired steam boilers with turbine-generators, and small hydro power stations are cost-competitive with traditional fossil fuel technologies in remote areas, or nearly so, depending on local conditionsand the level of subsidies to conventional energy [32].

# 4. Model

## 4.1. Wind data analysis

To make decision on whether the power supply of stations using wind turbines is a feasible and adequate solution, it is needed to acquire data on wind parameters in that area. Reference area was chosen to be small town Troickoe, Khabarovsky Region.


Figure 9. Location of Troickoe

This particular place has been chosen as it is a remote area outside of the cities – the closest big one, Khabarovsk, is in 170 kilometers away and it is located on the gas pipeline site. Selo Troickoe is the place with wind characteristics, which are quite similar to the most of the pipeline area along the Chinese border (see figure 10), this makes it a good reference point to make calculations for. The town was founded in 1852 and now has the population of 5200 people, weather data, such as wind speeds, is available at the local meteorological station since year 2000.

For my research I have used data for the last 5 years, which has been acquired from the online open source database [33] and contains almost 8500 entries of wind speed measurements from years 2007 to 2012. Wind speeds have been measured at the height of 10 meters above ground with the averaging interval of 1 hour. Older data has been measured once a day at midnight, more recent one contains entries gathered each 6 hours - at 0:00, 6:00, 12:00 and 18:00.

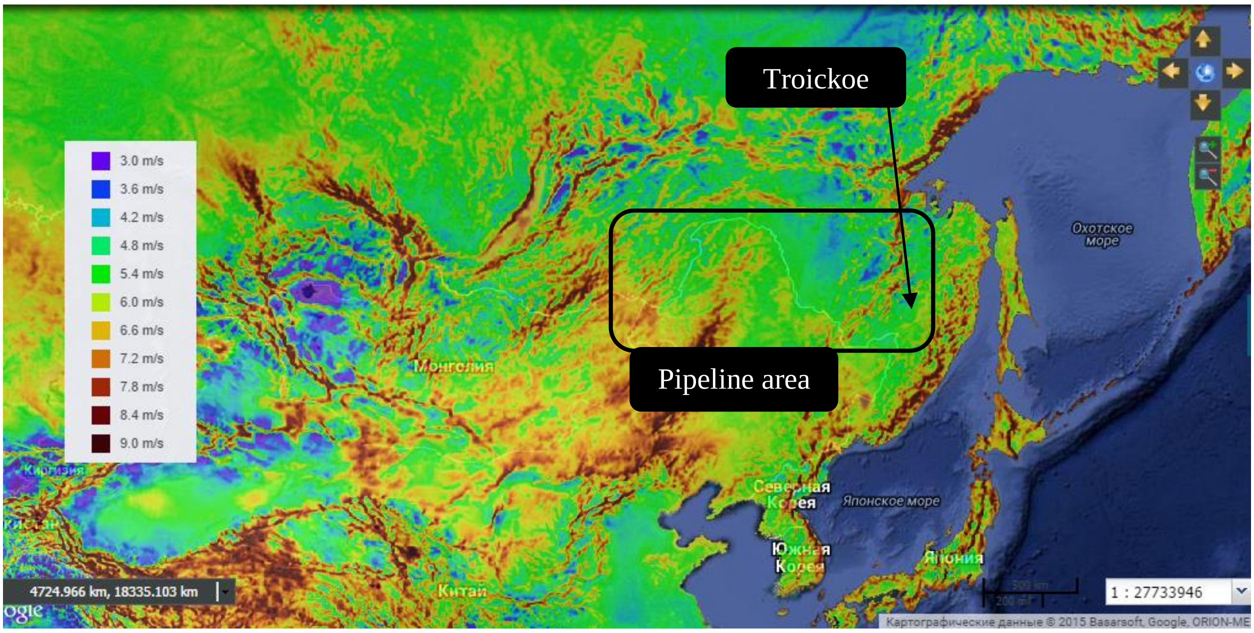


Figure 10. Average wind speed maps [34]

Using Microsoft Excel, the data has been filled into tables, sorted by times of measurement and by months, which made the acquisition of the wind speed distribution tables possible. As a result, for each measurement time probability density table has been created (see Annex Tables 3 – 6). Some of the months have less than 100% data, because of outlying points, which do not fall into applicable wind speed or do not follow reason (statistically can be considered as faulty data).

Based on known peak and average load of the consumption stations, which is 3.2 and 1.2 kW respectively, we can assume that low power wind turbines, not more than 5 kW, should be used. Such turbines usually have cut-in speed of 2-3 m/s and have power curves, presented in the Picture XXX. Using this intuition, it was decided to divide all the wind speeds into three categories – low, moderate and good. Low wind speed was considered to be lower than 3 m/s and it means that the turbine does not generate power or generates amounts lower than 10% of demanded; with such low speeds system will have to discharge the accumulators or use diesel engine. Moderate wind speeds, from 3 to 8 m/s, allow us to cover demand at least during low load hours, allowing not to consume fuel. Good wind speeds over 8 m/s mean that the load is covered and the excess of energy can be stored.

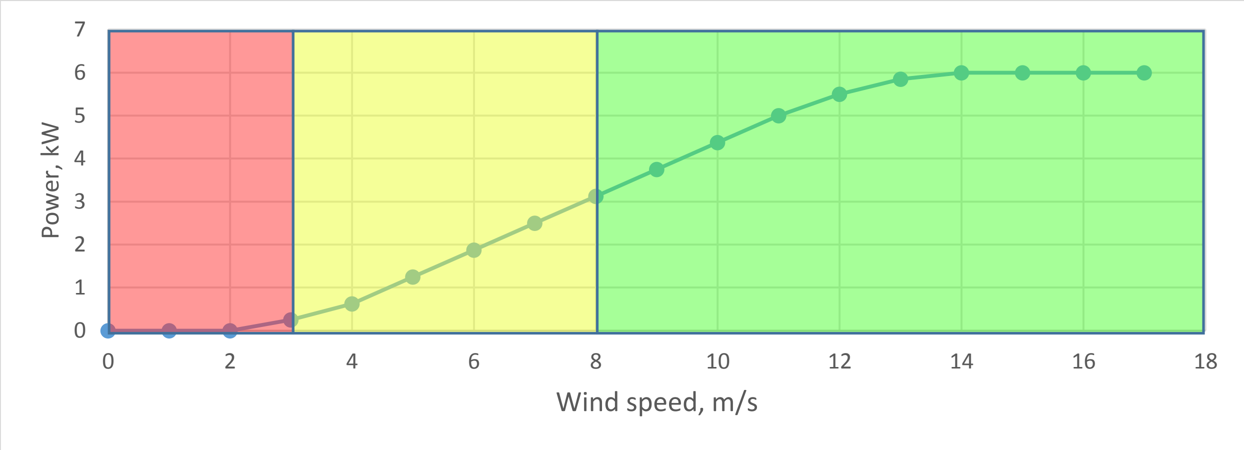


Figure 11. Power curve of a 5 kW wind turbine

To see how often each category of wind speed is present further analysis for each measurement period has been performed. Results are presented in Tables 7 – 10. To get a picture of wind speed distribution for a day of each month, those tables have been combined. First, table for low wind speed probability during different times of a day has been constructed. Same tables were created for moderate and good speeds. Average presence of given wind speed category during the day has been calculated for each month (see tables 11 – 13). From this point total mean wind speed distribution for an average day of each month has been acquired (presented in the figure 12).

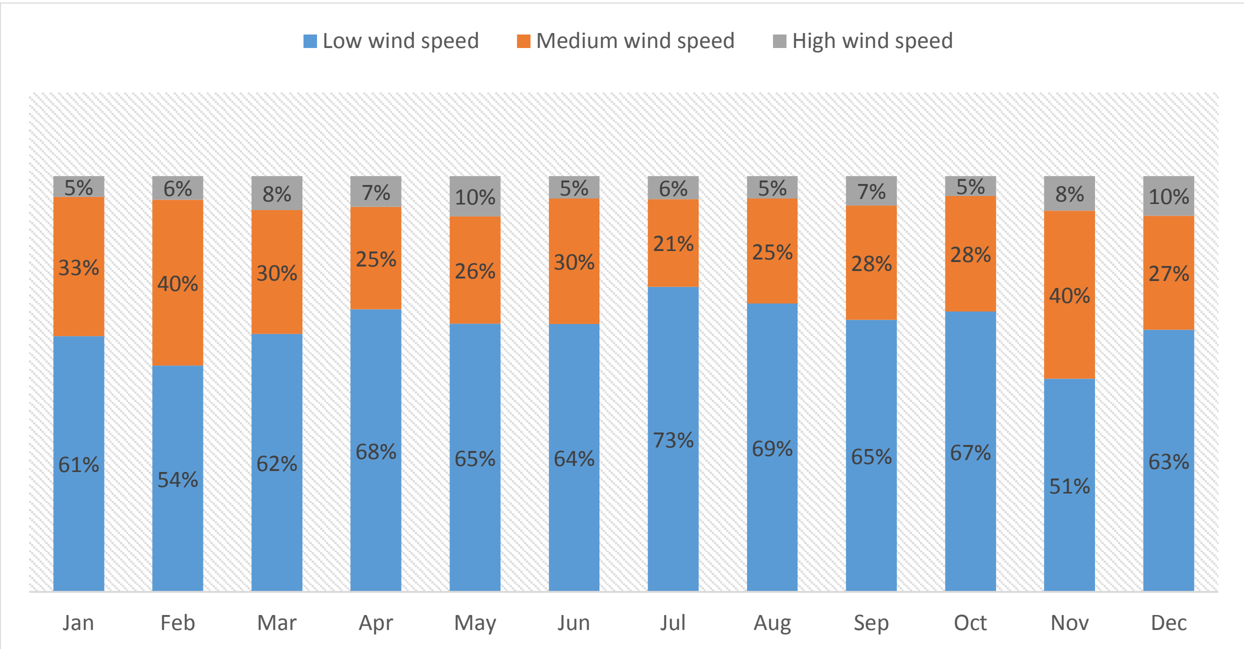


Figure 12. Wind speed distribution for an average day of a month

### 4.2. Wind speed model

To evaluate the impact of wind variance on the technical and economic performance of the project, the excel model has been composed. As a basic principle, hourly comparison of generation and consumption has been implemented. Due to meteorological data has only 4 measurements per day, and such model requires 24, I had to come up with the wind speed data generator, that would keep the probability density distribution from the factual data. To do so, following logic has been used (illustrated in Figure 13): knowing the frequency of each wind speed category for each month, we compare randomly generated number X from 0 to 100 with those percentages. If X's value is lower than probability of low wind speed ($P_{low\ wind\ speed}$) for this month, than wind speed for this hour ($V_w$) is randomized between low speed category limits – 0 and 3 m/s. If the value of X is higher than the latter probability, it (X) is being compared with probabilities of moderate wind speed ($P_{moderate}$) and if it is lower, than accumulated probability of moderate wind speed, $V_w$ is randomized between 4 and 8 m/s, which are the limits for the moderate wind speed category. In case value of X is higher, than $P_{low}$ + $P_{moderate}$, high wind speed is being randomly generated. The upper limit for the high wind speed category has been chosen to be 13 m/s, as probability of wind speeds higher than this is highly unexpected (less than 1% in all months) and at such speed wind turbine is already operating at a saturated part of the characteristic, so the output does not change.

