# Adaptation of Russian energy companies to a changing Arctic


***Produced by:*** *John Morrow, Peishan Wang, and Mercedes Brown*

***In Partnership With:*** *Alexey Dokuchaev, Ekaterina Tertyshnaya, Kseniya Laktionova*

***Project Advisor:*** *Svetlana Nikitina*



***Project Sponsor:*** *Ernst & Young (CIS) B.V., Moscow Branch, Kirill Kharlashkin*

***Project Location:*** *Moscow Project Center, Fall 2013*

# Abstract

Russian energy companies are unprepared for a climate-changed future in the Arctic. Their lack of preparation leads to unsustainable business practices that are not economically viable. This project gives energy companies a glance ahead at what their unsustainable business practices will lead to. In addition, the project explores existing adaptation solutions to the worst climate change impacts, as well as provides a framework for energy companies to follow to develop their own adaptations. We believe that giving companies a glance ahead at what their unsustainable business practices will result in will increase their awareness of their activities and encourage them to find adaptation solutions.

# Table of Contents

# 1. Introduction

Due to its harsh climate the Russian Arctic (also known as the Extreme North) remains mainly uninhabited and an untapped resource. Since the middle of the 20th century, state energy companies led by Soviet ministries have begun to venture into the Extreme North looking for energy resources (such as oil and gas), building drilling rigs, large power plants, and transmission lines. Today, as they move towards the North, state and private energy companies are claiming an increasing amount of the previously untouched land. Coincidentally, the Extreme North, the area of the Arctic with the most extreme conditions, is changing due to climate change trends. As energy companies move northward, they continue to use the same business practices as before. The problem is that these practices are no longer relevant in the climate-changed Arctic. Thus, companies already in the Arctic, such as Gazprom and Rosneft, are unprepared for the changes that are occurring in the region. But how unprepared are they?

According to the Carbon Disclosure Project (CDP), an international organization that publishes worldwide reports on climate change, Russian energy companies are lagging behind all the others in awareness to climate change. In CDP's recent energy sector rankings, Gazprom, the highest rated Russian energy company, was rated at a 62, Novatek, a Russian natural gas company, was rated at a 40. Surgutneftegas, a large Russian oil and gas company, held the lowest score in the energy sector, a 23, while Statoil, a Norwegian oil and gas company, was rated at an 86. Thus, key Russian energy companies are unaware of the key problems of climate change and the risks linked to its effects in the Arctic (PWC 2013, PWC 2013).

The purpose of this project is to fix this issue by providing adaptation solutions to Russian energy companies. This will be accomplished by an outline of impacts that Arctic climate change has on energy companies, an assessment of the greatest impacts, a recommendation of existing solutions to adaptation, and the development of a roadmap for companies to follow to develop their own adaptation solutions. Prior to the outline of key climate change impacts in the Arctic, an inventory of Russian energy companies and their assets in the Arctic will be done, followed by the brief outline of the Russian government policies in the area.

## 1.1 Overview of the Energy Sector in the Russian Arctic

There are two significant types of energy enterprises in the Russian Arctic: oil and gas and power utilities companies. The following table will go into detail into those energy companies, as well as outline Russian policy in the region.

| Company | Assets | Key characteristics of assets |
|---|---|---|
| Gazprom | The key enterprises operating in the Arctic are the following:<br>• Gazprom Dobycha Nadym<br>• Gazprom Dobycha Urengoy<br>• Gazprom Dobycha Yamburg<br>• Gazprom Neft Shelf. | • Gazprom Dobycha Nadym is licensed by the state to explore and develop Bovanenkovo gas field (4900 billion m³ of gas reserves) and Kharasaveyskoe gas field (1900 billion m³ of gas reserves) in Yamal-Nenets region.<br>• Gazprom Dobycha Urengoy is developing Urengoyskoe oil and gas field which is one of the largest oil and gas fields in the world (located in Yamal-Nenets region).<br>• Gazprom Dobycha Yamburg is developing five oil and gas fields in Yamal-Nenets region and is currently controls app. 40% of the total gas reserves of Gazprom.<br>• Gazprom Neft' Shelf is developing Prirazlomnoe and Shtokman oil fields in Nenets region. |
| Rosneft | The key enterprises operating in the Arctic are the following:<br>• Rosneft-Severnaya Neft<br>• Rosneft-Yuganskneftegas<br>• Rosneft-Purneftegaz. | • Rosneft-Severnaya Neft is developing 17 oil and gas fields in Timano-Pechora oil and gas province (393 mln barrels of oil and gas reserves).<br>• Rosneft-Yuganskneftegas is developing oil and gas fields in Priobskoe, Prirazlomnoe, Mamontovskoe and Malobalykskoe oil fields (12 176 mln barrels of oil and gas reserves) in Khanty-Mansy region.<br>• Rosneft-Purneftgaz is developing Kharampurskoe, Tarasovskoe, Barsukovskoe, and Komsomolskoe oil and gas fields (4 750 mln barrels of oil and gas reserves) in Yamal-Nenets region. |
| Lukoil | Lukoil-Western Siberia is developing Bolshekhetskaya field. | Bolshekhetskaya field (929.5 billion m³ of gas reserves) consists of Nakhodkinskoe gas field and Pyakyahinskoe gas field in Yamal-Nenets region. Lukoil plans to develop the fields and extract 22 billion m³ of gas and 4.5 million tons of |

| Company | Assets | Key characteristics of assets |
|---|---|---|
| | | liquid hydrocarbons annually. |
| Novatek | Novatek is the key shareholder of Yamal SPG and SeverEnergy. | Yamal SPG is developing Yuzhno-Tambeyskoe gas field (1.3 billion m³ of gas reserves) in Yamal-Nenets region. SeverEnergy is developing Samburg oil and gas field (322.9 billion m³ of gas and 54.4 mln tons of liquid hydrocarbons) in Yamal-Nenets region. |
| Norilsk Nickel | Norilsk Nickel controls Taimyr Fuel Company. | Taimyr Fuel Company provides electricity, heat and water to households and industrial consumers in five cities, two villages, as well as to the consumers of Norilsk industrial district. It is one of the largest local power supply companies in the Arctic region. Its power system is geographically and technologically isolated from the Unified Energy System. |
| Energoatom | Energoatom controls Kola nuclear power plant. | Kola nuclear power plant (1760 MWh of installed capacity) provides electricity and heat to households and industrial consumers in Murmansk Oblast. |
| Yakutskenergo | Yakutskenergo controls a number of power plants in Republic Sakha (Yakutia). | Almost all assets of Yakutskenergo (1 299.9 MWh) are located in permafrost zone, including Yakutskaya gas power plant, the largest gas power plant located in the permafrost zone. |
| Inter RAO | Inter RAO controls Pechora power plant. | Pechora power plant (1060 MWh installed capacity) provides electricity and heat to households and industrial consumers in the Republic of Komi. It is the most powerful asset of the company in the Arctic region, and its operation is crucial for Komi economy (mining, processing and transportation of energy resources). |
| Urals Energy | Urals Energy is developing Timano-Pechora oil field. | Urals Energy is extracting app. 2.4 thousand barrels of oil per day from Petrosakh (Sakhalin) and Arcticneft (Timano-Pechora). |
| Magadanenergo | Magadanenergo controls Chaunskaya power plant and Anadyrskaya power plant. | Chaunskaya power plant (30.2 MWh of installed capacity) and Anadyrskaya power plant (56 MWh of installed capacity) are the ley suppliers of electricity and heat in Chukotka. |

Sources: Websites of companies.

## 1.2 Policy Context: frameworks, strategies and legislation on the Arctic

Today the Russian government considers maritime transportation, resource extraction, and infrastructure development as its most important activities in the Arctic.

Global climate change has created new possibilities for the development of northern sea routes. Currently, about 1.5 mln tons of cargo is being transported each year along the Northern Sea Route alone. By 2020, this number is expected to increase twofold. More extensive trade will require the improvement and construction of new infrastructure sites, particularly seaports (especially, in Yamal-Nenets and Nenets districts).

The Russian government is also working on oil and gas extraction, providing licenses to the extraction companies that would develop their operations in the Arctic (Lukoil, Gazprom, Rosneft, Novatek etc.). Today the government reduces taxes for oil and gas companies, subsidizes the development of Arctic oil and gas companies, and supports investments in exploration and research in the Extreme North (exploration of resource-rich shale areas, construction of floating research stations, seismic scanning, geological scouting etc.).

Another important direction of the government activities is the development of infrastructural “mega-projects”, such as the “Ural Arctic – Ural Industrial” and “Belkomur” railroads, which will strengthen infrastructure and allow extraction industries to transport the resources to the consumers. There is also a promising project of intercontinental railroad through the Bering Strait. Another example is the “Academic Lomonosov” floating nuclear power plant, which is expected to go into operation in 2017. It is one of the eight floating nuclear power plants that are to be constructed for energy supply of oilrigs and coastal towns (RT news, 2013).

Moreover, the Russian government has recently promised that protection of the Arctic environment and adaptation to possible climate change would be one of its priorities in the region. Solutions to this problem could be the development of more environment-friendly technologies in the Arctic, social and economic partnership with non-governmental organizations and indigenous people, international cooperation with other Nordic countries (e.g. via the Arctic Council), as well as initiation of interregional and intergovernmental projects.

However, today the Russian government fails to consider some of the important impacts of the climate change in the Arctic. Namely, the ice melting can provide not only benefits, but also threats. If the ocean level rises, some inhabited areas of the Extreme North may be flooded, and infrastructure may be destroyed. The government response to this possible impact may be construction of dams and reinforcement of buildings, though the government's stance on these solutions is still unclear. The government has mostly ignored the possible negative effects of climate change. Recently, Russia refused to participate in the next round of Kyoto Protocol – an international treaty that tries to reduce adverse effects of climate change by reducing greenhouse gas emissions – and may even consider exiting it. Moreover, there's still too little that is actually being done by the government. Most of the proposed actions are still in the project stage. Climate change policy is definitely not one of Russia's top priorities – and that may have contributed to its unpreparedness.

In sum, the Russian government takes into the consideration the benefits that the global warming in the Arctic may provide, but not its threats. As there are estimated to be more than 160 billion barrels of oil in the Arctic, it's only natural that the government will focus further on the potential gains of climate change instead of its costs. However, this means that the energy companies that want to operate in the Arctic will have to raise their awareness, preparedness, and sustainability by themselves in order to avoid large-scale negative effects of climate change later (Dobrovidova, 2013) (Dobrovidova, 2012 ). They will have to rely less on government and think more about the climate change risks rather than possible benefits.

# 2. Methodology

This section details the methodology of the project.

## 2.1 Outline of the method used to assess risks

To provide adaptation strategies to energy companies, we first did desk research on Arctic climate change effects, trends and their potential impacts. Two main methods were used in the first step: content analysis through searching required information from intergovernmental reports and scientific articles and an interview with a Civil Engineering professor from Worcester Polytechnic Institute. Next, we prioritized the risks and focused on existing adaptation solutions to the top two by using econometric modeling and content analysis. Finally, we developed an adaptation roadmap for companies to follow to develop their own adaptation solutions.

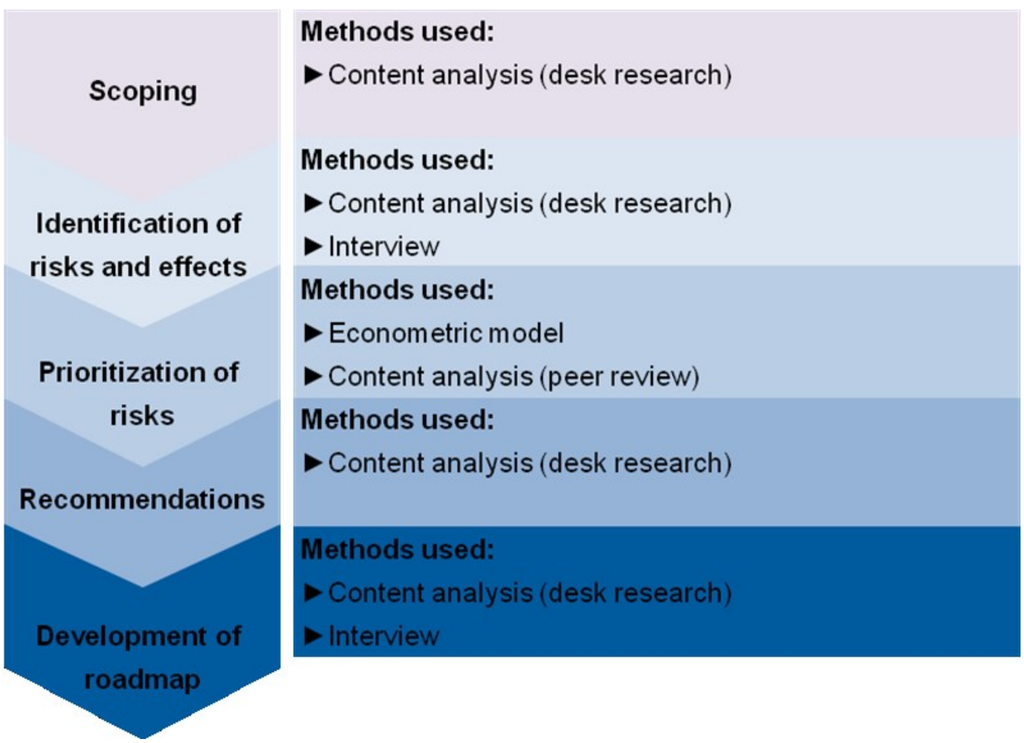


*Figure 1: Methodology of the project*

Figure 1 organizes the previous paragraph's explanation into an easy to read diagram. The methods used in each step will be described in the following sections.

# 2.2 Project approach

## 2.2.1 Content analysis

Content analysis is used at each step of our research since it helps to understand a topic-related material (Berg & Lune, 2011). Content analysis can be conducted in multiple ways, by close examination of books, newspapers, the Internet, speeches, or any other occurrence of communicative language. The information that we get from this can be used to make conclusions and inferences to further our knowledge of the material. We apply content analysis for searching background information through the Internet, reading published reports by energy companies and intergovernmental organizations, and conducting interviews with the professor. After that, based on the analysis of the information, our team can make informed adaptation solutions and roadmap for ECU companies' development in the Arctic region. (Berg & Lune, 2011)

## 2.2.2 Interviews

Interviews are used at the second and the final steps of the research. Interviews are one of the most controlled options since we can get our expected detailed information directly. The purpose of interview is to use the recommendations of interviewed experts in order to help us create a base for our project. This base is used to provide more background information for our research and create adaptation strategies for ECU companies. Our team uses the results of the interviews with Okumus Pinar, WPI Civil Engineering professor, and Sergey Dayman, EY Cleantech and Sustainability Manager.

## 2.2.3 Econometric Modeling

Econometric modeling is used in social and managerial sciences for analysis of existing trends and interrelations, as well as for forecasting and planning. This can be done by combining the data, exercising tests, confirming the hypothesis about the interdependence of variables and finding out the strength of this interconnection.

In the research, due to the restriction of available data, panel data analysis has been chosen to help with finding whether there are any relationships between climate change effects (11 effects) and economic indicators (3 indicators, including operating revenue, cost of goods sold or COGS and gross profit) of companies located in the Russian Arctic.

The econometric modeling used in the research consists of the following steps:

1. Construction of database;
2. Identification of dependent and independent variables;
3. Identification of the interdependence between variables;
4. Specification of equations;
5. Evaluation;
6. Result description.