In order to make my research more precise and scientific, I decided to use Monte Carlo method for simulation of project's performance. Monte Carlo method is a problem solving technique used to approximate the probability of certain outcomes by running multiple trial runs, called simulations, using random variables. Problems handled by Monte Carlo methods are of two types called probabilistic or deterministic according to whether or not they are directly concerned with the behavior and outcome of random processes. In the case of a probabilistic problem the simplest Monte Carlo approach is to observe random numbers, chosen in such a way that they directly simulate the physical random processes of the original problem, and to infer the desired solution from the behavior of these random numbers [35]. Task of my diploma thesis has been considered appropriate for Monte-Carlo methods solution, as a crucial part of wind turbine power supply reliability depends on random values of a wind speed.

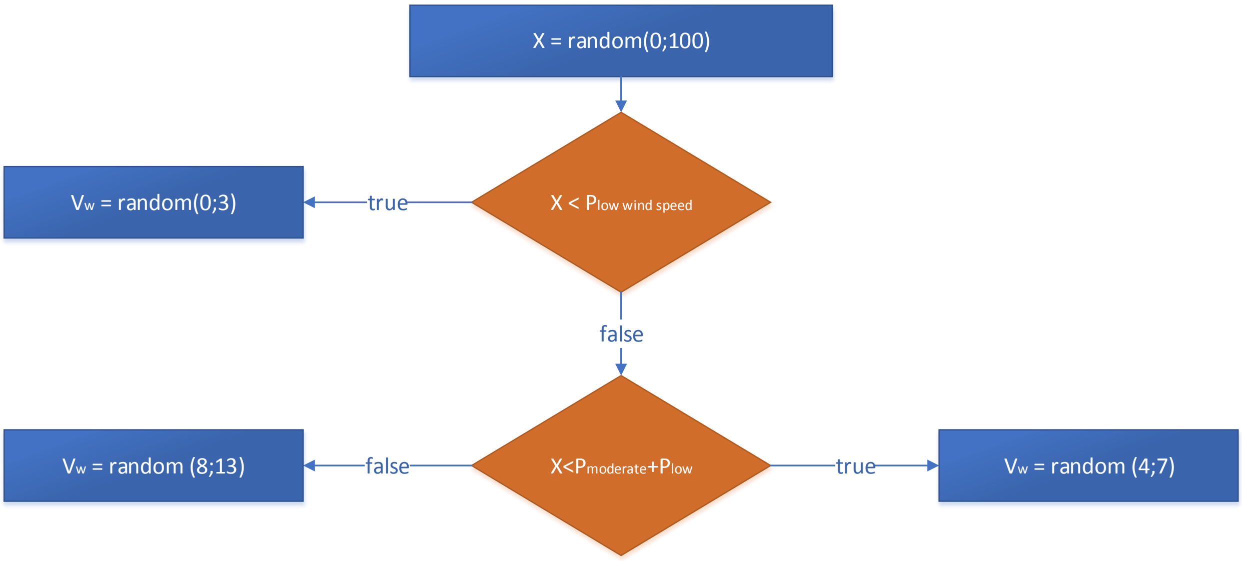



Figure 13. Wind speed generator logic

To check, whether algorithm for wind speeds generation works correctly, 12000 data points of wind speed has been generated using above-mentioned method, 1000 for each month, and then compared to the data from the meteorological station. Both data arrays have been analyzed for Weibull distribution using specialized script [36] in Matlab program, the results are presented in the Figures 14, 15). Weibull distribution is oftenly used to describe wind speed distributions [37] and the general formula is the following:

$$f(V) = \frac{\alpha}{\beta^{\alpha}} V^{\alpha-1} e^{-(\frac{V}{\beta})^{\alpha}} \quad (1)$$

Acquired equations of distributions are presented in the Table 5.

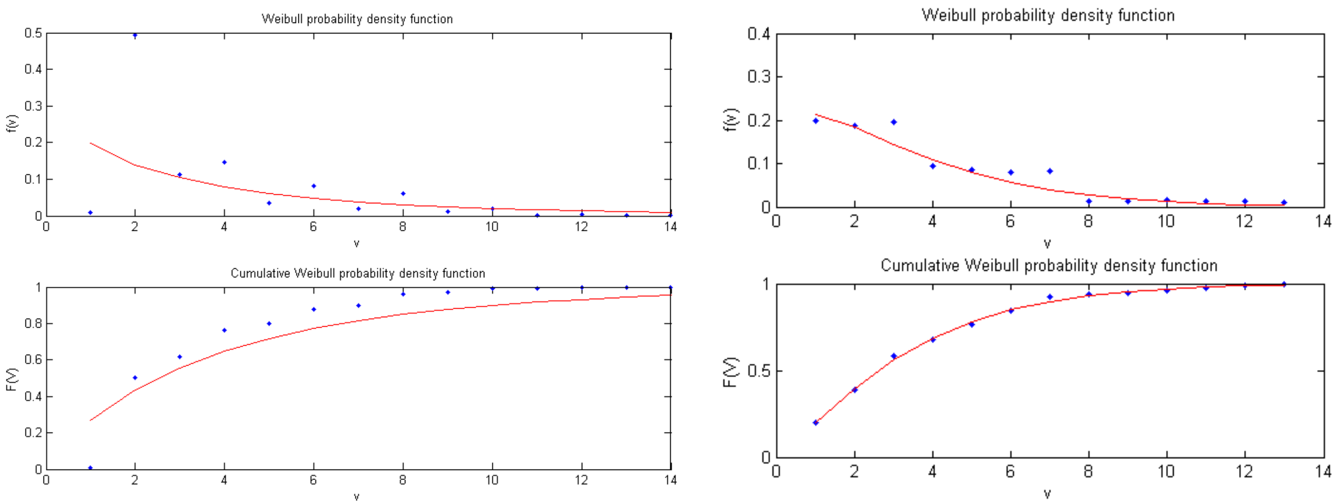



Figure 14. Weibull distribution (generated data – left; factual data – right)

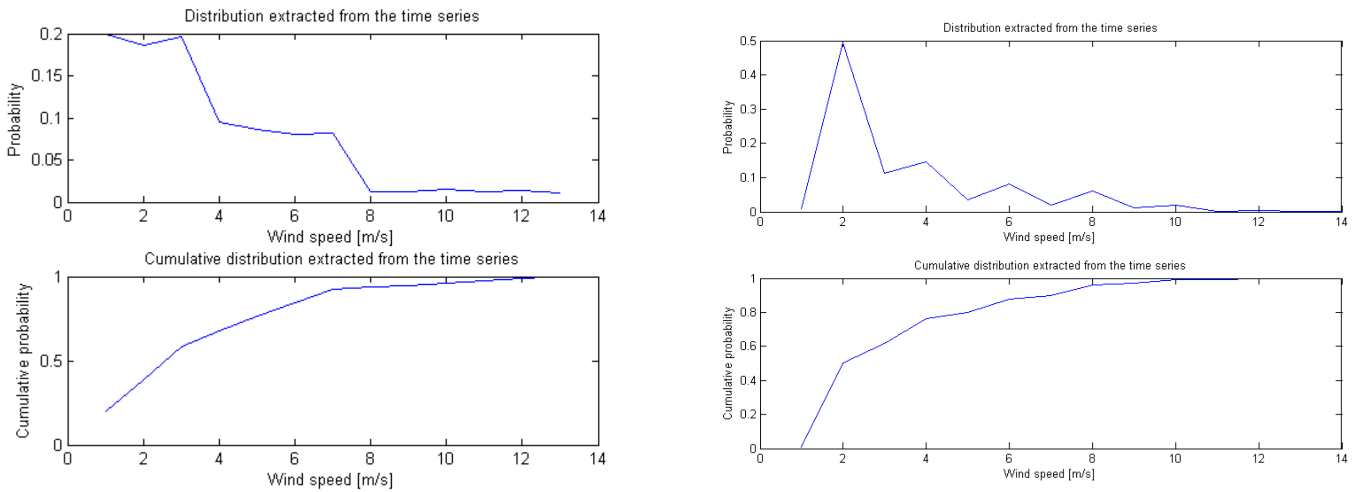



Figure 15. Probability density (generated data – left; factual data – right)

Table 3. Weibull coefficients for two sets of data

| | α | β |
|---|---|---|
| Meteorological | 0,8629 | 3,8153 |
| Generated | 1,1975 | 3,5318 |

It can be seen, that distributions are quite similar which is a sign of a correct logic and result. In order to evaluate correlation between two data arrays, meteorological and generated, Pearson correlation coefficient has been computed for arrays' Weibull distributions. Acquired result of 98,82% indicates, that this data arrays can be considered almost identical and shows us high accuracy and low error level.

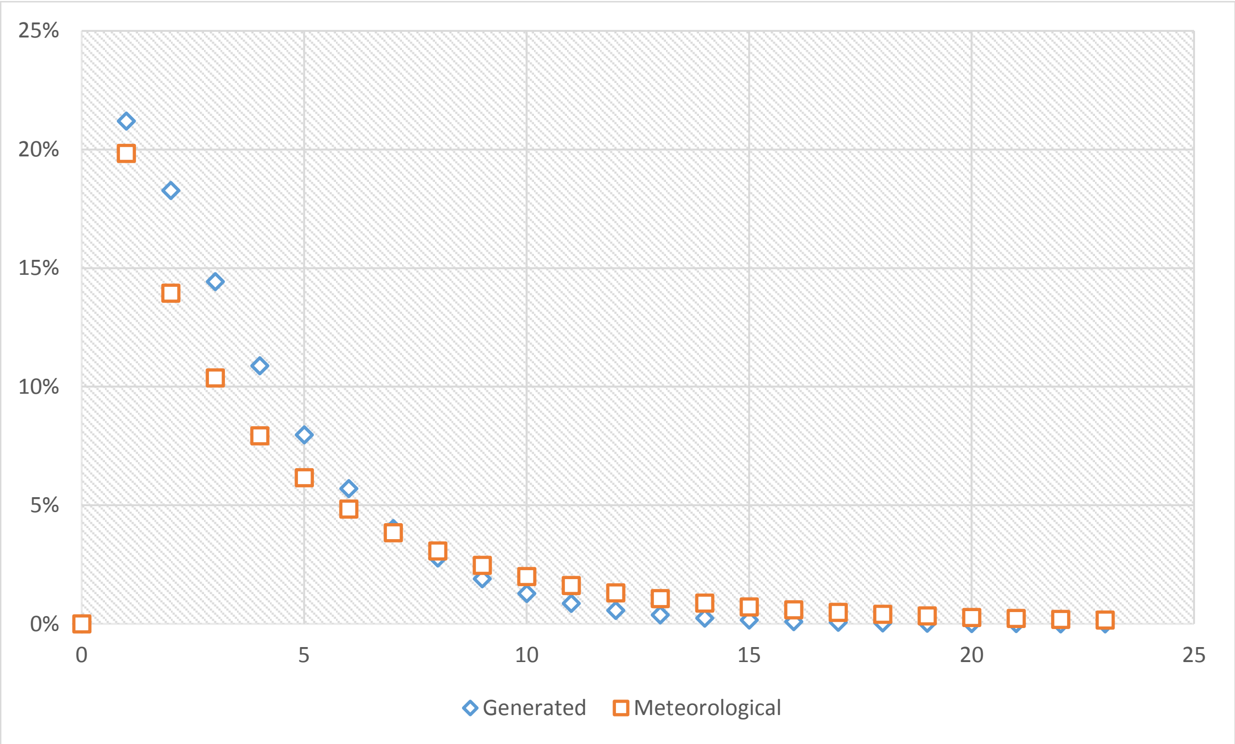



Figure 16. Weibull distributions of data arrays

### 4.3 Simulation

Knowing each day's load, which is fixed, and having pseudo-random wind speeds I was able to simulate the system's operation. How the model works:

- From the wind speed corresponding power output of a turbine is being found for each hour;
- On the balance table sized 12 by 24 (12 month, 24 hours), the power output of the turbine is being subtracted from the consumption of the station;
- For each month cells, containing positive value are being added up and multiplied by the number of days in a month – this sum represents the amount of energy, that should be covered by diesel generator in this month;
- Negative values of the balance table is the energy, that can be stored for further use;
- Energy for diesel generation is being added up into annual sum, which is later used to calculate the amount of diesel generator operation time, total fuel consumption and, therefore, fuel expenses;
- Annual amount of energy for storage can be used to optimize the system's structure and make a decision on how much of accumulation capacity it is needed;
- Total annual power consumption of the station is 10507,52 kWh.

Simulation has been run 10000 times in order to get accurate results. Probability density function for diesel generator variable costs has been acquired (see Figure 17).

Diesel engine's variable cost are the highest production volume dependent costs for the proposed variant and it is largely dependent on the wind conditions of the corresponding year. Diesel engine's VC probability density function has signs of normal distribution and it demonstrates, how much money on the average, company will have to spend with the given wind speed distribution. In the following chapter, it will be used in further analysis of Modular-packed Power Station performance based on annuity principle. Based on mean value of the distribution and its' standard deviation, given distribution can be reproduced in the MS Excel.

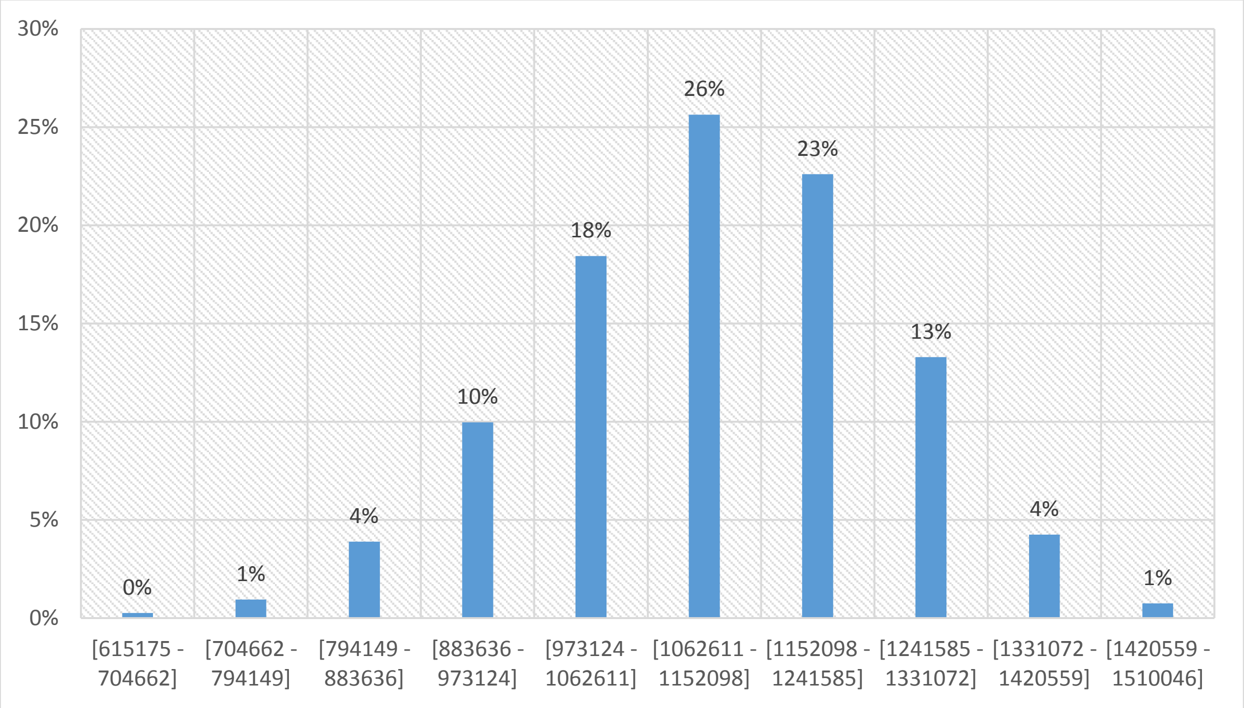



Figure 17. Probability density of diesel generator variable costs in Rubles

Based on the probability density distribution, cumulative probability density for diesel engine's variable costs has been composed (Figure 18). From this curve, using random number generator, the point for each year will be taken, representing corresponding costs.

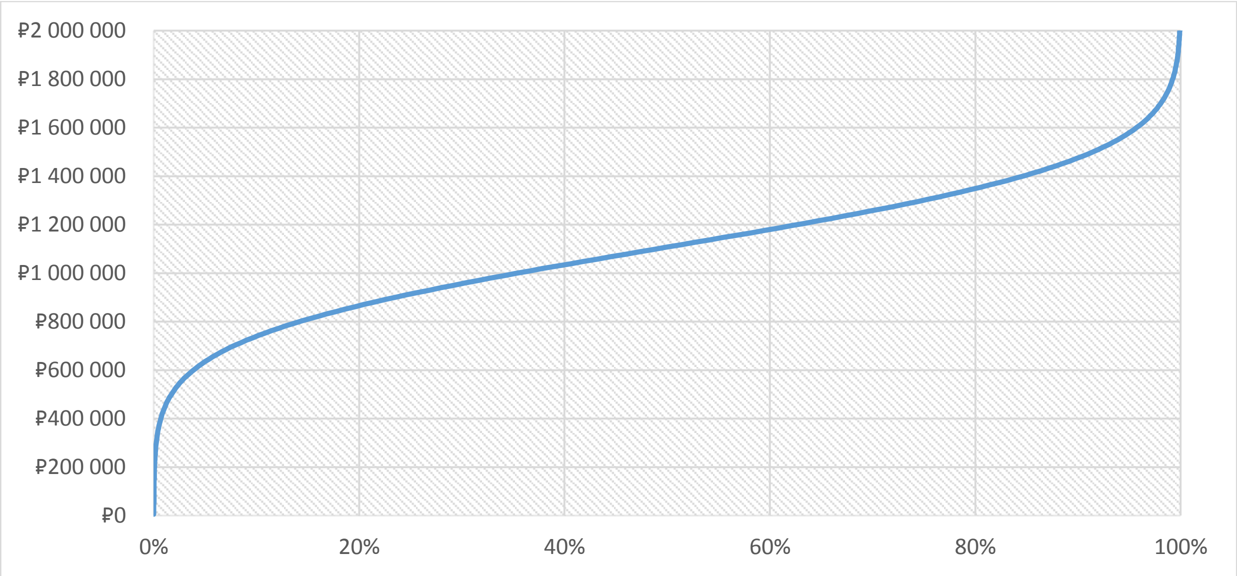



Figure 18. Cumulative probability density for diesel generator's variable costs

# 5. Economic Evaluation

## 5.1. Annuity

For project's economic performance evaluation annual based model has been constructed. The basic idea behind it is to compare the initial variant of power supply (gas burner backed up with diesel generator) and proposed variant (wind turbine backed up with diesel generator) with the basis option of just having diesel powered energy supply. Model includes following external parameters: discount rate, gas price, ruble to US dollar rate and others.