The model is based on data obtained from Russian data resource called “RUSLANA” and international source www.tutiempo.net. MS Excel and RStudio are used as research tools.

# 3. Changes in the Arctic climate

In order to understand the impact that current climate trends have on these energy companies, the trends themselves need to be understood. What follows is a description of the various changes in the environment and their current and projected trends.

## 3.1 Changes in Temperature

Possibly the best known global climate change trend is the rising global temperatures. There are regional differences due to terrain, atmospheric winds and ocean currents, but for the Arctic as a whole, temperature is experiencing a positive trend. In fact the Arctic temperature has increased at almost twice the rate of global mean temperature over the past few decades, confirmed by the Arctic Climate Impact Assessment (ACIA) and the International Programme on Climate Change (IPCC). This phenomenon has been named “polar amplification” by experts. (“Impacts of a Warming Arctic”, 2004) (Hamilton & Sommerkorn, 2008)

Polar amplification which is also known as Arctic amplification refers to the greater temperature increases in the Arctic compared to the earth as a whole due to the effect of climate feedbacks and other processes. (Climate Change Adaptation Report) The ACIA gives several explanations to Arctic amplification. As Arctic snow and ice melt, the uncovered darker land and ocean surfaces absorb more solar energy. More of the extra trapped energy from increasing concentration of greenhouse gases goes directly into warming the atmosphere. The atmospheric layer that has to warm in order to warm the surface is shallower in the Arctic. As sea ice retreats, solar heat absorbed by the oceans is more easily transferred to the atmosphere. Alternation in atmospheric and oceanic circulation can increase warming. (“Impacts of a Warming Arctic”, 2004)

According to the ACIA, temperatures in winter are rising more rapidly in most places.

(“Impacts of a Warming Arctic”, 2004) Recent warming has been shown to be strongest in autumn and spring, as reported by SWIPA. (Dicks & Symon. 2012) However, the best indicators of change are the data on annual temperature difference and on the temperatures in the winter.

The ACIA has divided the Arctic into four regions as shown in Figure 2. The ACIA gives data corresponding to each of these regions. In addition to current climate data, they have also given projections into the future. (“Impacts of a Warming Arctic”, 2004)


*Figure 2: ACIA’s four regions*

General Arctic temperature has increased 1-3 ℃ in the past five decades and will continue to rise rapidly, estimated to about 6 ℃, in the future shown in Figure 3 on the next page. The Russian Arctic is located in sub-region two and three, which are shown in detail in Figures 4 and 5 on the next pages. (“Impacts of a Warming Arctic”, 2004).

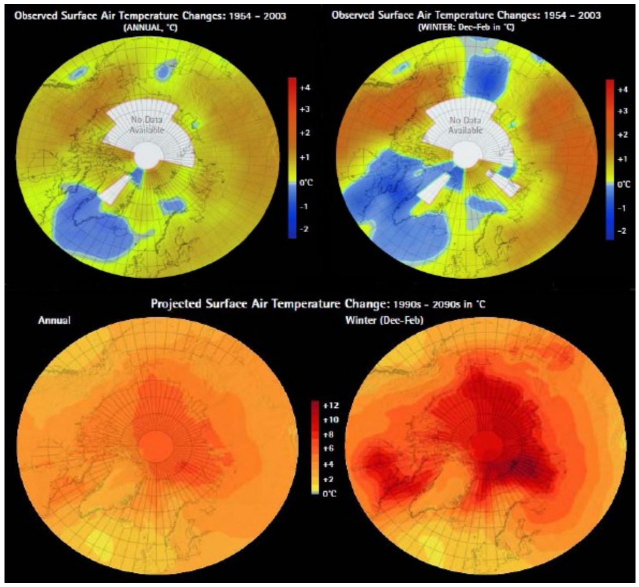


*Figure 3: Observed and projected general Arctic temperature change*

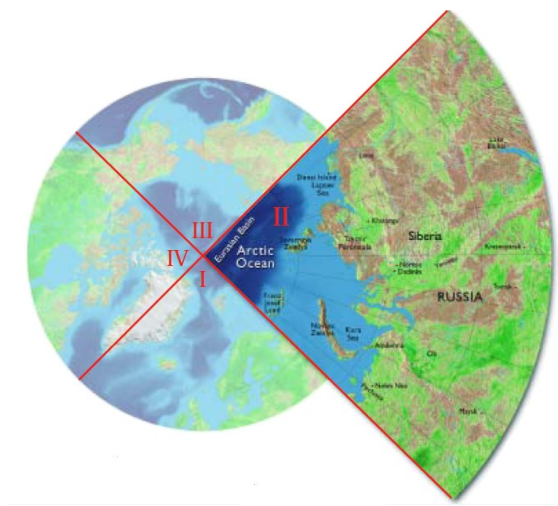


*Figure 4: Sub-region 2 (Siberia and adjacent seas)*

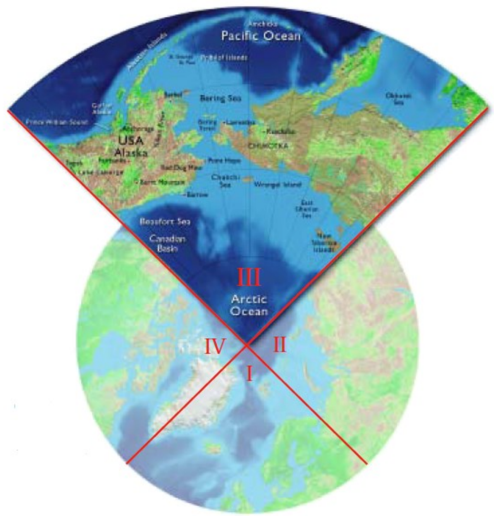


*Figure 5: Sub-region 3 (Chukotka, Alaska, Western Canadian Arctic, and adjacent seas)*

Based on the records provided by the ACIA, annual temperatures around Siberia and Russia increased 1-3℃ in the past 50 years. Also, warming happens mostly in some inland areas during winter, where temperatures rose about 3-5 ℃. Since the duration of inland snow cover has reduced, temperature has increased. Projected by their simulation model, annual temperature increase over land will be around 3-5℃ by the 2090s. Increases of 3-7℃ over land and 10℃ or more over the adjacent ocean areas during wintertime are projected as well. (“Impacts of a Warming Arctic”, 2004)

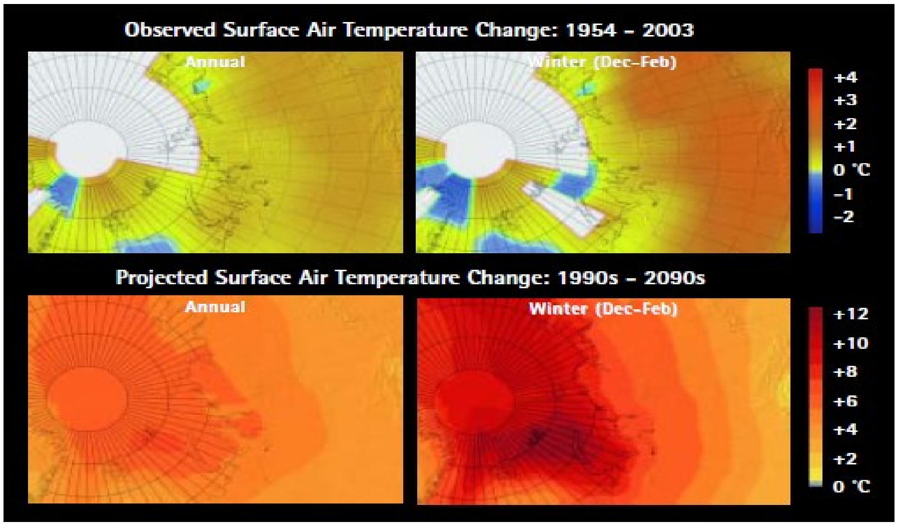


*Figure 6: Observed and projected temperature change in sub-region 2*

At the same time, Figure 6 shows that there is a greater increase of temperature closer to the Arctic Ocean.

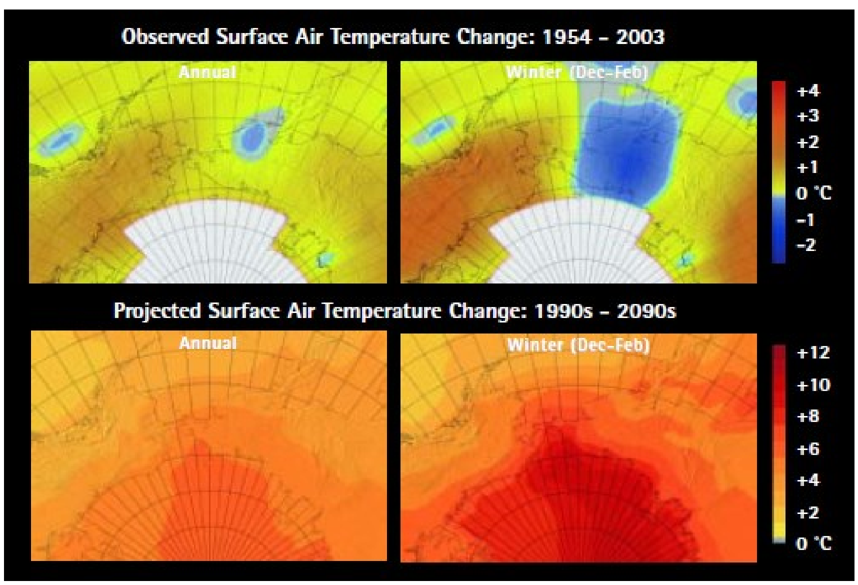


*Figure 7: Observed and projected temperature change in sub-region 3*

We can get similar findings from Figure 7, except the observed data shows that the temperature of the Chukotka region decreased, especially in winter got 1-2℃ colder.

## 3.2 Changes in Precipitation

The National Snow and Ice Data Center show that precipitation patterns, mainly around the Arctic region, are beginning to change. ("*All about Arctic Climatology and Meteorology*") Figure 8 shows which areas have changed and their recorded results based on past results.

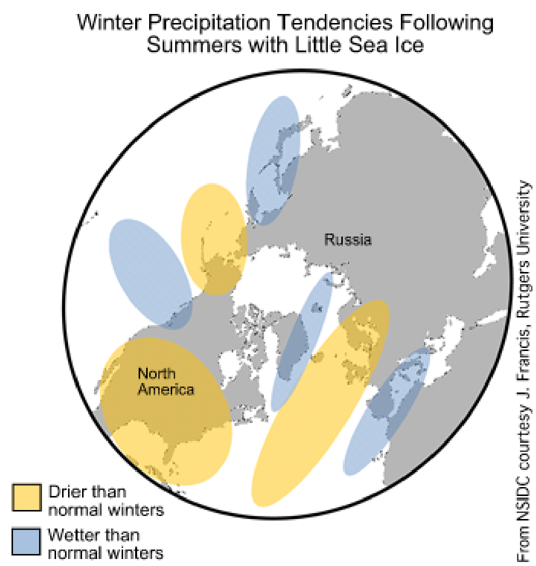


*Figure 8: Precipitation trends observed in winter and summer*

Figure 9 uses the temperature and sea level measurements in order to gauge the measurement of precipitation. A report done at the Arctic Monitoring and Assessment Programme writes that precipitation in the Arctic could increase from 5 to 70% by 2100. (Dicks & Symon, 2012).

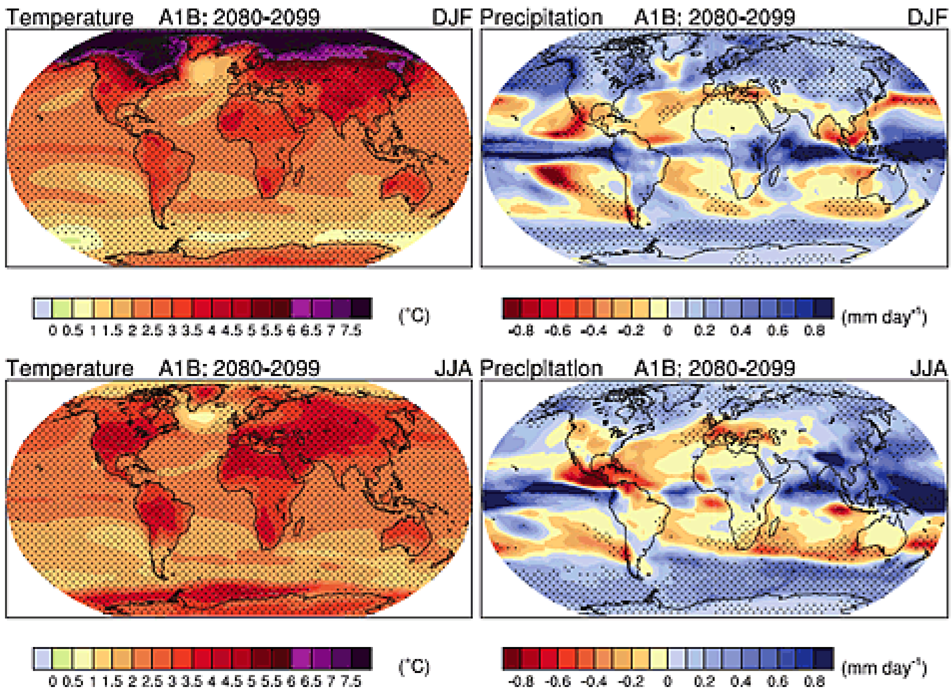


*Figure 9: Projected temperature (left) and precipitation (right) predicted for 2080-2099*

Each part of the world will be affected differently by precipitation depending on altitude, latitude, and nearby water sources. Locations near oceans, lakes, or rivers will experience an increase in precipitation while landlocked areas will experience a decrease.

Areas seeing an increase of precipitation will see a number of impacts from the weather. This includes flooding, ice, storm increase, acid rain, and wind changes. (Forbes & Kremer, 2011) Each of these impacts influences each other greatly in its turn. When the area has a lot of water nearby, the water evaporation rate occurs at a faster pace. The water that evaporates will increase chances of forming a storm. With constant precipitation, floods and avalanches will begin to appear and cause more damage. If flooding were to occur, then ice will also become an issue for the area. But when evaporation begins to escalate, it begins to take moisture from the land as well. ("*Weather and Climate*") The area will become deserted if the evaporation continues to rise.

Areas experiencing a decrease in precipitation may be cause of concern in terms of droughts. Fires are also something to be noted if the area has plant life. (Lenart, 2008)

Another concern for increased precipitation is acid rain. Acid rain occurs after water mixes with nitric and sulfuric acids. (“*Acid Rain Facts*”) This rain can be very damaging to plant and animal life. The acid rain attracts aluminum like substances that are in the soil, even when in bodies of water. The aluminum begins to block other nutrients for plants; the water will also become toxic and deadly to animals. The acids come from coal burning factories, which mean that acid rain will continue if coal burning factories continue their operations.

As stated earlier, increase in water evaporation can cause more storms, but this will also affect the wind and its patterns. The increased temperature has already caused a change in Arctic winds. (Sinclair, 2011) The winds normally blow in east and west direction, but they have recently started blowing north and south directions. This change pushes warm air into the Arctic and pushes the Arctic winds into the warmer regions.