Investments are made in the year 0, when all of the equipment is considered to be bought and set up. As expenses maintenance costs and variable costs (fuel consumption) are used; also, as some of the components have lifetime of 2-5 years, reinvestments are required. Main economic performance indices to evaluate in this model are NPV, IRR and payback period, so the variants could be compared.

- Net Present Value

Because of the time value of money, earnings and expenses of the same money amount made in different time periods don't worth as much, which makes determining the value of a project is challenging because there are different ways to measure the value of future cash flows. Net Present Value represents the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyze the profitability of an investment or project [38]. Formula for NPV calculation is presented below:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0 \text{, where} \qquad (2)$$

$C_t$ – net cash inflow during the period,

$C_0$ – initial investment,

r – discount rate, and

t – number of time periods.

The discount rate in the NPV formula is a way to account for the time value of money. Companies have different ways of identifying the discount rate, although a common method is using the expected return of other investment choices with a similar level of risk. Choosing appropriate discount rate is a major problem and has a big impact on the evaluation results. There are several methods to choose discount rate, which will be discussed later in the paper. According to the indicator logic, NPV value should be positive for a profitable for a profitable project and when choosing between two options by this criteria, the one with higher NPV should be preferred.

- Internal Rate of Return

IRR is the discount rate often used in capital budgeting that makes the net present value of all cash flows from a particular project equal to zero. Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project. As such, IRR can be used to rank several prospective projects a firm is considering. Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first [39].

- Payback Period

Payback period is an economical indicator, which shows how many time periods it takes for the project to cover initial investment [38]. This parameter does not include time value of money and is supplemental to other indices. The lower the payback period, the better.

### 5.2. Investment Costs

As it was stated earlier RES market is only starting in Russia. This fact can explain, why the price level of equipment significantly differ from the world prices. Moreover prices can vary depending on the region where purchase is being made. Transportation to the installation site cost for the equipment can mean significant increase in project overall price, as it will have to be transported using helicopters or using all-purpose vehicle. Investment costs for most of the equipment has been acquired from online catalogues, for the ORMAT 5 kW gas burner unit – it was estimated based on blind data provided by manufacturer at the level of $20000.

Table 4. Investment costs of the equipment [40]

| Position | Investment Cost |
|---|---|
| Wind turbine | 319 000 ₽ |
| Rectifier | 22 500 ₽ |
| Inverter | 22 500 ₽ |
| Accumulator | 9 500 ₽ |
| Accumulator controller | 7 000 ₽ |
| Diesel generator | 250 000 ₽ |
| ORMAT Gas Burner | 20 000 $ |

### 5.3. Economic Model Parameters

- Lifetime

Lifetime for the project has been decided to be 20 years, as the generating equipment, both gas burner’s and wind turbine’s useful lifespan is about 20 years. Lifetime of the equipment has been acquired from an online database [41].

Table 7. Lifespan of the equipment

| Position | Lifespan, years |
|---|---|
| Wind turbine | 20 |
| Rectifier | 5 |
| Inverter | 2 |
| Accumulator | 4 |
| Accumulator controller | 2 |
| Diesel generator | 20 |
| ORMAT Gas Burner | 20 |

- Maintenance costs

As the maintenance costs are one of the biggest expenses of the project, it is important to estimate corresponding O&M costs correctly. These costs are represented in the Table 8 and were decided based on my intuition and electrical equipment performance reports.

Table 8. Annual maintenance costs

| Position | Maintenance cost, % of investment |
|---|---|
| Wind turbine | 5% |
| Rectifier | 3% |
| Inverter | 3% |
| Accumulator | 5% |
| Accumulator controller | 3% |
| Diesel generator | 7% |
| ORMAT Gas Burner | 5% |

- Discount rate

For any commercial project appropriate discount rate should be chosen. Discount rate basically represents riskiness of the investment and indicates requirement level of returns. There are several approaches to determine the discount rate, but in the present work, it will be evaluated using Weighted Average Cost of Capital (WACC) method.

A calculation of a firm's cost of capital in which each category of capital is proportionately weighted. All capital sources - common stock, preferred stock, bonds and any other long-term debt - are included in a WACC calculation. All else equal, the WACC of a firm increases as the beta and rate of return on equity increases, as an increase in WACC notes a decrease in valuation and a higher risk. Broadly speaking, a company's assets are financed by either debt or equity. WACC is the average of the costs of these sources of financing, each of which is weighted by its respective use in the given situation. By taking a weighted average, we can see how much interest the company has to pay for every dollar it finances [42].

A firm's WACC is the overall required return on the firm as a whole and, as such, it is often used internally by company directors to determine the economic feasibility of expansionary opportunities and mergers. It is the appropriate discount rate to use for cash flows with risk that is similar to that of the overall firm [43].

$$WACC = \frac{E}{D+E} r_e + (1-t)\frac{D}{D+E} r_b$$

$E$ – equity;

$D$ – debt;

$r_e$ – cost of equity;

$t$ – tax rate;

$r_b$ – cost of debt.

Cost of equity for current project will be determined using CAPM model. Capital Asset Pricing Model suggests that an investor’s cost of equity capital is determined by beta, a measure of systematic risk based on how returns co-move with the overall market, as well as by the risk free investment rate and country-specific risk premium.

$$r_e = r_f + \left(r_m - r_f\right) \cdot \beta = r_f + ERP \cdot \beta$$

$r_f$ – risk free investment discount rate;

$r_m$ – expected market return;

$\beta$ – measure of risk for a given company;

ERP – country-specific total equity risk premium [44].

CAPM is a widely used model to determine expected return for an investment The capital asset pricing model was the work of financial economist (and, later, Nobel laureate in economics) William Sharpe, set out in his 1970 book "Portfolio Theory And Capital Markets." His model starts with the idea that individual investment contains two types of risk: systematic (risks that cannot be diversified away, p.e. market specific risks) and unsystematic risk (risk is specific to individual stocks, which can be diversified away) [45].

- Risk free investment rate for Russia should be considered to be Russian bonds, which currently have interest rate of 11% [46].
- Total equity risk premium for Russia is 8,90% [47].
- Beta coefficient against Moscow Interbank Currency Exchange for GAZPROM is 1,03 [48]; against NASDAQ – 1,87 [49]. These numbers show the limits for beta variation for the company, which can be used in cost of equity and thus discount rate sensitivity analysis. As the project is implemented inside the country, discount rate against Russian market usage should be more appropriate.

This way, cost of equity can be estimated at the level of 20 – 22%.

Tax rate – 16,3% to 19,3% [50]. For initial calculations, tax rate for year 2014 (18,3%) has been used.

Cost of borrowing money for GAZPROM should be close to Russia's Central Bank's prime rate, which is 14% and it is being gradually decreased over time. Such a high prime rate is set due to regulatory politics against currency exchange speculations and recently started crisis. Average interest rate for Russia for years 2003 – 2015 was 6,75%. Cost of debt for current project's evaluation can be set for 10 to 14 percent, depending on economic situation [51].

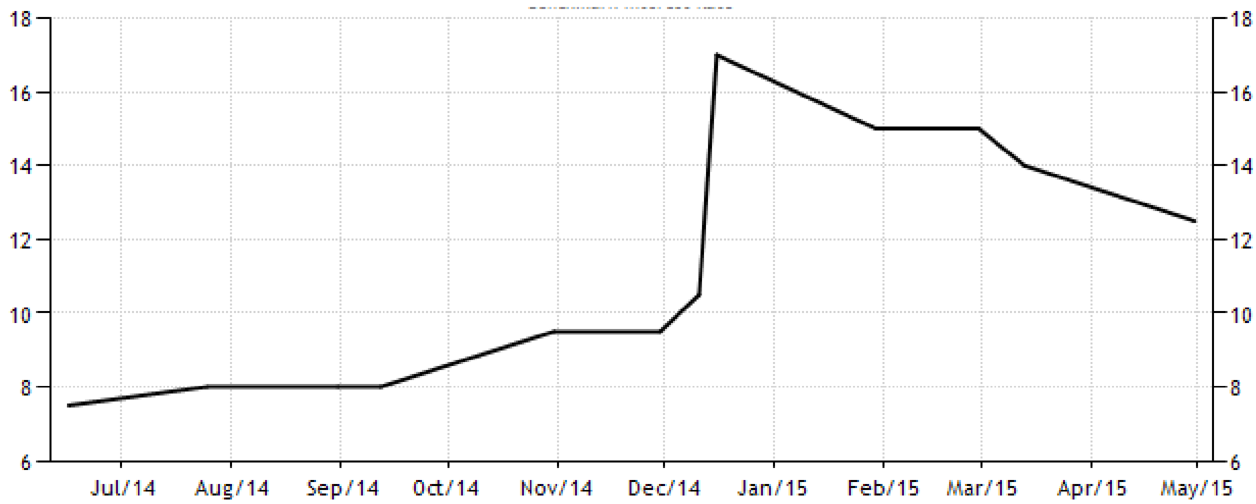



Figure 18. Russia's interest rate over time [51]

Debt and equity portions in the finance composition is a subject for a sensitivity analysis, but for the initial calculations it can be set at 50-50 level.

- Ruble to USD exchange rate

Value of this ratio is crucial for initial investment values, as big part of the equipment is imported and paid in dollars.

- Arctic modification of turbines

According to wind turbines exploitation reports [52, 53], using wind energy in cold areas could be troublesome, what for an investment project means more expenses and costs. In severe weather conditions of Russian Far East, icing of wind turbine's blades and rotor, moisturization of electrical components of the equipment and increased vibrations due to wind gusts and turbine imbalances are the engineering problems that should be solved by personnel.

To solve above mentioned difficulties, blades of the turbine should be painted with special black anti-moisture coat, special frost-resistant lubrication should be used and electrical components should be hermetically sealed. Moreover, either external heating or special pneumatic systems should be used for de-icing process. All of these measures are quite expensive and should be distributed both in investment and running costs, significantly increasing the expenses of the project [53].

In the present model, investment costs increase for an arctic modification has been evaluated at the level of 150%. This coefficient can be increased or decreased depending on the requirements of the buyer and the possibilities of the contractor. The better initial de-icing is implemented (higher water-resistance materials, etc.), the more rare will be icing situations, therefore, running costs should be divided by this coefficient. Running costs increase due to possible icing depends on frequency of icing conditions. For Khabarovsk region average number of days with icing conditions is 9, observed maximum is 14 [54]. Considering that single de-icing procedure requires 5kWh of energy, which can only be supplied by back-up source, diesel engine in proposed scheme case, running costs of wind turbine de-icing can be estimated at approximately 5 liters of diesel fuel per one procedure.

- Fuel prices

As in both variants of consumer's power supply there are pieces of equipment that consume fuel, project is quite sensitive to the changes in fuel prices. Following types of fuel will be researched: diesel fuel, natural gas and liquefied petroleum gas. As the location of power station is remote, the price of diesel fuel can be up to two times higher than in the city of Khabarovsk due to high transportation costs. Diesel fuel has been estimated to cost 65 ₽ per liter. At the same time, gas used at the station can cost lower price for the company, than for the end customer. Prime cost of gas for GAZPROM in 2013 was 1381 ₽ per 1000 $m^3$ ($0,021) [55]. Base retail price for gas transported to China, according to the contract, is $360 per 1000 $m^3$ ($0,36) [56].

- Depreciation

Linear depreciation method has been used. Accounting useful lifespan of the equipment has been determined based on Russian Law Codex article #258 'On Classification of Fixed Assets Included into Depreciation Groups' [57].

Table 9. Accounting depreciation terms of the equipment

| Position | Lifespan, years |
|---|---|
| Wind turbine | 9 |
| Rectifier | 2 |
| Inverter | 2 |
| Accumulator | 5 |
| Accumulator controller | 5 |
| Diesel generator | 8 |
| ORMAT Gas Burner | 5 |

### 5.4. Model Solution

In the present two investment projects are being simulated. The first one is the proposed scheme (wind turbines plus diesel generator), the second one is currently implemented solution (gas burner). In the proposed scheme variant, the main costs for the project are the diesel fuel expenses, which depend on the amount of harnessed wind energy, when in the second variant the main expenses are gas spenditures. In both variants, diesel fuel economy (compared to reference option of diesel generator being the only source) has been used as a benefit, which turns NPV positive. Such expenses as maintenance differ between variants by two positions (wind turbine and ORMAT gas burner) depending on equipment configuration. To get more precise results in case of wind generation scheme, NPV of the project is being solved for 10000 lifetimes (20 years each) and the solutions' average value is being taken. Spreadsheet example can be seen in the Annex Figure 1.

## 6. Results and sensitivity analysis

### 6.1. Initial calculation

The initial parameters for the simulation were the following:

| | |
|---|---|
| Equity to total funds portion | 50% |
| Discount rate | 15,8% |
| Diesel fuel price | ₽ 34 |
| Annual gas price rise rate | 1% |
| LPG price | $ 0,3 |
| USD to RUB | ₽ 50 |
| Wind turbine arctic modification | 150% |
| Annual wind turbine decrease in output | 1% |

Results of the calculations with these parameters for both projects are presented in the Table 10.

Table 10. Initial calculation results

| | NPV, ₽ | IRR | Payback Period, years |
|---|---|---|---|
| Wind Turbine + Diesel Generator | 1 783 261 | 36% | 3,25 |
| Gas Burner | 2 700 333 | 29% | 3,33 |

As it can be seen from results, both variants show positive NPV, meaning they both are attractive for investors. Existing variant promises 50% better NPV value, which means, that from economic point of view, usage of gas turbines in such conditions is more profitable. Payback period is almost identical for both variants, but internal rate of return is better for a proposed scheme.

The fact that proposed scheme from financial point of view is less profitable, it does not exactly mean, that it should not be applied. First of all, the usage of wind turbines is feasible from technical standpoint and is profitable from money side. Usage of renewable energy by a large natural resource-mining company can be used as a publicity stunt, as well as a contribution in meeting environmental energetic targets 2030. Also, if some regulation regarding renewables in Russian Federation will change, allowing government support of small-scale projects, the project may become more attractive. Reduction in diesel fuel consumption from 53 thousands of liters on the average annualy to 32 thousand liters has been reached – a 40% economy

For sensitivity analysis randomization of wind generation had to be switched off and model had to be frozen at the most probable state, so the influence of input parameters would be more obvious and it would not be lost while average of 10 thousand calculations is being taken. “Frozen” NPV of a proposed scheme with initial parameters is 1 717 485 ₽.

### 6.2. Portion of invested equity and cost of debt against discount rate

Table 11. Investment portion of equity and cost of debt influence on NPV

| W&G | | Equity to total funds | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0% | 20% | 40% | 60% | 80% | 100% |
| Cost of debt ($r_d$) | 8% | 6,5% | 9,3% | 12,0% | 14,7% | 17,4% | 20,2% |
| | 9% | 7,4% | 9,9% | 12,5% | 15,0% | 17,6% | 20,2% |
| | 10% | 8,2% | 10,6% | 13,0% | 15,4% | 17,8% | 20,2% |
| | 11% | 9,0% | 11,2% | 13,5% | 15,7% | 17,9% | 20,2% |
| | 12% | 9,8% | 11,9% | 13,9% | 16,0% | 18,1% | 20,2% |
| | 13% | 10,6% | 12,5% | 14,4% | 16,3% | 18,3% | 20,2% |

In the table 11 possible discount rates for the project depending on market environment and companies decision are presented. It can be seen that the discount rate varies for more than two times, and it is extremely important to consider external environment, when undertaking project, and evaluate it correctly.

### 6.3. Portion of invested equity and cost of debt against project’s NPV

Table 12. Investment portion of equity and cost of debt influence on NPV of a proposed (wind) scheme

| W | | Equity to total funds | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0% | 20% | 40% | 60% | 80% | 100% |
| Cost of debt ($r_d$) | 8% | 3 527 965 | 2 810 468 | 2 271 125 | 1 856 492 | 1 531 077 | 1 270 823 |
| | 9% | 3 290 065 | 2 667 316 | 2 188 594 | 1 813 337 | 1 513 838 | 1 270 823 |
| | 10% | 3 072 718 | 2 533 434 | 2 109 811 | 1 771 403 | 1 496 826 | 1 270 823 |
| | 11% | 2 873 716 | 2 408 058 | 2 034 555 | 1 730 644 | 1 480 039 | 1 270 823 |
| | 12% | 2 691 123 | 2 290 498 | 1 962 620 | 1 691 016 | 1 463 470 | 1 270 823 |
| | 13% | 2 523 236 | 2 180 128 | 1 893 815 | 1 652 477 | 1 447 118 | 1 270 823 |

Table 13. Investment portion of equity and cost of debt influence on NPV of an existing (gas burner) scheme

| G | | E/(E+D) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0% | 20% | 40% | 60% | 80% | 100% |
| Cost of debt ($r_d$) | 8% | 5 138 241 | 4 014 652 | 3 179 554 | 2 544 313 | 2 050 616 | 1 659 295 |
| | 9% | 4 764 270 | 3 792 126 | 3 052 605 | 2 478 580 | 2 024 593 | 1 659 295 |
| | 10% | 4 423 807 | 3 584 563 | 2 931 649 | 2 414 781 | 1 998 928 | 1 659 295 |
| | 11% | 4 113 158 | 3 390 698 | 2 816 322 | 2 352 841 | 1 973 614 | 1 659 295 |
| | 12% | 3 829 092 | 3 209 387 | 2 706 285 | 2 292 687 | 1 948 644 | 1 659 295 |
| | 13% | 3 568 776 | 3 039 597 | 2 601 224 | 2 234 253 | 1 924 013 | 1 659 295 |

It can be seen from tables 12 and 13 that both investment options are feasible and profitable in case of any discount rate, which basically means, that project can be undertaken in the current changing Russian economical environment.

### 6.4. Fuel prices against project's NPV

As is was expected, NPV of a wind scheme does not depend on gas prices, what indicates correct model logic. It can be observed from the table 14, that at some point of diesel fuel price project becomes unprofitable, as usage of diesel generator becomes more profitable. Nevertheless, such situation is unlikely as diesel fuel prices tend to rise from year to year [Annex Figure 2], moreover, as it was stated earlier in the text, price of diesel used in such remote area as Troickoe can be much higher than average countries' of region's price.

Table 14. Fuel prices influence on NPV of a proposed (wind) scheme

| W | | Gas price, $ | | | | |
|---|---|---|---|---|---|---|
| | | 0,3 | 0,35 | 0,4 | 0,45 | 0,5 |
| Diesel price, ₽ | 10 | -421 674 | -421 674 | -421 674 | -421 674 | -421 674 |
| | 20 | 469 642 | 469 642 | 469 642 | 469 642 | 469 642 |
| | 30 | 1 360 959 | 1 360 959 | 1 360 959 | 1 360 959 | 1 360 959 |
| | 40 | 2 252 275 | 2 252 275 | 2 252 275 | 2 252 275 | 2 252 275 |
| | 50 | 3 143 591 | 3 143 591 | 3 143 591 | 3 143 591 | 3 143 591 |
| | 60 | 4 034 907 | 4 034 907 | 4 034 907 | 4 034 907 | 4 034 907 |

Table 15. Fuel prices influence on NPV of an existing (gas burner) scheme

| G | | Gas price, $ | | | | |
|---|---|---|---|---|---|---|
| | | 0,3 | 0,35 | 0,4 | 0,45 | 0,5 |
| Diesel price, ₽ | 10 | -4 857 140 | -5 862 073 | -6 867 006 | -7 871 939 | -8 876 872 |
| | 20 | -1 861 307 | -2 866 240 | -3 871 173 | -4 876 106 | -5 881 039 |
| | 30 | 1 134 526 | 129 593 | -875 340 | -1 880 273 | -2 885 206 |
| | 40 | 4 130 359 | 3 125 426 | 2 120 493 | 1 115 560 | 110 627 |
| | 50 | 7 126 193 | 6 121 260 | 5 116 327 | 4 111 394 | 3 106 461 |
| | 60 | 10 122 026 | 9 117 093 | 8 112 160 | 7 107 227 | 6 102 294 |

At the same time, gas burner variant's NPV depends both on LPG prices and on diesel fuel price level. The latter fact is due to counting unused diesel fuel as the benefit of the project, and the lower its price, the lower is the NPV value. Dependence on LPG price level is obvious: the lower the cost of main fuel for power generation, the better is profitability of the project.