## 3.3 Changes in Sea Level

As observed by the EPA, the rate at which the absolute sea level is increasing, that is sea level measurements taken relative to the rest of the ocean's levels, is 0.07 in/yr from 1880 to 2011. (Climate change indicators in the United States, 2012) From 1993 to 2011 however the average rate of growth is double that; around 0.12 in/yr. Data collected by the Colorado Sea Level Research Group (CSLRG), run by the University of Colorado, and the National Oceanic and Atmospheric Administration Satellite and Information Service (NOAASIS) collaborates this data; they calculated the average rate of sea level growth during 1992-2013 to be about 3.2 mm/yr, which is about 0.125 in/yr as shown in Figure 10. (Nerem & Chambersi. 2010) The Arctic region is close to the global average. Older data released by the Arctic and Antarctic Research Institute (AARI) in St. Petersburg shows a significant rise in the sea level during that time, about a sea level rise of about 1.8 mm/yr. The highest observed reading is 3.2 mm/yr and the lowest is 0.9 mm/yr. (Proshutinsky & Pavlov, 2001)

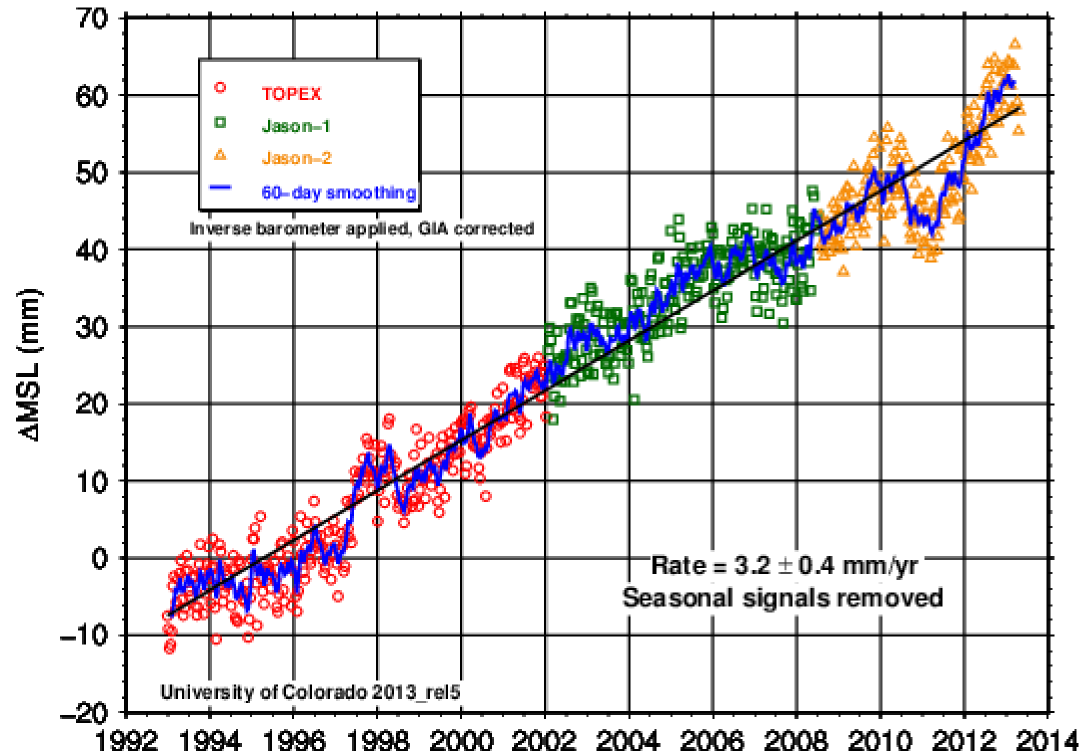


*Figure 10: UC sea level data taken by 3 satellites (Topex, Jason-1, Jason-2) over two decades. (Nerem & Chambersi. 2010)*

In 2050 sea levels are forecasted to rise about 0.32-0.38m. By 2100 the global sea level is estimated to have risen 0.57 to 1.1m depending on what RCP scenario is used. (Jevrejeva & Moore, 2012) There are four RCP scenarios and each one is a plausible carbon concentration trajectory. The main difference between each scenario is a different carbon emission future.

Not only does the sea level rise, but river levels do too. Each year since 1935 the total amount of water flowing out of the six largest rivers in the Eurasian Arctic has increased by about 10%. (Dicks & Symon. 2012)

## 3.4 Changes in Ice/Snow/Permafrost

The following sections will describe the changes in ice, snow, and permafrost in the

Arctic.

### 3.4.1 Sea Ice

In the past decade the sea ice levels have continued to set record lows. According to the National Snow and Ice Data Center (NSIDC), Arctic sea ice area reached a new record low of 3.41 million square kilometers at the end of the summer season. According to their past data, this new record low is 44% below their 1981-2010 average. This level is also 17% lower than the previous record set in 2007. *("SOTC: Overview", 2013)*

The average age of ice in the Arctic is also rapidly decreasing. In the figure below tabulated by the EPA, the amount of ice that is 3+ years is almost becoming extinct. Most of the Arctic is becoming 1 and 2 year old ice. (Climate change indicators in the United States, 2012)

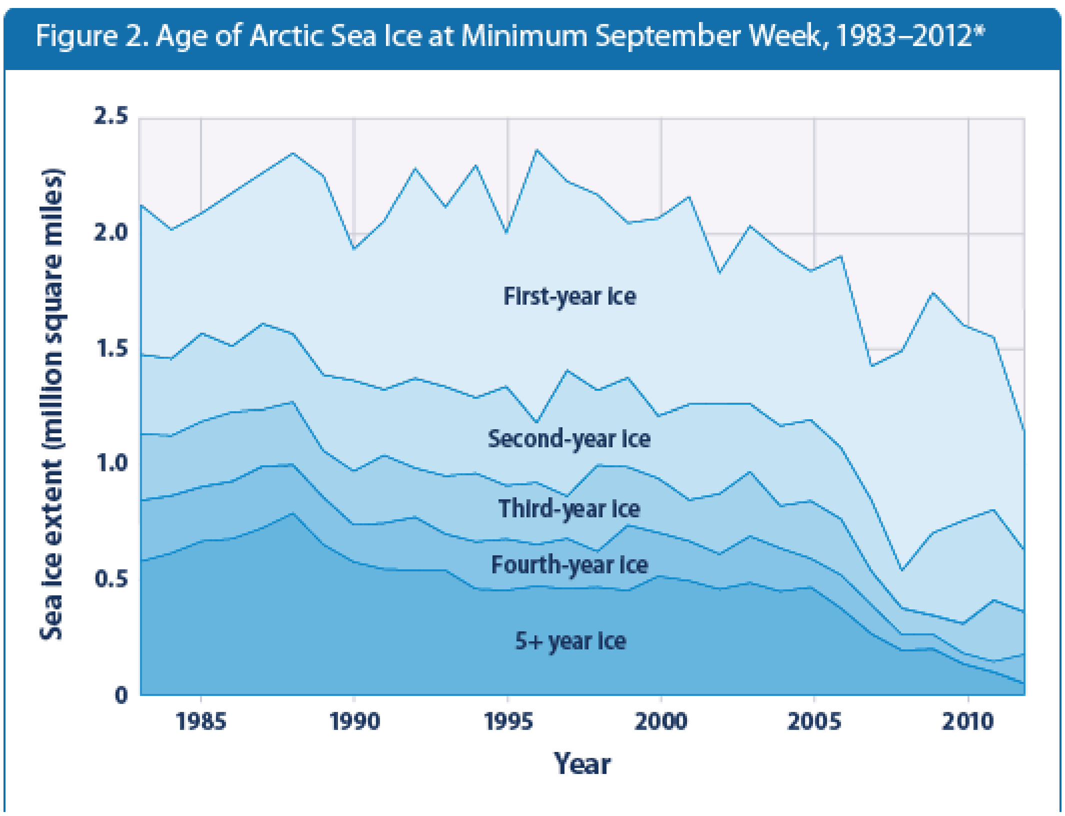


*Figure 11: Age of ice estimates taken at the end of the summer season. (Climate change indicators in the United States, 2012)*

The age of ice is only expected to decrease more and more. The NSIDC has also taken the location of the older ice and compared it with previous years, shown in Figure 12. The darker blues on the map below indicates where the older ice is. *("SOTC: Overview", 2013)*

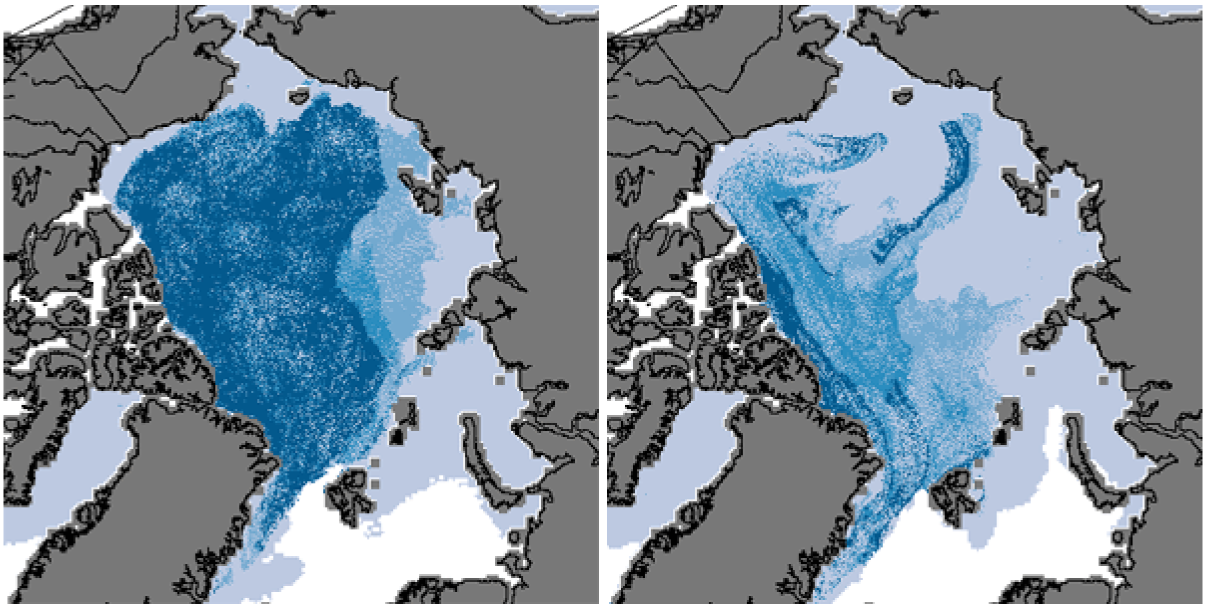

*Figure 12: Ice age comparison taken March 1985 (left) and 2011 (right). ("SOTC: Overview", 2013)*

The contrast between the two years is immediately quite apparent. By March 2011, ice 4+ years accounts for only 10% of the ice cover. (Dicks & Symon. 2012) Younger ice has a different structure than older ice. As stated before, younger ice is thinner ice. This ice is more susceptible to strong winds, meaning that they are more mobile and move faster than the older ice. (Acclimatise, 2009)

Pessimistic projections estimate that the Arctic will be ice free in 30 to 40 years. According to Arctic Monitoring and Assessment Programme (AMAP) the Arctic is projected to lose about all of its ice by the mid-century. (Dicks & Symon. 2012) The figure on the next page shows AMAP's projections to help demonstrate the scale of sea ice loss that the Arctic will be experiencing. (Dicks & Symon. 2012)

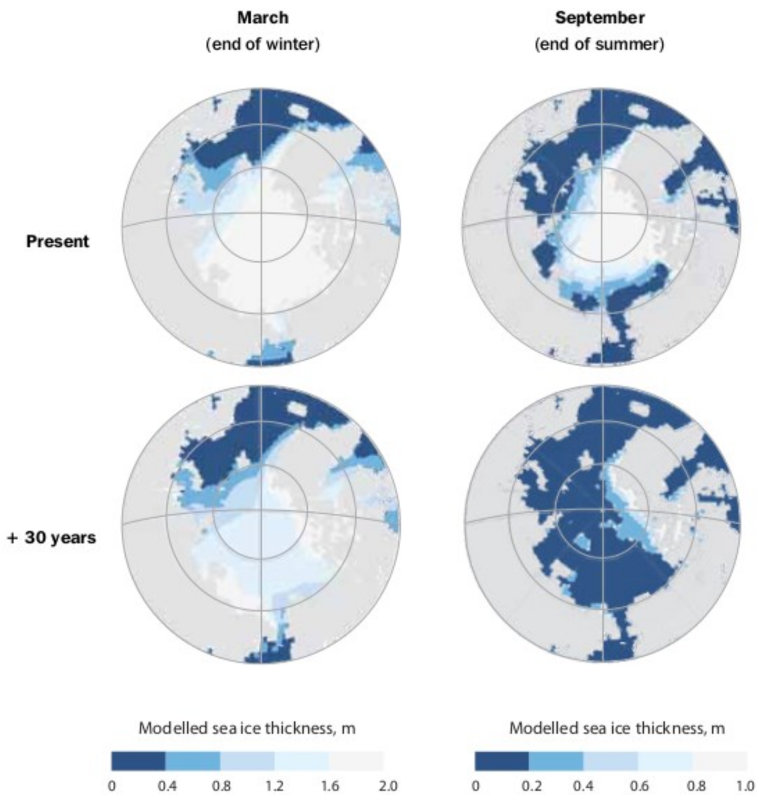


*Figure 13: Recent and projected states of Arctic sea ice at the ends of winter and summer*

AMAP also includes sea ice thickness projections in Figure 13 (above) as well. They project that the sea ice in the Arctic will be much thinner than before. (Dicks & Symon. 2012) Coupled with the ice age measurements by the EPA, the Arctic will be estimated to be dominated by one and two year ice. *("SOTC: Overview", 2013)*

River ice has also seen a negative trend. Lakes and rivers are covered in ice between two and fourteen days less during the time between 1980 and 2000 as compared to the ice cover duration between 1950 and 1979. [6.1] (Dicks & Symon. 2012)

## 3.4.2 Arctic Snow Coverage

The land area covered by snow in the Arctic during the summer has been in constant decline since 1966. In 2011 the land area was about 18% less than the amount in 1966. Interestingly enough the snow depth in the Russian Arctic has increased, however the warmer climates and more frequent winter thawing are making the snow pack differently than before. The duration of snow cover has decreased from 4 to 9 days per decade. (Forbes & Kremer, 2011)

In Russia the snow cover is following a positive trend. In Siberia snow cover duration has been decreasing since 1980, but the snow depth follows no consistent negative trend. Snow is settling earlier in autumn in northern Russia, which has lengthened snow cover duration by two to four days since 1972. Snow depth has also seen a positive trend as well, the number of days when the snow is more than 20 cm deep in Russia has increased between 1966 and 2007. (Biancamaria & Cazenave, 2011)

Snow depth is projected by AMAP to increase in some areas, including Russia, however the duration that snow is on the ground is expected to decrease. In Siberia snow depth is projected to increase 15 to 30% in the next 50 years. Across the Arctic snow duration is expected to drop 10-20% by 2050. Siberia is expected to lose the least at about 10%. (Dicks & Symon. 2012)

### 3.4.3 Arctic Permafrost Coverage

The lower boundary of permafrost in the Russian Arctic has moved northward 30 to 80 km between 1970 and 2005. In addition to the northward migration of the southern border, temperatures have typically risen 2 degrees in Arctic permafrost. (Forbes & Kremer, 2011)

AMAP projects ground temperature to increase from 0.6 to 1 degree C by 2020. In other parts of the world the top 2 to 3 meters of permafrost is expected to decrease 16-20% across land with permafrost in Canada and 57% in Alaska. (Dicks & Symon. 2012) The following figures give a clear look at the northward progression of permafrost in the span of seven years (1998-2005).