### 6.5. Diesel fuel price and initial investment cost against NPV of a wind turbine scheme

Table 16. Diesel fuel price and investment cost change influence on NPV of a proposed (wind) scheme

| W | | Increase in initial investment | | | | |
|---|---|---|---|---|---|---|
| | | 20% | 25% | 30% | 35% | 40% |
| Diesel price, ₽ | 10 | -684 272 | -749 921 | -815 571 | -881 220 | -946 870 |
| | 20 | 207 044 | 141 395 | 75 745 | 10 096 | -55 554 |
| | 30 | 1 098 361 | 1 032 711 | 967 062 | 901 412 | 835 763 |
| | 40 | 1 989 677 | 1 924 027 | 1 858 378 | 1 792 728 | 1 727 079 |
| | 50 | 2 880 993 | 2 815 343 | 2 749 694 | 2 684 044 | 2 618 395 |
| | 60 | 3 772 309 | 3 706 659 | 3 641 010 | 3 575 361 | 3 509 711 |

From the table 16 it can be seen that the proposed renewable energy variant is able to remain profitable even in case of more than 40% initial investment (equipment price level) increase. This is a quite big opportunity window, which indicates adaptability of the variant to the external environment changes. Critical diesel price is 15 ₽ per liter (50% drop from the current price) – at this value NPV value crosses the 0 and using just diesel generators becomes more attractive.

### 6.6. Exchange rate and gas prices against NPV of gas burner variant

In the present model exchange rate affects only gas burner variant performance, due to following reasons: firstly, the ORMAT gas burner itself is an imported equipment, which is being bought in dollar amount; secondly, gas trading with China is an international business, meaning the payments are being made in US dollars. Wind turbine and the corresponding equipment is considered to be produced and purchased inside the country.

Table 17. Exchange rate and gas prices influence on NPV of existing (gas burner) scheme

| G | | Exchange rate, ₽/USD | | | | |
|---|---|---|---|---|---|---|
| | | 30 | 40 | 50 | 60 | 70 |
| Gas price, $ | 0,2 | 6 422 518 | 5 382 622 | 4 342 726 | 3 302 829 | 2 262 933 |
| | 0,3 | 5 216 599 | 3 774 729 | 2 332 860 | 890 990 | -550 880 |
| | 0,4 | 4 010 679 | 2 166 836 | 322 993 | -1 520 849 | -3 364 692 |
| | 0,5 | 2 804 760 | 558 943 | -1 686 873 | -3 932 689 | -6 178 505 |
| | 0,6 | 1 598 840 | -1 048 949 | -3 696 739 | -6 344 528 | -8 992 317 |
| | 0,7 | 392 920 | -2 656 842 | -5 706 605 | -8 756 367 | -11 806 130 |

This sensitivity table show, that gas price and exchange rate fluctuations can lead to a negative NPV. This notion means, that in case of deep economical crisis in Russia, which usually leads to a rise of the exchange rate or in case of higher cost of gas consumption for the GAZPROM, the future usage of a gas burner is not financially attractive. Using MS Excel's solver, model equations have been enumerated to find critical values for the gas burner project:

- The exchange rate of 66 ₽/USD is the number, which turns NPV to zero in case of 0,3 USD per liter of LPG.
- With the current exchange rate of 50 ₽/USD, own price of gas of 0,42 USD/liter (15% rise) is required to make the project unprofitable.

### 6.7. Exchange rate and initial investment cost against NPV of a gas burner scheme

Table 18. Exchange rate and investment cost change influence on NPV of a proposed scheme

| G | | Exchange rate, ₽/USD | | | | |
|---|---|---|---|---|---|---|
| | | 30 | 40 | 50 | 60 | 70 |
| Investment cost increase | 40% | 4 933 459 | 3 397 209 | 1 860 960 | 324 710 | -1 211 540 |
| | 45% | 4 898 066 | 3 350 019 | 1 801 972 | 253 925 | -1 294 122 |
| | 50% | 4 862 674 | 3 302 829 | 1 742 985 | 183 140 | -1 376 705 |
| | 55% | 4 827 281 | 3 255 639 | 1 683 997 | 112 355 | -1 459 287 |
| | 60% | 4 791 889 | 3 208 449 | 1 625 010 | 41 570 | -1 541 870 |
| | 65% | 4 756 496 | 3 161 259 | 1 566 022 | -29 215 | -1 624 452 |

As it can be seen from table 18, the ORMAT gas burner variant is more flexible in terms of equipment price than a wind turbine one. This option remains profitable even in case of 65% of investment costs increase. Although the critical investment value vastly depends on the exchange rate.

## Conclusion

In the present Diploma Thesis problem of supplying along the line long-distance gas pipeline’s measurement and control stations with electrical power has been researched. Two possible power supply schemes have been investigated: the solution based on burning gas that is being transported through the pipeline, or proposed wind turbine based renewable energy variant, backed-up with diesel generator. These options have been compared to the default variant based only on diesel generators. Firstly, Russian renewable energy market and support schemes for renewables have been overviewed. In order to evaluate attractiveness of investing in alternative energy, available renewable resources of the region have been investigated, and, as a result, decision to rely on wind has been made. Region wind potential has been a very important part of the work, based on which the further technical and economical comparison has been made. To take into account variation in wind speed variation, Monte Carlo method of problem solving has been used – randomized simulation has been sampled ten thousand times, letting acquire result that is more precise. For economical evaluation of the variants, investment and running costs have been estimated. Discount rate has been decided to be evaluated using Weighted Average Cost of Capital method; to apply this method, Capital Asset Pricing Model had to be used in order to enumerate riskiness of the market, GAZPROM company and find the cost of debt. Attractiveness of the investment projects has been compared by Net Present Value, Internal Rate of Return and Payback Period criteria.

Result of the simulation indicated that with the current external market parameters (listed in the chapter 6.1) both projects are applicable from the economic point of view. Both of them show significant amount of profit compared to diesel generator based power supply scheme (listed in the Table 10). In spite of having over 30% difference in options’ NPV value, this can not be used as the only decision making factor. Renewable energy provides quite non-monetary benefits, which can be used by GAZPROM: it reduces $CO_2$ emissions to the atmosphere, reduces pollution, creates possibility for the state-controlled company to take part in meeting renewable energy production target. Moreover, as it was stated in the text, the fact of application of renewables can be used as a publicity stunt. Decision on which scheme to choose vastly depends on external conditions, such as Russian economy state (USD to RUB exchange rate, risk free investment rate, bank interest) or equipment price level. Sensitivity analysis has been conducted, and critical values for the most important parameters and possibilities window have been found.

From the sensitivity analysis tables it can be seen, that depending on the external environment, discount rate for the project varies for more than two times, but even with the highest investigated discount rate both projects still show positive NPV value. Gas burner variant is more sensitive to the fuel price fluctuation in relative values – 15% price change upwards for gas is critical against 50% price decrease for diesel for wind. From the increase in investment costs point of view, renewable option is more fragile – it can survive just 40% cost increase compared to gas burner's over 70%.

As a result of the work, compared options show parity, in other words, benefits from these two options are almost equal, but there is a very important factor for investors' consideration – reliability of power supply. Disruption of power supply at a gas pipeline may lead to unavailability of the control equipment for the dispatch. This in case of emergency may cause disruption of gas transition process and significant economic damage. Due to this factor, GAZPROM company will probably prefer using gas burners as they seem to be more reliable than wind generation, because of easy availability of primary fuel (gas) and have more predictable performance.

# Annex

Annex Table 1. List of Modular-packed Power Station's Electrical Loads

| № | Name | Current (A) | Voltage (V) | Power (kW) |
|---|---|---|---|---|
| **Linear consumers** | | | | |
| **Name and the number of the station** | | | | |
| 1 | **Automated Diesel Power Station Section** | | | |
| | Lightning | **0,91** | **230** | **0,21** |
| | External Ligtning | **0,3** | **230** | **0,07** |
| | Heating | **2,17** | **230** | **0,5** |
| | Engine warming | **2,17** | **230** | **0,5** |
| | Accumulator charger | **0,3** | **230** | **0,07** |
| | Fire alarm | **0,65** | **230** | **0,15** |
| 2 | **Connection and Telemetry Section** | | | |
| | Lightning | **0,91** | **230** | **0,21** |
| | External Ligtning | **0,3** | **230** | **0,07** |
| | Heating | **4,34** | **230** | **1** |
| | UKV | **0,5** | **220** | **0,12** |
| | Cisco Router | **0,9** | **220** | **0,2** |
| | Cisco Commutator | **0,12** | **220** | **0,2** |
| | Video Surveilance System | **0,68** | **220** | **0,4** |
| | Relay Protection | **5,2** | **48** | **0,25** |
| | Multiplexor | **2,08** | **48** | **0,1** |
| | Telemetry Unit | **1,3** | **230** | **0,3** |
| 3 | **Modular-packed Power System Section** | | | |
| | Lightning | **0,6** | **230** | **0,14** |
| | External Lightning | **0,3** | **230** | **0,07** |
| | Invertor | **0,89** | **230** | **205** |
| | Accumulation charge current | **21** | **56** | **1176** |
| | ORMAT Gas Burner Switchgear | **50** | **56** | **2,8** |
| | Low Voltage Switchgear | **7** | **230** | **1624** |