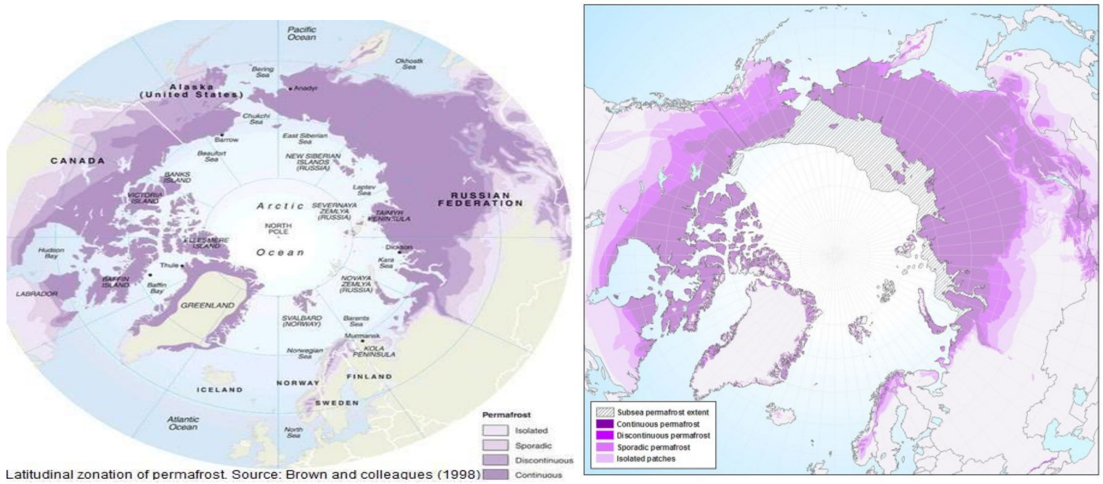


*Figure 14: Permafrost concentrations in 1998 (left) and 2005 (right)*

In both pictures the legend is the same. The darkest purple indicates areas with continuous permafrost. The next lighter shade of purple indicates areas with discontinuous permafrost, where permafrost covers 50-90% of the landscape and the mean temperature is between -2 and -4 °C. The next lighter shade indicates sporadic permafrost, where permafrost cover is less than 50 percent of the landscape and the mean temperature is between 0 and -2 °C. Finally the gray indicates areas with no permafrost. (Dicks & Symon. 2012)(Forbes & Kremer, 2011)

Soil degradation resulting from permafrost has already started to form. Permafrost thawing and then soil degradation is annually responsible for an estimated 7000 oil pipeline failures in western Siberia. (Dicks & Symon. 2012)

## 3.5 Summary

Recently, energy company assets have been influenced by different climate change drivers, especially the companies in the Arctic region. Based on our research, we figured out that the main climate change effects are: global temperature increasing especially in winter; precipitation variation is more obvious depends on the location and side effects; sea level rising; sea ice melting and snow coverage decreasing; and permafrost thawing. All of these climate change effects are interrelated and has been projected to change much greater in the future to affect the energy companies. To provide better solutions of how energy companies could adapt to the vicious circular climate change, we will analyze these climate drivers main impacts to energy sector in Russia in the next section.

# 4. Risks from Arctic Climate Change

The following sub-sections describe the impacts associated with the risks described in the previous section.

## 4.1 Risks driven by changes in temperatures

Global temperatures rise and accelerated ice melt has many effects on the Oil & Gas companies. Offshore oil and gas exploration will be enhanced by the reduced ice. (“Impacts of a Warming Arctic”, 2004)(Doggett, 2004)(Ball & Breed) At the same time, onshore resources extraction will be hampered due to the shortened ice frozen season during which the ground is better for travel (Clement & Bengston, 2013) (Ball & Breed). Besides the marine and land exploration, transportation is also greatly influenced by global warming. The Eurasian Arctic has been projected to be relatively ice-free region in a few decades during the summertime which could provide more Northern sea shipping routes to shorten the time, distance and cost. (“Impacts of a Warming Arctic”, 2004) All of these effects will be discussed in detail in sections 4.4 and 4.5.

Electricity companies will also be affected by the temperature rise, which mostly affects power generation, making it less efficient. Global warming makes the soil drier and warmer which in turn will make any underground cables lose their thermal conductivity and heat capacity. When building a power plant, one of the first things set is the maximum temperature of the plant. This ensures that the plant won't adversely affect the environment.  From the set maximum temperature, the amount of current that the plant can carry could be planned. If the surrounding temperature increases, the available temperature rise will decreases and the maximum current rating will be reduced, which will make thermal generation less efficient. (Wills & Power, 1975) Especially during summertime, air conditioning demand and load is likely to increase. (Ball & Breed)

## 4.2 Risks driven by changes in precipitation

The change in precipitation patterns could be devastating to all areas that are unable to adapt. The areas that are expected to see an increase in precipitation are at risks of flooding. Flooding will require assistance from the government and will also cause citizens to relocate to areas that are very likely already overpopulated. The areas that are expected to see a decrease in precipitation are more prone to droughts and fires.

In 2007, a Norwegian gas plant located in Snohvit was shut down for repair after receiving much damage from the ocean and cold temperatures. (McLoughlin, 2012) Figure 15 shows that the plant was located off the shore of Norway in the Arctic. Sea water leaked into the cooling systems of the plant. When the Arctic wind came and temperature dropped, the water began freezing the system and the plant had to be shut down. The company plans on reopening the plant but will have to replace the entire cooling system before they can begin anything else; however, the new system will cost millions of dollars.


*Figure 15: Location of Snohvit oil rig*

Acid rain can also cause damage to coatings of automobiles and factories. The damage witnessed in previous studies shows that it is permanent and can only be repaired by applying new coats of paint, water resistant coating, etc. (Forbes & Kremer, 2011)

Increase in storm incidence will also affect industry. The plant in Snohvit was shut down for an ice storm and once again during a snow storm because it lost power. Storms can also delay transportation and push back deadlines. With increasing demands, delay is something a gas plant can't afford.

One thing that will be greatly affected by these impacts is transportation. The change in precipitation increases chances of storms. The plant was already destroyed by an ice storm and the damage it sustained is going to be a costly one. But sea transportation and exportation could become more difficult with increasing storm lengths. Changing winds can also greatly affect these modes of transportation. (Skjaerseth & Skodvin. 2001) Roads are an option but with increased chances of flooding and ice, it will be very difficult to navigate.

## 4.3 Risks driven by changes in sea level

According to the EPA, rising sea levels can cause a higher frequency of coastal flooding and erosion. Coastal infrastructure would face increased vulnerability to coastal storms. The loss of snow and ice in the Arctic would cause the cooling effects of the Arctic to disappear, causing an increased global warming. (Climate change indicators in the United States, 2012)

AMAP estimates that about 200 million people inhabit areas less than one meter above sea level globally. A higher average sea level and a higher frequency of storm surges increase the risk of flooding in these areas. Storm frequency has not been formally measured in the Arctic, but reports in Alaska indicate that the frequency has been increasing. (Dicks & Symon. 2012) As reported in section 3.3, pessimistic projections of sea level by 2100 are around 1.1 m. If this is the case, those 200 million people will have to move inland. (Jevrejeva & Moore, 2012)

Concerning oil and gas companies, sea level rise alone won't have much impact unless there are installations that are close enough to sea level to be affected. Harbors will be affected the most, but only when the rising sea level is coupled with the extreme weather that result from the melting sea ice. (Rottem & Moe. 2007) In addition, sea level rise can destroy refineries and threaten the safety and reliability of operations near the coast. This can only happen during extreme weather events, but a higher sea level will increase the chance of such events happening. (Martikainen & Holttinen, 2005)

A higher sea level will change how certain resources are accessed. Access and exploration of oil and gas in the oceans will be enhanced; however, increased wave forces and mobile sea ice will force companies to invest more in stronger equipment. (Martikainen & Holttinen, 2005)

Regarding energy companies, given the fact that Arctic power stations are on land, there should be no negative effects from sea level rise. Plants on the coast however are potentially in danger of flooding. RosAtom currently has two plants near the coast, its Bilibino and Kolsky plants, which could be affected. (2011 Public Annual Report, 2012) For nuclear power plants in particular, storm events may raise the sea level in large increments. In Finland, a storm in January 2005 raised the sea level of the Gulf of Finland approximately 2 m, which prompted the closure of the Loviisa nuclear power plant. (Martikainen & Holttinen, 2005)

Hydro-electric plants in Russia would benefit from the increased water flow in rivers that would result from a higher sea level. It is estimated that hydro-electric power in northern Russia will see a 15-30% increase in hydro-electric potential. (Martikainen & Holttinen, 2005)

Russia's nuclear-powered utility ships, named the Akademik Lomonosov, indicate its deployment in 2016. (RT News, 2013) If they are implemented en masse, these ships would be immune to any adverse effects from sea level rise.

## 4.4 Risks driven by changes in ice coverage/snow/permafrost

As before, each climate change driver's risks will be detailed in their own respective subsections.

### 4.4.1 Ice levels

Reduced ice levels will affect private and public enterprise in the Russian Arctic heavily. The decrease in ice age will make the oceans full of icebergs and smaller ice chunks. Older ice has different properties than the newer ice. Older ice is 'stiffer' which is harder for ice-breakers to break through. The younger ice might make things easier for the Arctic shipping industry, because shipping routes will be open longer; however, the relative shallowness of the Siberian coast will still limit the size of ships that can be utilized. The shipping industry is not the only industry that will experience the benefit of the melting sea ice, the tourism industry will also be able to utilize the longer summer season to its advantage by increasing cruise activity in that area. (Dicks & Symon. 2012)

However the Arctic waters will not be devoid of danger. Despite a longer summer season to ship cargo around the Arctic, the icebergs and storms, maintain the current levels of risk associated with this type of transportation. Currently Canada is trying to handle transportation through the Northwest passage in the Arctic archipelago, located in the Canadian extreme north. So far they have not found a way to ensure a safe, cost-effective and predictable passage through the Northwest passage. (Prowse & Furgal. 2009) Ships will have to deal with icebergs with increased speed; less sea ice also gives icebergs more mobility in the waters. Not only do ships need to look out for this new danger, but oil platforms as well. Icebergs have been known to cause structural damage to oil rigs. (Dicks & Symon. 2012)

On the contrary, a shipping lane near Greenland, dubbed “Iceberg Alley” is now ice-free during the summer months, increasing ship travel. (Harsem & Eide. 2011)

Another danger is the formation of fog over the open water as the summer ice melts. This can make navigation more difficult and potentially freeze up the ships as well. Higher ship traffic through the Arctic would also require the expansion of search and rescue operations because of the higher traffic of the area. (Dicks & Symon. 2012)

Lower ice levels also mean that ice roads will not be able to be used or relied on as often. In Canada about 2500 shipments to 30,000 natives are made on Canadian ice road networks. With these ice roads thawing, an increasing number of transport vehicles are stranded on these thawing roads. In the 2009/10 Canadian winter, a 2200 km portion of a ice road network was shut down due to thawing of ice roads. Similarly, a state of emergency was declared in 11 communities in the Canadian Arctic for the same reason. (Dicks & Symon. 2012) This trend is only expected to continue. This will force a reliance on water; transportation of the same shipments through use of rivers or other waterways.

Transport vehicles aren't the only things that need to be wary of the melting ice on land. The thawing of underground ice and the resulting craters made, called a thermokarst, can cause a lot of damage to cities and towns caught in the way. In Yakutsk, Russia in 2006, several cars fell into a huge thermokarst crater that had formed under a car park. (Dicks & Symon. 2012)

This melted ice water can also cause flooding in low lying coastal areas. (Forbes & Kremer, 2011) East Siberian rivers already experience extreme flooding. After catastrophic flooding of the Lena River in 2001, the city of Lensk was damaged so badly that it had to be rebuilt. Flash floods and mud flows can also occur from the melt water. (Dicks & Symon. 2012)

Wind can push ice chunks onto the coast, sometimes even 100 meters in just hours. These chunks are and will remain a hazard for coastal communities as well. (Dicks & Symon. 2012)

Offshore drilling platforms will have to adapt themselves to the decreasing amount of sea ice. (Prowse & Furgal. 2009) If the sea ice disappears, platforms will have to adapt to handle an increased frequency and severity of waves and storm surges. Already, storms in the North Sea have resulted in Norwegian oil production being cut by 10% in companies with older unprepared assets, which is estimated at around 220,000 barrels per day. At the very least, companies will have increased operational costs when working in the Arctic sea area. (Firth, 2009)

A perfect example of the difficulty of building in the Arctic seas is Gazprom's attempt to develop an oil rig at the Shtokman oil field in the Barents Sea. One of the main reasons that the project failed was because of the dangers that plagued the area, and the cost to develop solutions to those dangers. When designing the oil rig, designers came upon one big problem in particular, that of gigantic icebergs that would move through the area. Some of these icebergs could be 100 km long and equal the total area of Jamaica. Some of these icebergs were also deep enough to scrape along the 600 m deep sea floor. (Pitt, 2007) In addition to this problem, ocean freezes and violent storms take development one step further. (Pitt, 2007)(Zhdannikov, 2007) Norway's Snohvit oil field was built in the same conditions, and although it was a relatively small rig, it cost upwards of $10 billion. (Pitt, 2007) The platform Hibernia has been built to withstand one million ton icebergs without damage. (Harsem & Eide. 2011) That structure cost $4-6 billion alone, development and exploration costs aside. (Morozov. 2012) If the current climate change trends hold, there will be more cases like Shtokman and Snohvit in the Russian Arctic. When developing plans for the Sakhalin-1 project off the coast of Russia, industry reports indicate that it took about 10 years for planners to gather reliable enough data to plan the rig. (Harsem & Eide. 2011) In order to succeed in the Arctic, companies need to pay big to have the right precautions taken. Otherwise their projects will fail.

With respect to utilities companies, thermal plants will get hit the worst. Abundant sea ice chunks that flow down rivers, a common occurrence in the Russian Arctic, can disrupt the effective capacity of the thermal plants. If intake structures are blocked, energy production of the power plant goes down and the operational costs of the plant rise. For the remote facilities all over the Russian Arctic, monitoring and fixing such problems can be an issue. (Prowse & Alfredsen. 2011)

Hydro-electric plants will benefit from the melting sea ice. Reservoir ice will only get thinner and weaker, meaning that the plants can use more of the reservoir water during winter, when electricity demand is high. In addition, reservoir structures won't have to be as costly as they are now because there will be less ice, and there is less risk of flooding when the reservoir ice melts at the end of winter. (Prowse & Alfredsen. 2011)

### 4.4.2 Snow Cover

Snow is a great reflector especially of the sun's energy. Cold snow reflects about 85% of the sun's energy, and wet snow reflects about 75%. For comparison, open water reflects about

7% of the sun's energy. If more snow melts, less of the sun's energy will be reflected meaning that the earth will absorb more heat from the sun. (Dicks & Symon. 2012)

Larger snow depth will also be a danger to buildings and infrastructure. Building strength is determined on snow loads of previous years, but with the snow loads increasing each year buildings will need to be continually re-assessed and strengthened until a new maximum limit has been reached. People have already died in Quebec in the winter of 2007/08 in building collapses. (Dicks & Symon. 2012)

The increasing amounts of precipitation in the Arctic, coupled with the melting of ice roads, will further limit transportation by land. (Prowse & Furgal. 2009) Operational costs will rise at various plants across the Arctic due to the increased amount of snow, however due to the shorter winter season, the adverse effects of snow coverage to oil and gas and energy companies is minimized.

### 4.4.3 Permafrost

Permafrost thaw will also be another significant danger to buildings and infrastructure. Many oil pipelines and communities, even some large cities, are built on permafrost. Foundation stability of buildings will be challenged when permafrost thaws; when permafrost thaws the ground becomes softer. The ground won't be as supportive when that happens and buildings could also begin to sink or tilt as the ground beneath them literally sags from the weight of the building. Buildings could crack or even tear themselves apart if this goes unchecked, as shown in Figure 16 on the next page. To ensure continued structural stability, buildings will need to be maintained more frequently or they could become uninhabitable. (Dicks & Symon. 2012)

More permanent structures will also have to adapt to the thawing permafrost. Most buildings in the Arctic are built relying on the permafrost as a foundation. If this foundation were to thaw, these buildings would lose their structural stability. In addition to that, thawing permafrost warps the ground, further wrecking what structural stability buildings might have left. Many processing plants and oil pipelines will have to adapt to this threat. (Prowse & Furgal. 2009) It is estimated that about 40% of the infrastructure in Russian cities is in critical condition due to permafrost thaw. (Morozov. 2012)

When constructing new pipelines, companies need to be aware of new changes in the climate and environment, for instance terrain stability, temperature, and drainage, all caused by permafrost thawing. (Prowse & Furgal. 2009) Older pipelines in the Russian Arctic are in serious danger of failure, which would have a major effect on the environment around it. (Martikainen & Holttinen, 2005)

Similar to the oil and gas sector, thawing permafrost will have a serious effect on energy structures in the Russian Arctic. Already infrastructure in Siberia has experienced major damage. (Martikainen & Holttinen, 2005) As stated above, about 40% of the infrastructure in Russian cities is in critical condition due to permafrost thaw. (Morozov. 2012)


*Figure 16: Structural damage caused by permafrost thaw*

Thawing permafrost will impact oil and gas exploration the most. Increased snow cover and the thawing permafrost will first force companies to use low-impact vehicles and/or change the timing of their exploration endeavors. With the unpredictability of the winter ice road system, transportation and exploration will take a significant hit. (Prowse & Furgal. 2009)

Transportation over land will also take another major hit as the permafrost thaws. Large scale transportation is also impossible in the marshy land which the permafrost is yielding to. This forces on-land transportation to increasingly rely on the shortening winter season. (Harsem & Eide. 2011) Coupled with ice road failure described above, this is spelling disaster for the on-land transportation services. Because of weakened soil strength, construction work is expected to be more difficult with present vehicles. Higher utility costs will arise from the need for new vehicles. (Martikainen & Holttinen, 2005)

Permafrost thaw will also adversely affect exploratory drilling. When performing exploratory drilling, prospectors dispose of the drill cuttings and fluids are disposed of in sumps, small excavations that are made next to the drill site for disposal. These sumps are covered with excavated material. Utilizing the permafrost, drilling waste is trapped between the permafrost and the layer of sediment covering it as shown in Figure 17. As long as excavators take the time to freeze the drilling waste before covering it, this is an effective way to dispose of the waste. (Kokeli. 2002) However, if the permafrost thaws, the permafrost becomes a much less effective container and the potential for contamination is greatly increased. (Kanigan & Kokeli. 2010)

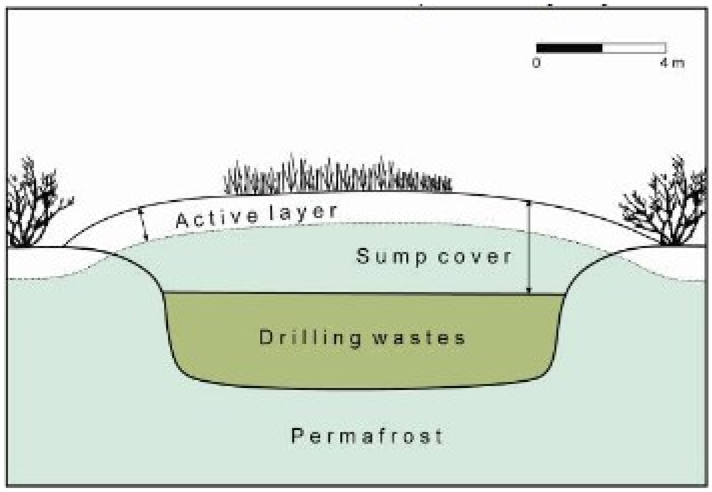


*Figure 17: A cross section of a sump*

## 4.5 Summary

Not a single risk is caused by only one climate change driver. Varies interrelated effects could lead to different risks for energy companies. Based on our research, we found the main risks that threaten the energy companies in Russia are: flooding; ice road melting; storm surges; power generation disruption; and structural failure. Generally, climate change is thought to have a mostly negative effect on the energy sector. Increasing costs and decreasing incomes mean that the profitability of energy companies will decrease. (Martikainen & Holttinen, 2005) In the next step of the project, we will prioritize two of the risk described ahead because of the time constraint in the next section to analyze for providing adaptation solutions for energy sector.

# 5. Priority Risks

Due to the short time frame to the project, it would have been impossible for the development of adaptation solutions for every climate change effect found. Instead, all risks were prioritized. This held a dual-purpose; companies would get a recommendation on which risks had the most impacts on their assets, and there would only be a need to research adaptation solutions for the most important effects.

## 5.1 Description of method used to choose priority risks

There were three methods used to prioritize risks. The first and the second methods involved the econometric modeling and surveys detailed in the methodology section to prioritize current and future risks. The results of the surveys were insufficient, so another method was needed for risk prioritization.

The next approach to prioritize risks involved the development of an impact chart. This impact chart identified which climate change effects impacted which type of asset. Priority was assessed on which risks affected the most assets. The survey we designed and impact charts for Oil & Gas and Utility company assets are provided in Appendices 1 and 2 respectively.

## 5.2 Results

What follows are the risks found to have the most impact in the present and the future.

### 5.2.1 Priority Risks of the Present

By using the econometric modeling method describe previously, we prioritized the current risks that affect economic indicators (gross profit, cost of goods sold, and operating revenue) of energy companies located in Russian Arctic. We analyzed a number of Russian companies which operate in the Arctic region: Belomorskaya Neftebaza (in Kandalaksha), Arkhangelsknefteproduct (in Arkhangelsk), Commandit Service (in Murmansk), Taymyrskaya Fuel Company (in Krasnoyarsk) and Yakutskenergo OJSC (in Yakutia-Sakha / Bukhta Tiksi).

According to our approach, $X_1$, $X_2$, ……, $X_{11}$ are independent and exogenous random variables: annual average temperature (°C), annual average maximum temperature (°C), annual average minimum temperature (°C), total annual precipitation of rain and / or snow (mm), annual average wind speed (Km/h), total days with rain during the year, total days with snow during the year, total days with thunderstorm during the year, total days with fog during the year, total days with tornado or funnel cloud during the year, total days with hail during the year, $Y_1$, $Y_2$, and $Y_3$ are dependent and endogenous random variables: gross profit, cost of goods sold, and operating revenue.

### 5.2.1.1 Gross profit

To determine the risks with the most impact on gross profit, assume $X_1$, $X_2$... $X_{11}$ are weather conditions (such as temperature, precipitation, etc.) and $Y_1$ is gross profit. The results of the modeling are as follows:

$R^2$ = 0.8104 means that *Var(*$X_1$*)* describes *Var(*$X_2$*)* by approximately 81.04%. $R^2$ coefficient is close to 1, which means that our model has good specification quality. Adjusted $R^2$ = 0.7294 means that the model explains 73% of all observations in the dataset. To verify the significance of the coefficients, the T-test was carried out. This test demonstrated that wind and snow are significant coefficients that have impact on gross profit of Russian companies in the Arctic region. DW-test showed absence of autocorrelation.

Based on the analysis, only two out of eleven climate variables have direct influence on gross profit. These variables are annual average wind speed (Km/h) and total number of days with snow during the year. Other set of variables such as maximum temperature, precipitation, wind, rain, snow, thunderstorm, fog, tornado or hail showed no correlation with gross profit.

### 5.2.1.2 Cost of Goods Sold

To determine the risks with the most impact on costs of goods sold, assume $X_1$, $X_2$… $X_{11}$ are weather conditions (such as temperature, precipitation, etc.) and $Y_2$ is Costs of Goods Sold (COGS). The results of the modeling are as follows:

$R^2$ = 0.06771 means that *Var($X_1$)* describes *Var($X_2$)* by approximately 6.77%. Adjusted $R^2$ = 0.06094 mean that the model correctly explains only 6.09% of all observations. Nevertheless, in order to determine influence of the related coefficients, T-test was checked. It displayed that wind and snow are not very significant variables, but still there is influence of temperature indicators on COGS of Russian companies in the Arctic region. DW-test showed absence of autocorrelation.

According to the tests that have been done, we got the same findings: annual average wind speed (Km/h) and total days with snow during the year are the only two variables that would have impact on COGS.

### 5.2.1.3 Operating revenue

Finally, to determine the risks with the most impact on operating revenue, assume $X_1$, $X_2$… $X_{11}$ are weather conditions (such as temperature, precipitation, etc.) and $Y_3$ to be operational revenue. The results of the modeling are as follows:

$R^2$ = 0.90157 means that *Var($X_1$)* describes *Var($X_2$)* by approximately 90.15%.$R^2$ is very close to 1 and regression line doesn't miss any points in the dataset. Adjusted $R^2$ = 0.81142 proves that the model explains 81% of all observations. The T-test showed that wind and snow are significant coefficients that have impact on operational revenue of Russian companies in the Arctic region. DW-test showed absence of autocorrelation. Thus, annual average wind speed (Km/h)) and total number of days with rain during the year are the two variables that have influence on operational revenue.

### 5.2.1.4 Conclusion

To conclude, the panel data analysis carried out for four energy companies in the Russian Arctic shows that wind speed has correlation with gross profit, COGS, and operational revenue. Also, all checked econometric tests prove that there is powerful dependence between all variables. Russian companies that operate in the Arctic region have certain risks associated with their activity because climate changes (like changing wind speed) could cause unpredicted costs for these companies.

### 5.2.2 Future prioritized risks

Based on the impact charts that can be found in Appendix 2, permafrost thaw and flooding were found to have the most impact on the Arctic energy companies in the future.

These findings correlate with the survey response given to us by a professor at Oxford University. To respect their privacy, their name will not be used. In their response, they echoed the findings from the impact chart, stating that permafrost thaw had the most significant impact that energy companies need to consider. In relation to the damage to infrastructure, they gave high scores to significance and impact. They also added commentary on the level of unpredictability that comes with permafrost thaw. They argued that in order for existing company infrastructure to have any benefit from the adaptation solutions they will need to solve their issues with transportation and increase local energy in the area. Contrary to our conclusions, the second risk with the most impact on the energy sector they felt was the melting of ice and the disruption it would have on Arctic transportation. The Oxford professor’s response is included in Appendix 3.

Due to the nature of impacts of the future priority risks, as well as the Oxford professor’s survey answers, solution focus was placed on the future priority risks.

# 6. Adaptation Solutions

This section details the adaptation solutions found for the two priority risks found in the previous section: permafrost thaw and flooding. Research was performed to find existing solutions to these issues developed by other companies and countries.

## 6.1 Description of Solution Assessment

The criteria for adaptation solutions are the following:

- An adaptation solution should lessen the effects of the climate change impact that it was supposed to "solve";
- An adaptation solution needs to concern some sort of change or addition to current operations in the Arctic.

Moreover, solutions were only considered if they were a proven solution. In order to be proven, these solutions needed to be implemented by countries or companies already in an arctic setting. Given below are the brief descriptions of the solutions found for the two priority risks.

## 6.2 Solutions to Permafrost Thaw

The main impact associated with permafrost thaw is structural failure. Adaptation solutions researched for permafrost thaw were focused on solving this problem.

### 6.2.1 Thermosiphons

Permafrost thaw occurs when the temperature in the permafrost rises above 0 degree Celsius. A thermosiphon is an adaptation solution that tries to keep the temperature in the permafrost below 0. They were developed in Alaska in 1965 (Holubec, 2008) ("Infrastructure in permafrost: a guideline...", 2010).

Thermosiphons are hollow tubes with gas inside of them. The gas absorbs the heat in the permafrost and rises to the top. At the top, the heat is released through a radiator and the now cool gas falls to the bottom of the tube. (Holubec, 2008) Figure 18 shows them being used to protect building foundations. The thermosiphons are the tubes that stick out of the ground next to the building. Gazprom is already using this method in their Bovanenkovo field in the Yamal-Nenets region as well as other fields. (“*Bovanenkovo”*, 2013)

*Figure 18: Thermosiphons used in building foundations*

This method is good for maintaining the status quo. It is already employed at roadbeds and other installations in the Arctic, mostly in America and Canada (Wagner & others, 2010). As the general Arctic temperature rises, the thermosiphons need to work harder. It is unknown whether or not thermosiphons will become ineffective if the temperature rises or not, but this should still be considered when implementing thermosiphons.

### 6.2.2 Foundation Leveling

Especially for pre-existing buildings, sometimes permafrost thaw is very hard to avoid and damage occurs. Leveling a foundation is a reactionary measure to fix any damage caused by permafrost thaw to a building's foundation.

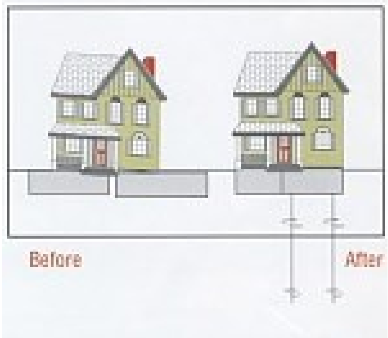


*Figure 19: Depiction of a foundation leveling*

Leveling a foundation is a standard practice; however there is still room for error. Depending on the damage, different types of piers, anchors, or lifts are used to move and hold the foundation into place, as shown in Figure 19 ("*Methods of Foundation Repair*").

### 6.2.3 Modified Pile Foundations

A pile is a long support placed in the ground that will support a structure above. They are usually made out of wood, steel, or concrete (McFadden, 2001).

Wood and steel piles need to be treated for rot and corrosion respectively. Concrete piles are used mostly in Russia. There are several things that can go wrong with concrete piles. First off, when poured into a hole on site, if the pile is big enough the heat of hydration could thaw the permafrost itself. The problem is that concrete piles casted on-site need to be big so that the soil from the ground does not damage the curing concrete. Concrete piles that are pre-casted are very heavy and unwieldy. It is hard to install pre-cast concrete piles without damaging them first. (McFadden, 2001)

Piles are considered to be the most effective foundational type when building on permafrost. However, many piles are based on the permafrost for support. If the permafrost is not thawing, then this is considered an effective foundation. However if the permafrost was indeed thawing, like it is in a good portion of the Russian Arctic, this foundation quickly loses this effectiveness. Although it is incredibly difficult, especially when modifying existing piles, extending the piles past the permafrost onto the bedrock below seems to be the best way to ensure structural stability (McFadden, 2001) ("Infrastructure in permafrost: a guideline...", 2010).