Annex Table 2. Electrical load of consumer station (typical day of the month)

| T | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 1 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 2 | 2240 | 2160 | 2080 | 2000 | 1920 | 1920 | 1920 | 1920 | 2000 | 2080 | 2160 | 2240 |
| 3 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 4 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 5 | 2240 | 2160 | 2080 | 2000 | 1920 | 1920 | 1920 | 1920 | 2000 | 2080 | 2160 | 2240 |
| 6 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 7 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 8 | 2240 | 2160 | 2080 | 2000 | 1920 | 1920 | 1920 | 1920 | 2000 | 2080 | 2160 | 2240 |
| 9 | 640 | 560 | 480 | 400 | 320 | 320 | 320 | 320 | 400 | 480 | 560 | 640 |
| 10 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 11 | 2880 | 2800 | 2720 | 2640 | 2560 | 2560 | 2560 | 2560 | 2640 | 2720 | 2800 | 2880 |
| 12 | 640 | 560 | 480 | 400 | 320 | 320 | 320 | 320 | 400 | 480 | 560 | 640 |
| 13 | 1920 | 1840 | 1760 | 1680 | 1600 | 1600 | 1600 | 1600 | 1680 | 1760 | 1840 | 1920 |
| 14 | 640 | 560 | 480 | 400 | 320 | 320 | 320 | 320 | 400 | 480 | 560 | 640 |
| 15 | 640 | 560 | 480 | 400 | 320 | 320 | 320 | 320 | 400 | 480 | 560 | 640 |
| 16 | 1920 | 1840 | 1760 | 1680 | 1600 | 1600 | 1600 | 1600 | 1680 | 1760 | 1840 | 1920 |
| 17 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 18 | 3200 | 3120 | 3040 | 2960 | 2880 | 2880 | 2880 | 2880 | 2960 | 3040 | 3120 | 3200 |
| 19 | 1280 | 1200 | 1120 | 1040 | 960 | 960 | 960 | 960 | 1040 | 1120 | 1200 | 1280 |
| 20 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 21 | 2240 | 2160 | 2080 | 2000 | 1920 | 1920 | 1920 | 1920 | 2000 | 2080 | 2160 | 2240 |
| 22 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |
| 23 | 960 | 880 | 800 | 720 | 640 | 640 | 640 | 640 | 720 | 800 | 880 | 960 |

Annex Table 3. T=0 hrs, Wind speed probability density by month

| Wind speed, m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 35% | 34% | 19% | 16% | 14% | 12% | 16% | 20% | 11% | 14% | 18% | 25% |
| 1 | 3% | 4% | 4% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 2% |
| 2 | 30% | 28% | 35% | 42% | 41% | 46% | 48% | 47% | 51% | 46% | 35% | 30% |
| 3 | 6% | 6% | 9% | 12% | 13% | 11% | 13% | 7% | 12% | 8% | 6% | 8% |
| 4 | 7% | 13% | 13% | 11% | 8% | 15% | 13% | 14% | 12% | 17% | 16% | 13% |
| 5 | 4% | 2% | 1% | 3% | 4% | 4% | 1% | 1% | 4% | 2% | 4% | 2% |
| 6 | 9% | 5% | 8% | 7% | 8% | 5% | 3% | 8% | 2% | 5% | 9% | 8% |
| 7 | 1% | 1% | 2% | 1% | 2% | 1% | 0% | 0% | 1% | 1% | 1% | 3% |
| 8 | 3% | 5% | 4% | 4% | 7% | 5% | 3% | 1% | 6% | 4% | 7% | 4% |
| 9 | 0% | 1% | 1% | 1% | 1% | 2% | 1% | 1% | 0% | 0% | 2% | 0% |
| 10 | 2% | 1% | 2% | 2% | 1% | 1% | 2% | 1% | 1% | 2% | 1% | 3% |
| 11 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% |
| 12 | 0% | 0% | 1% | 1% | 1% | 0% | 0% | 0% | 1% | 0% | 0% | 0% |
| 13 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% |
| 14 | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 15 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 16 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% |
| TOTAL | 100% | 100% | 99% | 100% | 100% | 100% | 99% | 99% | 100% | 100% | 100% | 100% |

Annex Table 4. T=6 hrs, Wind speed probability density by month

| Wind speed, m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 28% | 25% | 15% | 16% | 12% | 7% | 13% | 13% | 12% | 15% | 17% | 28% |
| 1 | 1% | 0% | 3% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 2% |
| 2 | 35% | 35% | 36% | 38% | 41% | 48% | 54% | 47% | 39% | 45% | 36% | 29% |
| 3 | 9% | 6% | 6% | 13% | 13% | 11% | 10% | 8% | 14% | 8% | 5% | 7% |
| 4 | 8% | 8% | 13% | 8% | 11% | 13% | 8% | 14% | 12% | 12% | 18% | 12% |
| 5 | 4% | 3% | 4% | 2% | 3% | 4% | 4% | 1% | 3% | 2% | 5% | 3% |
| 6 | 5% | 8% | 8% | 5% | 5% | 8% | 5% | 9% | 7% | 9% | 8% | 6% |
| 7 | 1% | 2% | 6% | 3% | 2% | 2% | 1% | 2% | 1% | 1% | 3% | 2% |
| 8 | 5% | 11% | 6% | 9% | 7% | 3% | 3% | 5% | 7% | 6% | 5% | 4% |
| 9 | 0% | 2% | 1% | 2% | 1% | 2% | 0% | 0% | 1% | 1% | 1% | 2% |
| 10 | 3% | 0% | 2% | 2% | 3% | 1% | 2% | 1% | 2% | 1% | 2% | 3% |
| 11 | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% |
| 12 | 0% | 0% | 1% | 0% | 2% | 0% | 0% | 0% | 1% | 0% | 0% | 1% |
| 13 | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% |
| 14 | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 15 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% |
| 16 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% |
| TOTAL | 98% | 100% | 100% | 100% | 100% | 100% | 100% | 99% | 100% | 100% | 100% | 100% |

Annex Table 5. T=12 hrs, Wind speed probability density by month

| Wind speed, m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 54% | 46% | 28% | 32% | 30% | 28% | 39% | 37% | 28% | 25% | 22% | 33% |
| 1 | 0% | 0% | 5% | 0% | 0% | 0% | 1% | 1% | 0% | 0% | 0% | 2% |
| 2 | 18% | 23% | 31% | 38% | 36% | 44% | 38% | 40% | 40% | 44% | 26% | 30% |
| 3 | 5% | 8% | 8% | 11% | 6% | 4% | 4% | 5% | 6% | 10% | 8% | 9% |
| 4 | 7% | 9% | 10% | 6% | 8% | 11% | 7% | 8% | 11% | 8% | 23% | 7% |
| 5 | 3% | 4% | 2% | 1% | 2% | 2% | 2% | 1% | 2% | 4% | 3% | 2% |
| 6 | 5% | 4% | 4% | 6% | 7% | 4% | 5% | 2% | 6% | 6% | 9% | 5% |
| 7 | 1% | 1% | 2% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 2% | 2% |
| 8 | 5% | 4% | 6% | 3% | 4% | 2% | 3% | 3% | 5% | 2% | 5% | 5% |
| 9 | 1% | 0% | 0% | 1% | 2% | 3% | 0% | 0% | 1% | 1% | 1% | 2% |
| 10 | 1% | 0% | 2% | 0% | 2% | 0% | 1% | 2% | 2% | 1% | 3% | 1% |
| 11 | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% |
| 12 | 0% | 0% | 1% | 1% | 1% | 0% | 1% | 0% | 0% | 0% | 0% | 0% |
| 13 | 0% | 0% | 1% | 1% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 14 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% |
| 15 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 16 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% |
| TOTAL | 100% | 100% | 99% | 100% | 100% | 99% | 100% | 100% | 100% | 100% | 100% | 100% |

Annex Table 6. T=18 hrs, Wind speed probability density by month

| Wind speed, m/s | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 47% | 38% | 30% | 34% | 28% | 28% | 34% | 34% | 33% | 26% | 21% | 28% |
| 1 | 0% | 0% | 3% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 2% |
| 2 | 24% | 33% | 29% | 37% | 33% | 37% | 39% | 34% | 35% | 38% | 27% | 29% |
| 3 | 7% | 6% | 8% | 8% | 8% | 10% | 8% | 6% | 7% | 11% | 6% | 7% |
| 4 | 9% | 9% | 9% | 7% | 9% | 12% | 6% | 13% | 12% | 12% | 16% | 9% |
| 5 | 3% | 1% | 4% | 2% | 5% | 2% | 1% | 2% | 2% | 2% | 6% | 4% |
| 6 | 5% | 6% | 6% | 4% | 4% | 5% | 3% | 4% | 6% | 8% | 12% | 8% |
| 7 | 1% | 1% | 4% | 1% | 2% | 1% | 2% | 0% | 0% | 1% | 1% | 3% |
| 8 | 3% | 6% | 4% | 3% | 5% | 3% | 3% | 4% | 3% | 3% | 8% | 5% |
| 9 | 1% | 0% | 1% | 1% | 1% | 2% | 1% | 0% | 0% | 0% | 1% | 1% |
| 10 | 1% | 1% | 2% | 1% | 3% | 0% | 2% | 1% | 2% | 1% | 2% | 1% |
| 11 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 1% | 0% |
| 12 | 0% | 0% | 0% | 1% | 1% | 0% | 1% | 1% | 1% | 0% | 0% | 1% |
| 13 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 14 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% |
| 15 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 16 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 1% | 0% | 0% | 0% | 1% |
| TOTAL | 100% | 100% | 100% | 100% | 100% | 100% | 99% | 99% | 100% | 100% | 100% | 99% |

Annex Table 7. Wind speed categories' probability for T=0 hrs

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 69% | 61% | 64% | 64% | 62% | 62% | 70% | 67% | 68% | 64% | 53% | 60% |
| Moderate | 26% | 33% | 27% | 29% | 29% | 32% | 24% | 30% | 25% | 30% | 38% | 31% |
| Good | 5% | 6% | 9% | 7% | 9% | 6% | 6% | 4% | 7% | 6% | 9% | 9% |

Annex Table 8. Wind speed categories' probability for T=6 hrs

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 58% | 47% | 54% | 61% | 63% | 61% | 71% | 63% | 59% | 64% | 53% | 62% |
| Moderate | 35% | 43% | 37% | 26% | 25% | 34% | 24% | 30% | 31% | 29% | 40% | 27% |
| Good | 8% | 9% | 9% | 13% | 12% | 5% | 5% | 7% | 10% | 7% | 7% | 11% |