### 6.2.4 Increased building air circulation

This method was actually developed in Russia, but it was expanded upon and improved in the USA. The idea behind increased air circulation is to intercept any heat from the building before it reaches the permafrost active layer. To facilitate this, buildings are raised on piles. Cold winter air will be able to circulate under the building and remove any heat that escapes from the building. It is used hand in hand with the pile methods mentioned above (McFadden, 2001) (McFadden, 2000) ("Infrastructure in permafrost: a guideline...” 2010).

The bottom of the raised building also needs to be properly insulated to ensure that not that much heat can escape from the building. This will also ensure that the floor is not cold (McFadden, 2001) (McFadden, 2000) ("Infrastructure in permafrost: a guideline...” 2010).

How much a building should be raised depends on the size and heat output of the building. The required airspace depends heavily on wind strength and typical snow depth of the area. An average rule given by the Design manual for stabilizing foundations on permafrost is that the “Aspect ratio defined by the minor dimension of the building divided by the clearance height above the ground should be less than 10.” It is necessary that the airspace underneath be as open as possible, otherwise the air underneath the building will heat up and warm the underlying ground and permafrost even more (McFadden, 2001). Construction wisdom has taught contractors that the minimum distance that a building can be without its heat affecting the ground is two feet (McFadden, 2000).

It is important that the space underneath the building is not used for any storage purposes. As stated before, air flow in this space is of optimal importance (McFadden, 2000).

## 6.3 Solutions to Flooding

The main impact associated with flooding is flash floods, high volume of water, and little warning time associated with them. Adaptation solutions researched for flooding were focused on solving this problem.

### 6.3.1 Hinged Flood Gates

One of the strategies for flooding that was discovered was hinged flood gates. These flood gates can be used to protect either a large general area, or can be fitted to protect sensitive equipment. It is a small aluminum gate that can be installed and removed easily. The gate can be put in before floods hit and can be removed once the area is safe again. The anchors of the gate are secured to the wall using compression gaskets to create a watertight seal.

There are two designs of the gate: one is an insert and the other is hinged like a door. The insert is a sheet of aluminum that is fitted to the anchors of the gate.

*Figure 20: Hinged flood gate examples*

The hinged door is hinged to the anchor and acts as a metal door. Both of these designs are customizable to be as long or as tall as seen fit, as detailed in Figure 20.

Companies such as Exxon Mobil, Chevron Texaco, Conoco Phillips, and GE Oil and Gas are using gates to prevent such damage. This is one of the easier solutions because it is customized to needs and current setup which will not require any alterations to the asset's setup.

### 6.3.2 Concrete Moats

Another strategy is concrete moats. These are trenches that are lined with concrete to catch overflow from floods and prevent them from entering facilities. These moats can be customized on location as well as size to fit the company's needs.

In addition to protecting the asset from floodwater, the moat also acts as a barrier between the oil and the water. If oil were to spill from an asset, the moat would prevent the oil from ever reaching any water and the spill will be contained for easier cleaning and removal.

One company that uses moats is Entergy. In 2010, one of Entergy's plants located in New York experienced a fire and the plant began to leak oil into the Hudson River. The original purpose was to create something that will prevent oil spill, but this also resulted in the benefit that the section for oil production has also been protected by any flood water that could possibly damage the section.

Water pumps would be used to remove water from the moats. Though it is a timely process, it is easier and less expensive than cleaning up an oil spill.

### 6.3.3 Polymer Foam

The last strategy to be discussed is polymer foam. Polymer is a chemical agent that is both water resistant and waterproof. The polymer can be applied as a coating for walls or pipes to seal any cracks found and prevent flood water from leaking into other areas. The foaming agent can also be used to fill pipes to act as a barrier between the water and wires or other equipment. The polymer will keep the cables dry without disrupting their activity or performance. Polymer coating has also been shown to prevent corrosion and protect against rust ("*Kraton Polymers…*").


*Figure 21: Polymer foam use example*

Another form of polymer that has been discovered and is currently being used is pipes that are already lined with polymer. Manufacturing companies have already created pipes that are lined with sheets of polymer. These pipes come with added benefits as they are resistant to water, electricity, shock, extreme temperatures, and show no signs of wear or cracking. These pipes are also flexible and can be used to fit any type of wiring or cables just as it is done in Figure 21. It is also safe enough to use them as gas lines with no concerns of leakage ("*Kraton Polymers…"*).

The physical polymer is a quicker solution to the pipes because it can be applied without installing or reworking present conditions. However, the pipes have a longer lasting effect, but they require re-piping the asset which would cost more ("*Kraton Polymers…"*).

# 7. Roadmap

## 7.1 Overview of Roadmap

This adaptation roadmap is for energy companies to develop their own Arctic climate change adaptation solutions. It contains 6 steps and is presented in the chart below. Each step will be described in detail in the next section.

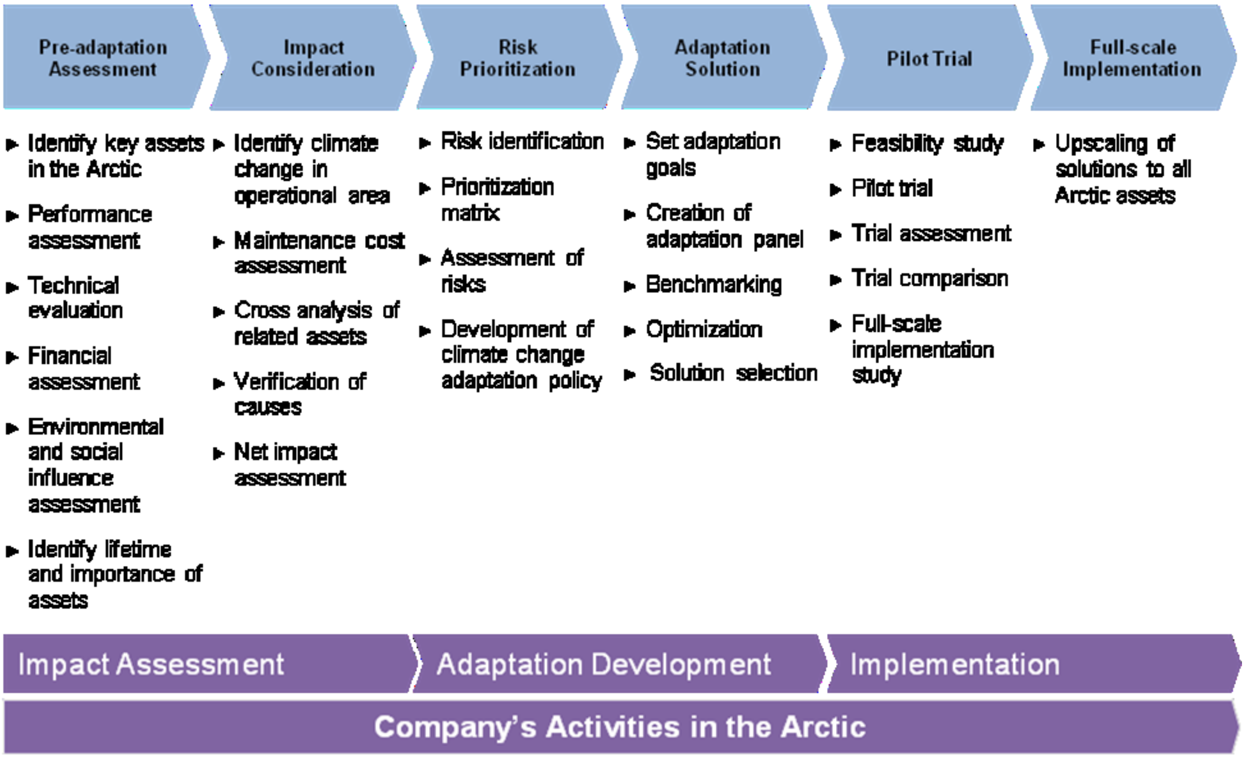


*Figure 22: Adaptation Implementation Roadmap*

## 7.2 Description of Roadmap

The adaptation roadmap is designed to help companies implement adaptation solutions. Each step is designed to give companies general guidelines to follow to assess climate change impacts and implement solutions to these impacts.

### Step 1: Pre-adaptation assessment

A company should begin with the identification of its key assets in the Arctic so that companies can start the adaptation process knowing exactly how important the Arctic is to their company. Companies need to assess the current performance of their Arctic assets in addition to performing technical evaluations and financial assessments to ensure maximum understanding of any impacts on these assets later in the next step. In addition, companies should keep in mind the social and environmental influences that their assets have in the surrounding area. The final part in the first step is for companies to determine the estimated lifetime of their assets in the Arctic. This final step will be expanded upon in later steps.

## Step 2: Impact Consideration

After having a comprehensive understanding of company activities in the Arctic, the company needs to identify what impacts may influence its Arctic assets. First, companies need to establish how the climate has changed in the asset's operational area. Focus should be placed on rises in maintenance or other operational costs. In order to prevent further damage, a comprehensive analysis should also include a cross analysis of the impacts on any related assets. Some assets might be experiencing impacts that others will experience later. It is better to be prepared. Since most assets usually have interrelations with each other, the damage of one asset could interfere with the normal operation of other assets. To provide better solutions in the later steps, causes should be verified and also the net impact assessment can be determined. Not all impacts are damaging, some have benefits that can help the asset. The net impact can be either beneficial or detrimental, once the cause is classified, the asset can determine whether or not a solution needs to be found.

For each impact, companies should define an "onset time", which is a time estimation when an impact will reach its greatest impact on company activities.

## Step 3: Risk Prioritization

Once impacts have been identified and verified, the next step is prioritization of risks. In order to do this, we recommend constructing a prioritization matrix, a chart that organizes impacts. This matrix would determine which impacts are most relevant to them. Companies should make sure to compare asset lifetimes with the onset times of impacts. If an onset time falls outside of the operational lifetime of an asset, then in most cases that impact should be given an extremely low priority.

Afterwards, the risks need to be assessed. Questions such as "How damaging are these risks?", "What are these risks damaging?" and "How are these risks impacting our performance?" will be asked here. Once the risks and their effect are determined, it is recommended that companies create an adaptation policy for their companies to increase awareness of the issue and increase response time to any unforeseen climate change impacts that can arise. By having a unified company policy on the matter, it could facilitate further adaptations later.

## Step 4: Adaptation Solution

Companies can then begin researching and developing solutions for the highest priority impacts. Companies should start with a quantifiable goal for adaptations to specific assets This will enable companies to assess solutions they find or develop more efficiently. The company should create an adaptation panel which consisting of experts in various fields themselves to increase the chances of finding a solution. The panel will find various solutions which should be optimized and benchmarked. Once the short list of the most viable solutions is created, the selection process can begin. The solutions should be studied more in depth and tested to determine which is the best.

## Step 5 and 6: Pilot Trial and Full-scale Implementation

Based on the ideal solutions, we need to test whether these solutions are practical and useful for the energy companies. Also in reality some solutions might differ from what was expected of them in theory. The only way to figure out if a solution works is to test it. That’s why we suggest a pilot trial to be performed on all viable solutions. Each adaptation solution should be implemented on an asset of low importance in the Arctic, to accurately measure its effects. During this pilot trial, the company can begin to look at the feasibility of the solution for further consideration. The trial should be monitored at all times to determine effectiveness and efficiency. Once this assessment is completed, each trial's results should be compared to determine which trial was most effective, feasible, and efficient. When the solution has been chosen, the company can begin working on full scale implementation.

# Summary

Russian energy companies are unaware of the strong influence they have over the Arctic and of the struggles that they also create for themselves in the future. Current energy company practices contribute to detrimental climate change effects that are causing changes in the Arctic, which negatively affect their own operations in that area.

These damaging effects are the reason a company should look to adaptive solutions. Through our research we found that an energy company that does not adapt will sustain damages, some that will be very costly and could potentially disrupt any advances that the company hopes to achieve. Energy companies seem to focus on the present, which our research has proven not to be an effective company standpoint. The project looked into the effects that had the most impact on energy company operations; priority was given to effects that were believed to be the most harmful to energy companies. We placed priority on permafrost thaw, which would result in permanent structure failure, and flooding, which would disrupt general operations.

To aid energy companies further with starting solution implementation, the project lists adaptation solutions already used by other companies and countries to combat our priority risks. We believe that the solutions we provided will ultimately help companies prevent catastrophic events if implemented soon.

The road map provides steps for a company that has heeded our warning and wishes to implement their own adaptations. From beginning to end, the roadmap gives developed instructions to implement adaptations on a full scale.

In general, rather than focus on the standpoint of the environment, this paper also focused on the standpoint of an energy company with regards to climate change. We understand that Russian energy companies will expand their operations in the Russian Arctic regardless of what pro-Arctic non-governmental organizations and indigenous people say. Our goal was not to stunt the progress of these companies, but to enable their progress uninhibited by future environmental concerns. The secret to profit in this changing environment does not lie in aggressive expansion. Rather, controlled expansion with proper precaution taken will prove to be the most profitable in the future.

This project aimed to find the best of both worlds: a working relationship between company operations and a thriving environment due in thanks to adaptation solutions. We feel that this unique perspective should be taken seriously for that reason: there are no other ulterior motives to consider. The motivation of this paper is to promote sustainable business practice with viable commercial reasoning. Companies can only be persuaded for climate change adaptation if they can see how climate change affects their own motivators, particularly profit, which we feel our paper addresses. Companies need to be made aware of climate change, conscious of the results of their methods, and have the motivation to implement those solutions. It is our hope that companies will actively pursue climate change adaptation to protect their own interests in the future.

# References

*2011 Public Annual Report* (2012). -RosAtom. Retrieved September 12, 2013, from: http://www.rosatom.ru/en/resources/2aabb8004ed9b097878e8f08a49b1a70/anrep_2011_eng.pdf

Acclimatise (2009). *Carbon Disclosure Project Report 2008: 'Building Business Resilience to Inevitable Climate Change'*. -CDP. Retrieved September 10, 2013, from: http://cssa.asu.edu/sites/default/files/IBM%20Carbon%20Disclosure%20Project%20Report%20Oil%20and%20Gas.pdf

*Acid Rain Facts, Acid Rain Information, Acid Rain Pictures, Acid Rain Effects - National Geographic*. (n.d.). Retrieved September 12, 2013, from http://environment.nationalgeographic.com/environment/global-warming/acid-rain-overview

*All About Arctic Climatology and Meteorology - The Arctic :: NSIDC.* (n.d.). Retrieved September 10, 2013, from http://nsidc.org/cryosphere/arctic-meteorology/factors_affecting_climate_weather.html#precipitation

Assessment, A. C. I. (2004). Impacts of a Warming Arctic-Arctic Climate Impact Assessment. *Impacts of a Warming Arctic-Arctic Climate Impact Assessment, by Arctic Climate Impact Assessment, pp. 144. ISBN 0521617782. Cambridge, UK: Cambridge University Press, December 2004.*, 1.

Ball, R., Breed, W. S., & Hillsman, E. Industry, Energy, and Transportation: Impacts and Adaptation.

Biancamaria, S., Cazenave, A., Mognard, N. M., Llovel, W., & Frappart, F. (2011). Satellite-based high latitude snow volume trend, variability and contribution to sea level over 1989/2006. *Global and Planetary Change*, *75*(3), 99-107.

*Bovanenkovo* (2013) –Gazprom. Retrieved October 8, 2013 from: http://www.gazprom.com/about/production/projects/deposits/bm/

Cavalieri, D. J., & Parkinson, C. L. (2012). Arctic sea ice variability and trends, 1979-2010. *The Cryosphere, Volume 6, Issue 4, 2012, pp. 881-889*, *6*, 881-889.

Clement, J. P., Bengston, J. L., & Kelly, B. P. (2013). *Managing for the future in a rapidly changing arctic: A report to the President*. Washington, D.C: Interagency Working Group on Coordination of Domestic Energy Development and Permitting in Alaska.

*Climate Change Adaptation Report* (n.d.). -Northern Powergrid. Retrieved September 18, 2013 from: http://www.northernpowergrid.com/som_download.cfm?t=media:documentmedia&i=1461&p=file

*Climate change indicators in the United States*. (2012). United States Environment Protection Agency.

Cronin, T. M. (2012). Rapid sea-level rise. *Quaternary Science Reviews*, *56*, 11-30.

Dicks, L. & Symon, C. (2012). *Arctic Climate Issues 2011 : Changes in Arctic Snow, Water, Ice and Permafrost*. Oslo: AMAP Arctic Monitoring and Assessment Programme.

Dobrovidova, O. (2012, October 25). *Comment: Think you know Russia's position on climate change? Think again.* Retrieved October 13, 2013, from http://www.rtcc.org/2012/10/19/comment-think-you-know-russias-position-on-climate-change-think-again/

Dobrovidova, O. (2012, September 25). *Comment: Why Russia's climate change policy is like a cargo cult.* Retrieved October 13, 2013, from http://www.rtcc.org/2012/09/21/comment-why-russias-climate-change-policy-is-like-a-cargo-cult/

Dobrovidova, O. (2013, June 6). *Climate change fails to make Russia's top 50 development priorities*. Retrieved October 13, 2013, from http://www.rtcc.org/2013/06/05/climate-change-fails-to-make-russias-top-50-priorities/

Doggett, T. (2004, November 9). *Global Warming Exposes Arctic to Oil, Gas Drilling.* Retrieved from http://www.commondreams.org/headlines04/1109-06.htm

Ericson, J. P., Vörösmarty, C. J., Dingman, S. L., Ward, L. G., & Meybeck, M. (2006). Effective sea-level rise and deltas: causes of change and human dimension implications. *Global and Planetary Change*, *50*(1), 63-82.

*Evonik Industries - Polyamide 12 and PEEK for oil & gas applications - Offshore Technology*. (n.d.). Retrieved October 14, 2013, from http://www.offshore-technology.com/contractors/lubricants/evonik-industries-polymers-energy

Field, C. B., Barros, V., Stocker, T. F., & Dahe, Q. (Eds.). (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Firth, J. (2009). *Oil and gas Understanding the investment implications of adapting to climate* change. Acclimatise.

*Flood protection with lightweight aluminum flood panels, flood barriers.* (n.d.). Retrieved October 6, 2013, from http://www.floodbarriers.net/hinged.htm

Forbes, D. L., Kremer, H., Lantuit, H., Rachold, V., & Reiersen, L. O. (2011).*State of the Arctic Coast 2010: Scientific Review and Outlook*. Land-Ocean Interactions in the Coastal Zone, Institute of Coastal Research.

Hamilton, N. & Sommerkorn, M. (2008). *Arctic climate impact science an update since ACIA*. Oslo, Norway: WWF International Arctic Programme.

Harsem, Ø., Eide, A., & Heen, K. (2011). Factors influencing future oil and gas prospects in the Arctic. *Energy policy*, 39(12), 8037-8045.

Hennegriff, W., Kolokotronis, V., Weber, H., & Bartels, H. (2006). Climate Change and Floods– Findings and Adaptation Strategies for Flood Protection.*KA-Abwasser, Abfall*, *53*.

Holubec, I. (March 2008). *Flat loop thermosyphon foundations in warm permafrost*. Retrieved October 7, 2013 from: http://www.pws.gov.nt.ca/pdf/publications/Thermosyphon%20Foundations%20in%20warm%20permafrost%20.pdf

*Infrastructure in permafrost: A guideline for climate change adaptation.* (2010). -Canadian Standards Association. Retrieved October 8, 2013 from: http://shop.csa.ca/en/canada/infrastructure-and-public-works/plus-4011-1st-ed-pub-2010/invt/27030762010

Irwin, J. (2012). *Oil and Gas Elastomers | DuPont Polymers*. Retrieved October 14, 2013, from http://www2.dupont.com/Plastics/en_US/Knowledge_Center/engg_design_mag/edmag2012_ed02/edmag2012_ed02_01.html

*Issue Overview of IPEC Transformer – Indianpoint Website*. (2012). Retrieved October 14, 2013, from http://www.safesecurevital.com/issue-overview-of-ipec-transformer.html

Jevrejeva, S., Moore, J. C., & Grinsted, A. (2012). Sea level projections to AD2500 with a new generation of climate change scenarios. *Global and Planetary Change*, *80*, 14-20.

Kanigan, J., & Kokelj, S. V. (2010). Review of current research on drilling-mud sumps in permafrost terrain, Mackenzie Delta region, NWT, Canada. In *GEO2010: 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference* (Vol. 6, pp. 1473-1479).

Kokelj, S. V. (2002). *Drilling Mud Sumps in the Mackenzie Delta Region: Construction, Abandonment and Past Performance*. GeoNorth Limited.

*Kraton Polymers - Giving Innovators Their Edge*. (n.d.). Retrieved October 14, 2013, from http://www.kraton.com/products/coatings/coatings_roof.php (Polymers in Extreme Environments)

Lenart, M. (2008, September 14). *Southwest Climate Change Network*. Retrieved September 12, 2013, from http://www.southwestclimatechange.org/node/790

Martikainen, A., Holttinen, H., Savolainen, I., Auvinen, O., & Syri, S. (2005).*Impacts on the energy sector and adaptation of the electricity network business under a changing climate in Finland*. Finnish Environment Institute.

Matishov, G. G., & Dzhenyuk, S. L. (2012). Arctic challenges and problems of polar science. *Herald of the Russian Academy of Sciences*, 82(5), 355-362.

McFadden, T. (July 2001) *Design Manual for Stabilizing Foundations on Permafrost*. Retrieved October 3, 2013 from: http://www.uaf.edu/ces/energy/housing_energy/resources/Permafrost-design-manual.pdf

McFadden, T. (September, 2000) *Design Manual for New Foundations on Permafrost*. Retrieved October 3, 2013 from: http://www.uaf.edu/ces/energy/housing_energy/resources/PermafrostNewFoundations.pdf

McLoughlin, P. (2012, November 19). *Norway's Statoil shuts in output at Snohvit LNG processing plant - Natural Gas | Platts News Article & Story*. Retrieved September 12, 2013, from http://www.platts.com/latest-news/natural-gas/London/Norways-Statoil-shuts-in-output-at-Snohvit-LNG-6820229

*Methods of Foundation Repair.* (n.d.). Retrieved October 2, 2013, from http://www.myfoundationrepairs.com/Methods_of_Foundation_Repair.asp

Morozov, Y. (2012). Arctic 2030: What are the consequences of climate change? The Russian response. *Bulletin of the Atomic Scientists*, 68(4), 22-27.

National Snow and Ice Data Center (2013, July 9). *SOTC: Overview*. Retrieved September 4, 2013 from: http://nsidc.org/cryosphere/sotc/

Nerem, R. S., Chambers, D. P., Choe, C., & Mitchum, G. T. (2010). Estimating mean sea level change from the TOPEX and Jason altimeter missions. *Marine Geodesy*, 33(S1), 435-446.

Olsen, M. S., Callaghan, T. V., Reist, J. D., Reiersen, L. O., Dahl-Jensen, D., Granskog, M. A., ... & Walsh, J. (2011). The changing arctic cryosphere and likely consequences: an overview. *Ambio*, *40*(1), 111-118.

Pitt, A. (2007, April 27). *'Iceberg threat' looms over Shtokman -Upstreamonline.com.* Retrieved September 8, 203, from http://www.upstreamonline.com/incoming/article1140023.ece

Polar amplification. (n.d.). In *Wikipedia, the free encyclopedia*. Retrieved October 13, 2013, from http://en.wikipedia.org/wiki/Polar_amplification

*Polymers in Extreme Environments.* (n.d.). Retrieved October 14, 2013, from http://www.twi.co.uk/technologies/material-properties/non-metallic/polymers-in-extreme-environments/

*Post Sandy Enhancement Plan*. (2013). Retrieved from http://www.coned.com/publicissues/PDF/post_sandy_enhancement_plan.pdf

Proshutinsky, A., Pavlov, V., & Bourke, R. H. (2001). Sea level rise in the Arctic Ocean. *Geophysical Research Letters*, *28*(11), 2237-2240.

Prowse, T. D., Furgal, C., Chouinard, R., Melling, H., Milburn, D., & Smith, S. L. (2009). Implications of climate change for economic development in northern Canada: Energy, resource, and transportation sectors. *AMBIO: A Journal of the Human Environment*, 38(5), 272-281.

Prowse, T., Alfredsen, K., Beltaos, S., Bonsal, B. R., Bowden, W. B., Duguay, C. R., ... & Weyhenmeyer, G. A. (2011). Effects of changes in arctic lake and river ice. *Ambio*, 40(1), 63-74.

PWC (2013, September 12). *Global 500 Climate Change Report 2013.* -CDP. Retrieved October 9, 2013, from: https://www.cdproject.net/CDPResults/CDP-Global-500-Climate-Change-Report-2013.pdf

PWC (2013, September 23). *CDP S&P 500 Climate Change Report 2013*. -CDP. Retrieved October 9, 2013, from: https://www.cdproject.net/CDPResults/CDP-SP500-climate-report-2013.pdf

Richter-Menge, J., Overland, J., Proshutinsky, A., Romanovsky, V., Bengtsson, L., Brigham, L., ... & Walsh, J. (2006). State of the Arctic Report. *NOAA OAR Special Report, NOAA/OAR/PMEL, Seattle, WA*.

Rottem, S.V.; Moe, A. *Climate Change in the North and the Oil Industry*; Fridtjof Nansens Instituit rapport 9/2007, 2007. Available online: http://www.fni.no/doc&pdf/FNI-R0907.pdf (accessed on 17 August 2012).

Schuur, E. A., Bockheim, J., Canadell, J. G., Euskirchen, E., Field, C. B., Goryachkin, S. V., ... & Zimov, S. A. (2008). Vulnerability of permafrost carbon to climate change: Implications for the global carbon cycle. *BioScience*, *58*(8), 701-714.

Sinclair, P. (2011, December 5). *NOAA: Arctic Report Card 2011 | Climate Denial Crock of the Week.* Retrieved September 12, 2013, from http://climatecrocks.com/2011/12/05/noaa-arctic-report-card-2011/

Skjærseth, J. B., & Skodvin, T. (2001). Climate change and the oil industry: Common problems, different strategies. *Global Environmental Politics*, 1(4), 43-64.

Wagner, A. M., Zarling, J. P., Yarmak, E., Long, E. L. (2010). *Unique Thermosyphon Roadway Test Site Spanning 11 years.* Retrieved October 3, 2013 from: http://pubs.aina.ucalgary.ca/cpc/CPC6-1770.pdf

Wald, M. L. (2012, March 27). $1.2 Million Fine for Indian Point Fire [Web log post]. Retrieved from green.blogs.nytimes.com/2012/03/27/1-2-million-fine-for-indian-point-fire/?_r=1 (Wald, 2012)

*Warning Arctic oil and gas drilling is too risky* | *Herald Scotland.* (2013, July 27). Retrieved September 10, 2013, from http://www.heraldscotland.com/news/environment/warning-arctic-oil-and-gas-drilling-is-too-risky.21715498

*Weather and Climate* | *Climate Change* | *US EPA*. (n.d.). Retrieved September 12, 2013, from http://www.epa.gov/climatechange/science/indicators/weather-climate

Willis, W. O., & Power, J. F. (1975). Soil temperature and plant growth in the northern Great Plains. In M. K. Wali (Ed.), *Prairie: A multiple view*(pp. 209-220). Grand Forks: University of North Dakota Press.

*World's first floating nuclear power plant to begin operating in Russia in 2016 — RT News*. (2013, July 7). Retrieved September 9, 2013, from http://rt.com/news/floating-nuclear-plant-russia-759/

Zellen, B. S. (2009). *Arctic doom, Arctic boom*. ABC-CLIO.

Zhang, T. (2005). Influence of the seasonal snow cover on the ground thermal regime: An overview. *Reviews of Geophysics*, *43*(4), RG4002.

Zhdannikov, D. (2007, June 15). *Shtokman Field Under Icy Threat* | *The St. Petersburg Times* | *The leading English-language newspaper in St. Petersburg*. Retrieved September 9, 2013, from http://www.sptimes.ru/index.php?action_id=2&story_id=22001

Additional sources:

[1] URL: https://ruslana.bvdep.com/version-2013924/home.serv?product=ruslana
[2] URL: http://www.tutiempo.net
[3]URL: http://www.tutiempo.net/en/Climate/ARHANGELSK/225500.htm

[4] URL: http://www.tutiempo.net/en/Climate/KANDALAKSA/222170.htm
[5] http://www.tutiempo.net/en/Climate/Murmansk/221130.htm
[6] http://www.tutiempo.net/en/Climate/KRASNOJARSK/295740.htm
[7] http://www.tutiempo.net/en/Climate/Yakutia-Sakha_Bukhta_Tiksi_Ice_Strip/218240.htm

# Appendix 1: Blank Survey

What follows is the blank survey template sent to experts to help prioritize risks:

“Dear <insert name here>,

We are the students from Worcester Polytechnic Institute working together with EY Cleantech and Sustainability Services (Moscow, Russia) on a non-commercial project on adaption of Russian energy companies to Climate Change in the Arctic. We believe that with global climate trends as they are, the Russian Arctic is a changing place; many companies, especially Russian ones, need to adapt to the changing climate trends and their effects. We wish to explore different adaptation measures that companies could perform to minimize climate change risks that occur in the Arctic.

In order to complete this project, we need your assistance. We hope to use your answers to the following survey to find out which effects should be considered the most influential and then work from that shorter list. By default, your answers will be kept confidential. If you want us to indicate your name in the report, please mention it in your response.

If you agree to participate in the survey, we kindly ask you to complete the survey and send it back to us till **October 10, 2013**.

This survey is in open-ended form. Please answer each question to the best of your ability, and with as much detail as you would like. If you are fine with potentially receiving a follow-up email with questions about your answers, please indicate that by marking in the box below:

[] I am fine with a follow-up email.

Thank you for your time and giving us the much-needed input for our project,

**John Morrow, Mercedes Brown, Peishan Wang**

Worcester Polytechnic Institute “Team Arctic”

Dear <insert name here>,

In all cases where we ask you to assign a rank to different items, a rank of 10 indicates the upper extreme and a rank of one indicates the lower extreme.

[1] Rate, on a scale of 1-10, your opinion on the level of awareness to global Climate Change in the Arctic of the groups specified:

| **Group** | **Rank**<br>**(10 – max, 1 – min)** |
|---|---|
| Energy (utilities) companies operating in the Arctic | |
| Oil & Gas Companies operating in the Arctic | |
| International Financial Institutions and Development Agencies | |
| Financial Institutions | |
| Experts on the Arctic | |
| NGOs (including environmental activists) | |
| Media | |
| Policymakers | |
| *Other groups (please specify)* | |

If possible, please elaborate on your rating.