Annex Table 9. Wind speed categories' probability for T=12 hrs

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 59% | 55% | 66% | 73% | 69% | 69% | 76% | 78% | 67% | 73% | 49% | 68% |
| Moderate | 37% | 42% | 25% | 22% | 23% | 25% | 19% | 18% | 27% | 24% | 43% | 23% |
| Good | 5% | 3% | 9% | 5% | 9% | 6% | 5% | 4% | 7% | 3% | 8% | 10% |

Annex Table 10. Wind speed categories' probability for T=18 hrs

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | 61% | 55% | 64% | 73% | 65% | 66% | 76% | 70% | 68% | 69% | 50% | 62% |
| Moderate | 36% | 40% | 30% | 22% | 26% | 29% | 17% | 23% | 27% | 27% | 40% | 28% |
| Good | 4% | 5% | 6% | 5% | 9% | 5% | 7% | 7% | 5% | 4% | 10% | 10% |

Annex Table 11. Low wind speed probability during the day

| T, hrs | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 69% | 61% | 64% | 64% | 62% | 62% | 70% | 67% | 68% | 64% | 53% | 60% |
| 6 | 58% | 47% | 54% | 61% | 63% | 61% | 71% | 63% | 59% | 64% | 53% | 62% |
| 12 | 59% | 55% | 66% | 73% | 69% | 69% | 76% | 78% | 67% | 73% | 49% | 68% |
| 18 | 61% | 55% | 64% | 73% | 65% | 66% | 76% | 70% | 68% | 69% | 50% | 62% |
| AVG | 61% | 54% | 62% | 68% | 65% | 64% | 73% | 69% | 65% | 67% | 51% | 63% |

Annex Table 12. Moderate wind speed probability during the day

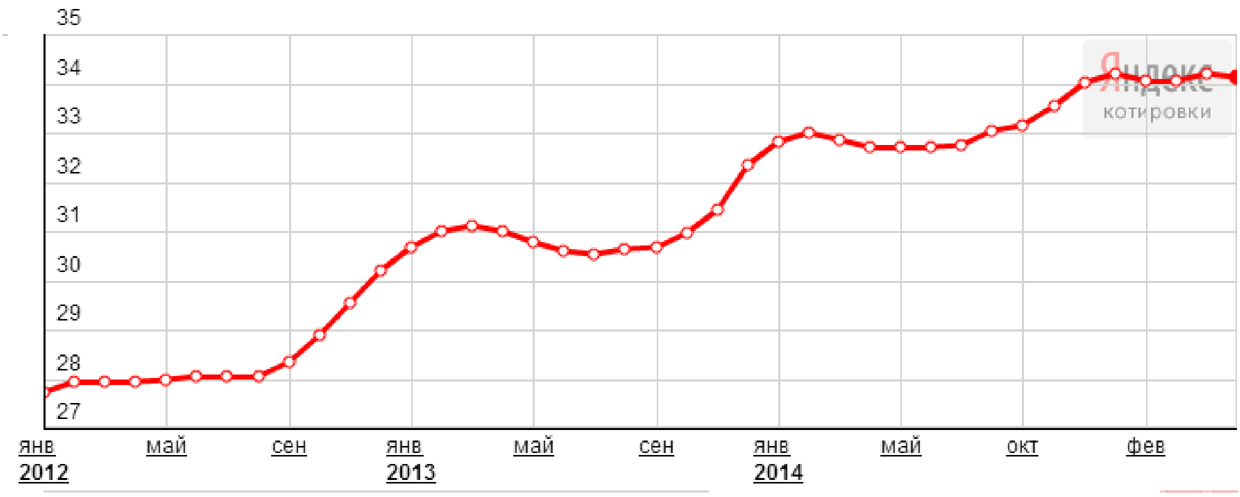
| T, hrs | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 26% | 33% | 27% | 29% | 29% | 32% | 24% | 30% | 25% | 30% | 38% | 31% |
| 6 | 35% | 43% | 37% | 26% | 25% | 34% | 24% | 30% | 31% | 29% | 40% | 27% |
| 12 | 37% | 42% | 25% | 22% | 23% | 25% | 19% | 18% | 27% | 24% | 43% | 23% |
| 18 | 36% | 40% | 30% | 22% | 26% | 29% | 17% | 23% | 27% | 27% | 40% | 28% |
| AVG | 33% | 40% | 30% | 25% | 26% | 30% | 21% | 25% | 28% | 28% | 40% | 27% |

Annex Table 13. High wind speed probability during the day

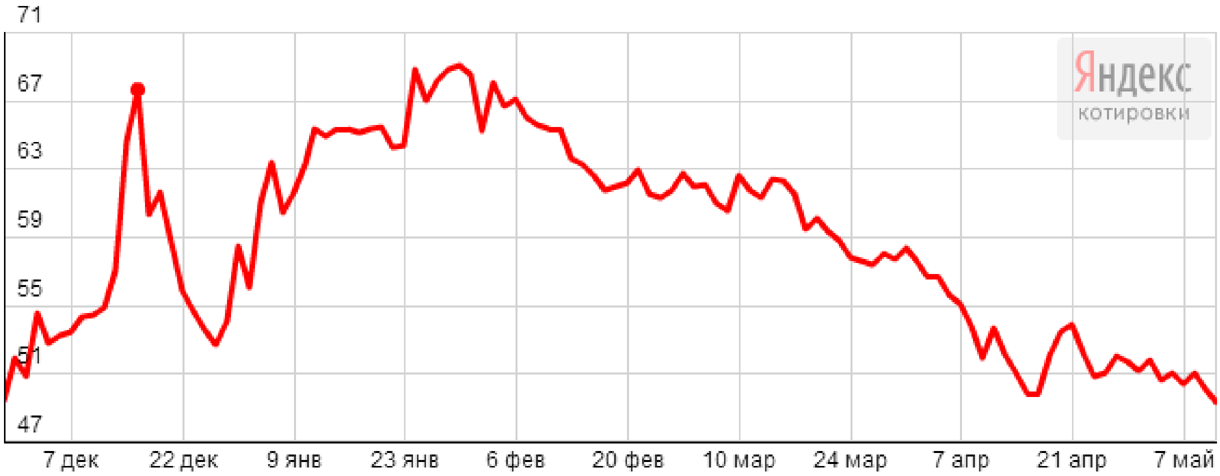
| T, hrs | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 5% | 6% | 9% | 7% | 9% | 6% | 6% | 4% | 7% | 6% | 9% | 9% |
| 6 | 8% | 9% | 9% | 13% | 12% | 5% | 5% | 7% | 10% | 7% | 7% | 11% |
| 12 | 5% | 3% | 9% | 5% | 9% | 6% | 5% | 4% | 7% | 3% | 8% | 10% |
| 18 | 4% | 5% | 6% | 5% | 9% | 5% | 7% | 7% | 5% | 4% | 10% | 10% |
| AVG | 5% | 6% | 8% | 7% | 10% | 5% | 6% | 5% | 7% | 5% | 8% | 10% |

| | G | H | I | J | K | L | M | N | O | P | Q | R | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 3 | Costs | | | | | | | | | | | | |
| 4 | Investments | | | | | | | | | | | | |
| 5 | Wind turbine | -478 500 ₽ | | | | | | | | | | | |
| 6 | Rectifier | -22 500 ₽ | | | | | -22 500 ₽ | | | | | -22 500 ₽ | |
| 7 | Inverter | -45 000 ₽ | | -45 000 ₽ | | -45 000 ₽ | | -45 000 ₽ | | -45 000 ₽ | | -45 000 ₽ | |
| 8 | Accumulator | -57 000 ₽ | | | | -57 000 ₽ | | | | -57 000 ₽ | | | |
| 9 | Accumulator contro | -7 000 ₽ | | -7 000 ₽ | | -7 000 ₽ | | -7 000 ₽ | | -7 000 ₽ | | -7 000 ₽ | |
| 10 | Diesel generator | -250 000 ₽ | | | | | | | | | | | |
| 11 | Ormat | -1 000 000 ₽ | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | |
| 13 | Maintenance | | | | | | | | | | | | |
| 14 | Wind turbine | | -15 885 ₽ | -16 225 ₽ | -16 395 ₽ | -16 395 ₽ | -15 545 ₽ | -15 545 ₽ | -15 885 ₽ | -15 885 ₽ | -16 225 ₽ | -16 735 ₽ | -16 565 ₽ |
| 15 | Rectifier | | -675 ₽ | -675 ₽ | -675 ₽ | -675 ₽ | -675 ₽ | -675 ₽ | -675 ₽ | -675 ₽ | -675 ₽ | -675 ₽ | -675 ₽ |
| 16 | Inverter | | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ | -1 350 ₽ |
| 17 | Accumulator | | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ | -2 850 ₽ |
| 18 | Accumulator controller | | -210 ₽ | -210 ₽ | -210 ₽ | -210 ₽ | -210 ₽ | -210 ₽ | -210 ₽ | -210 ₽ | -210 ₽ | -210 ₽ | -210 ₽ |
| 19 | Diesel generator | | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ | -17 500 ₽ |
| 20 | Ormat | | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ | -30 000 ₽ |
| 21 | | | | | | | | | | | | | |
| 22 | Variable costs | | | | | | | | | | | | |
| 23 | RNG | | 20,0000% | 41,0000% | 0,0000% | 44,9000% | 90,0000% | 44,1000% | 89,6000% | 64,8000% | 78,7000% | 98,1000% | 13,8000% |
| 24 | DG Fuel spendings | | -1 000 956,60 ₽ | -1 082 437,23 ₽ | -615 175,00 ₽ | -1 097 569,35 ₽ | -1 305 269,07 ₽ | -1 094 465,32 ₽ | -1 281 909,12 ₽ | -1 174 781,94 ₽ | -1 228 714,36 ₽ | -1 438 115,83 ₽ | -891 266,50 ₽ |
| 25 | ORMAT Gas spendings | | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ | -945 000,00 ₽ |
| 26 | | | | | | | | | | | | | |
| 27 | Benefits | | | | | | | | | | | | |
| 28 | Savings wind (DG) | | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ | 1 700 000,00 ₽ |
| 29 | | | | | | | | | | | | | |

Annex Figure 1. Spreadsheet example




Annex Figure 2. Average Russian diesel fuel price in Rubles [58]




Annex Figure 3. USD to RUB exchange ratio [58]

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