*Response:*

[2] Do you know of any good examples of Climate Change adaptation in the Arctic Circle by companies operating in Alaska, Northern Canada, Greenland, and Norway? Please explain your opinion.

*Response:*

[3] What do you think should be the most important technology or field of technology that companies operating in the Arctic should invest in to adapt to current global Climate Change trends?

*Response:*

[4] Do you feel current sustainability and climate / environment protection policies of Arctic energy (utilities) and oil & gas companies are adequate? Are there any policies that you feel have been most effective / least effective in promoting sustainable practice in the Arctic? What do you think is the reason for their success / failure?

*Response:*

[5] Please elaborate specifically on Russian energy (utilities) and oil & gas companies operating in the Arctic. What is your opinion on their corporate sustainability and climate / environmental protection policies? Do you feel that they are on par, above, or below the world standard?

*Response:*

[6] Highlight what you consider to be the **three** most detrimental Climate Change effects to the energy (utilities) and oil & gas companies operating in the Arctic.

1. Temperature change
2. Precipitation change
3. Sea ice melting
4. Sea level change
5. Permafrost thaw
6. Seasonal change
7. *Other (please specify)*

If possible, please elaborate on your choice.

*Response:*

Questions 7 to 9 pertain to specific Climate Change drivers in the Arctic and their effect on energy and oil & gas companies in the Arctic. These questions are optional; please provide responses as per your convenience.

[7] There are significant amount of oil & gas resources stored in the Russian Arctic. Temperature rising causes decreases of ice thickness that provide both benefits and weaknesses to offshore / onshore exploration and transportation. What is the current method and technology applied by oil & gas companies to deal with the decreased thickness of ice?

*Response:*

[8] With increasing possibilities of negative effects of the Arctic weather (storms, floods etc.), will energy (utilities) and oil & gas companies be able to properly prepare for these changes? If yes, will they need to make any changes in their activities?

*Response:*

[9] Changes in sea ice, permafrost thaw, and snow cover have led to some detrimental effects on both the land and sea transportation sectors, and general infrastructure of the Arctic. Do you think that the infrastructure and transportation routes already in place can be adapted to the current Climate Change trends, or do you feel that they are irrecoverable? What would you propose be the best solution to adaptation to these effects?

*Response:*

[10] Finally, the table organizes our findings on Climate Change in the Arctic. Please review each Climate Change trend and rank each impact, **on a scale of 1 to 10**, on the level of its probability and significance for oil & gas and energy (utilities) companies (columns "**Probability**" and "**Significance**" respectively). Impacts that only affect specific companies will be marked.

**Main climate driver: Temperature**

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| Global mean temperature | Increasing | Impacts on Oil & Gas companies: | | |
| | | Enhancement of offshore exploration | | |
| | | Decreased time for onshore exploration | | |
| | | Opening of shipping routes | | |
| | | Shortened transportation time in winter | | |
| | | Declining demand and cost for heating fuel in winter | | |
| | | Impacts on Energy (utilities) companies: | | |
| | | Less efficient thermal conduction | | |
| | | Heavy demand and load of air conditioning in summer | | |
| | | Damage of infrastructure (turbines, transmission lines, etc.) | | |
| | | Increasing cost of infrastructure maintenance and repair | | |
| | | Both types of companies: | | |
| | | Decrease of death rate among the employees | | |
| | | Increased disease rate among the employees caused by contaminants etc. | | |
| Winter temperature | Increasing | Impacts on Oil & Gas companies: | | |
| | | Shorten ice roads transportation time | | |
| | | Declining duration and demand of heating fuel in winter | | |
| Frequency and length of heat | Increasing | Impacts on Energy (utilities) companies: | | |
| | | Damage of infrastructure (transmission lines, power plants, etc.) | | |

| | | | | |
|---|---|---|---|---|
| waves | | Increasing cost of infrastructure maintenance and repair | | |

If possible, please elaborate on your rating.

*Response:*

**Main climate driver: Precipitation**

*Since precipitation frequency varies on location, both trends have been included

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| Precipitation Frequency* | Decreasing | Impacts on Oil & Gas companies: | | |
| | | Chance of fires can halt production and cause severe damage | | |
| | | Droughts can effect current oil deposits and slow down machiningDroughts can effect current oil deposits and slow down machining | | |
| Precipitation Frequency* | Increasing | Impacts on Oil & Gas companies: | | |
| | | Flooding could slow down search for new deposits, production, and transportation | | |
| | | Avalanche slow down transportation and halt production | | |
| | | Ice can slow down transportation and damage equipment | | |
| Storm Seasons | Increasing | Both types of companies: | | |
| | | Storm seasons may become longer | | |
| | | More frequent storms effect transportation and production | | |
| Rate of Evaporation | Increasing | Impacts on Oil & Gas companies: | | |
| | | More storms can effect production, transportation and deposits | | |
| | | Dries out land can effect oil deposits | | |
| Wind | Varies | Both types of companies: | | |
| | | Change in direction can effect transportation | | |

If possible, please elaborate on your rating.

*Response:*

**Main climate driver: Sea level / sea ice / snow cover / permafrost change**

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| Snow cover thickness | Increasing | Both types of companies: | | |
| | | Increased maintenance costs (snow cleanup) | | |
| | | Increased risk of structural failure (from increased snow on roofs) | | |
| | | Impacts on Oil & Gas companies: Increased operational cost (snow cleanup) | | |
| | | Specialized equipment for dealing with the higher amount of snow | | |
| Sea level | Rising | Both types of companies: | | |
| | | Flooding of coastal sites | | |
| | | Impacts on Oil & Gas companies: | | |
| | | Potential change in resource access | | |
| | | Impacts on Energy (utilities) companies: | | |
| | | Higher potential for hydro-electric (more power) | | |
| Sea ice | Decreasing | Both types of companies: | | |
| | | Increased ice road failure (melting) | | |
| | | Increased maintenance costs (icebergs, beached ice, waves, storm surges) | | |
| | | Impact on Oil & Gas companies: | | |
| | | Increased mobility through arctic waters | | |
| | | Increased wave strength | | |
| | | Increased water traffic through the Arctic | | |
| | | Impacts on Energy (utilities) companies: | | |
| | | Increased percentage of reservoir availability during the winter | | |

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| Sea chunks/ icebergs | Increasing | Impacts on Oil & Gas companies: | | |
| | | Increased operational risk | | |
| | | Increased platform cost to protect against icebergs | | |
| | | Impacts on Energy (utilities) companies: | | |
| | | Potential hydro-electric failure due to clogging | | |
| | | Increased maintenance costs (to clean ice chunks) | | |
| Ocean variability | Increasing | Impacts on Oil & Gas companies: | | |
| | | Increased survey / exploration cost and time | | |
| | | Decreased reliability of ocean transportation | | |
| Average sea ice age | Decreasing | Impacts on Oil & Gas companies: | | |
| | | Easier water transportation | | |
| | | Lighter ice, meaning increased ice mobility and speed | | |
| | | Impacts on Energy (utilities) companies: | | |
| | | Increased percentage of reservoir availability during the winter | | |
| Ground solidity | Softening | Both types of companies: | | |
| | | Increased chance of structural / foundational failure (for buildings that rely on permafrost as a foundation) | | |
| | | Impacts on Oil & Gas companies: | | |
| | | Potential pipeline failure (due to support failure) | | |
| | | Decreased land transportation reliability | | |
| | | Decreased time for asset exploration | | |

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| | | every year | | |
| | | Increased building costs (different type of foundation) | | |
| Ground warping | Increasing | Both types of companies: | | |
| | | Increased chance of structural failure | | |
| | | Impacts on Oil & Gas companies: | | |
| | | Increased chance of pipeline failure (due to support failure) | | |
| Ground drainage | Increasing | Impacts on Oil & Gas companies: | | |
| | | Sump failure | | |
| | | Increased contamination risk | | |
| | | Impacts on Energy (utilities) companies: | | |
| | | Potential lake and river drainage (damage to hydro-electric potential) | | |

If possible, please elaborate on your rating.

*Response:*

[10] Is there anything that you think we missed, or want to go further into detail? If so, please describe it below.

*Response:*

Thank you very much for your time. Have a nice day!”

# Appendix 2: Prioritization Matrix

| Assets of Oil and Gas companies | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Impact | Offshore drilling | Onshore drilling | Coastal | Infrastructure | Exploration | Sea transportation | Land transportation | Pipeline | Workforce | Total √ |
| Precipitation frequency | | | | | √ | √ | | √ | | 3 |
| Storm surges | √ | | √ | | √ | √ | | | | 4 |
| Longer summer | | | | | √ | | √ | | | 2 |
| More icebergs | √ | | | | √ | √ | | | | 3 |
| Wind pattern change | | | | | | √ | | | | 1 |
| Flooding | | | √ | √ | √ | √ | | √ | | 5 |
| Ice melting | | | | √ | | √ | √ | | | 3 |
| Permafrost thaw | | √ | √ | √ | √ | | √ | √ | | 6 |
| Snow cover decrease | | | | √ | | | | | | 1 |
| Snow volume increase | | √ | | √ | | | √ | | √ | 4 |

| Assets of Utility companies | | | | | |
|---|---|---|---|---|---|
| Impact | Load | Electric transportation | Infrastructure | Coastal | Total √ |
| Precipitation frequency | | | | √ | 1 |
| Storm surges | | | √ | √ | 2 |
| Longer summer | √ | | | | 1 |
| More icebergs | | √ | | √ | 2 |
| Wind pattern change | | | | | 0 |
| Flooding | | √ | √ | | 2 |
| Ice melting | | | | | 0 |
| Permafrost thaw | | √ | √ | √ | 3 |
| Snow cover decrease | | | | | 0 |
| Snow volume increase | √ | √ | | | 2 |

# Appendix 3: Oxford Survey Answers

"In all cases where we ask you to assign a rank to different items, a rank of 10 indicates the upper extreme and a rank of one indicates the lower extreme.

[1] Rate, on a scale of 1-10, your opinion on the level of awareness to global Climate Change in the Arctic of the groups specified:

| **Group** | **Rank (10 – max, 1 – min)** |
|---|---|
| Energy (utilities) companies operating in the Arctic | 8 |
| Oil & Gas Companies operating in the Arctic | 6 |
| International Financial Institutions and Development Agencies | 9 |
| Financial Institutions | |
| Experts on the Arctic | 9 |
| NGOs (including environmental activists) | 9 |
| Media | 8 |
| Policymakers | 6 |
| *Other groups (please specify) Indigenous peoples* | 10 |

If possible, please elaborate on your rating.

*Response:*

[2] Do you know of any good examples of Climate Change adaptation in the Arctic Circle by companies operating in Alaska, Northern Canada, Greenland, and Norway? Please explain your opinion.

*Response: There are some interesting engineering/architectural (to combat less stable permafrost, etc.), energy (geothermal, small hydro, wave, biomass, and wind generation) and transport (portable boat/sleds to contend with less predictable/stable ice) responses to climate* *change in the arctic but the real adaptation must be to lower carbon and other GHG emissions so as to mitigate the anthropogenic cause of climate change. This means moving away from fossil fuel development, which is NOT happening in the arctic.*

[3] What do you think should be the most important technology or field of technology that companies operating in the Arctic should invest in to adapt to current global Climate Change trends?

*Response: Low cost, localized energy generation (solar/wind/geothermal, etc. with local storage). Improved, low carbon, fuel efficient transport systems..*

[4] Do you feel current sustainability and climate / environment protection policies of Arctic energy (utilities) and oil & gas companies are adequate? Are there any policies that you feel have been most effective / least effective in promoting sustainable practice in the Arctic? What do you think is the reason for their success / failure?

*Response: No. Energy utilities have to be regulated and incentivized toward transition. The oil and gas companies appear to be in a race to extract all the fossil fuels that can profitably be extracted. From the standpoint of climate/environment protection, this is madness. The Arctic Council, created to promote sustainable development and environmental protection should lead on this. Slow down and phase out arctic fossil fuel development (unless emission capture becomes economical) and insure that what does take place follows the strictest environmental protocols to avoid contamination, etc. to fragile arctic terrestrial and marine ecosystems and the people who depend on them.*

[5] Please elaborate specifically on Russian energy (utilities) and oil & gas companies operating in the Arctic. What is your opinion on their corporate sustainability and climate / environmental protection policies? Do you feel that they are on par, above, or below the world standard?

*Response: In Russia, it seems that there is an oligopoly controlling oil development and local communities have no choice but to accept their terms and can only negotiate minor environmental mitigation and social development plans, according to the law. And the law is often under-implemented and under-enforced. This leaves local communities relatively powerless in the process and potential victims of the fallout from rapid fossil fuel development both onshore and offshore.*

[6] Highlight what you consider to be the **three** most detrimental Climate Change effects to the energy (utilities) and oil & gas companies operating in the Arctic.

1. Temperature change
2. Precipitation change
3. Sea ice melting
4. Sea level change
5. Permafrost thaw
6. Seasonal change
7. *Other (please specify)*

If possible, please elaborate on your choice.

*Response: The combination of all these factors means that the "Earth is Faster Now" (title of book on climate change impacts in the arctic, translating an Inuit phrase), and less predictable. In terms of catastrophic short term impacts, changing sea-ice and permafrost thawing are huge, but both are obviously triggered by temperature change (warming).*

Questions 7 to 9 pertain to specific Climate Change drivers in the Arctic and their effect on energy and oil & gas companies in the Arctic. These questions are optional; please provide responses as per your convenience.

[7] There are significant amount of oil & gas resources stored in the Russian Arctic. Temperature rising causes decreases of ice thickness that provide both benefits and weaknesses to offshore / onshore exploration and transportation. What is the current method and technology applied by oil & gas companies to deal with the decreased thickness of ice?

*Response: Platform drilling*

[8] With increasing possibilities of negative effects of the Arctic weather (storms, floods etc.), will energy (utilities) and oil & gas companies be able to properly prepare for these changes? If yes, will they need to make any changes in their activities?

*Response: I doubt it. And we know less about how the impacts will affect the marine ecosystem than in the Gulf of Mexico (where our better knowledge still produced the huge Horizon disaster).*

[9] Changes in sea ice, permafrost thaw, and snow cover have led to some detrimental effects on both the land and sea transportation sectors, and general infrastructure of the Arctic. Do you think that the infrastructure and transportation routes already in place can be adapted to the current Climate Change trends, or do you feel that they are irrecoverable? What would you propose be the best solution to adaptation to these effects?

*Response: It will take a huge investment, which in the long-run may be unsustainable without local energy and transport solutions that are energy efficient and climate friendly. I*

[10] Finally, the table organizes our findings on Climate Change in the Arctic. Please review each Climate Change trend and rank each impact, **on a scale of 1 to 10**, on the level of its probability and significance for oil & gas and energy (utilities) companies (columns "**Probability**" and "**Significance**" respectively). Impacts that only affect specific companies will be marked.

**Main climate driver: Temperature**

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| Global mean temperature | Increasing | Impacts on Oil & Gas companies: | | |
| | | Enhancement of offshore exploration | 7 | 8 |
| | | Decreased time for onshore exploration | 6 | 4 |
| | | Opening of shipping routes | 7 | 6 |
| | | Shortened transportation time in winter | 8 | 8 |
| | | Declining demand and cost for heating fuel in winter | 7 | 5 |
| | | Impacts on Energy (utilities) companies: | | |
| | | Less efficient thermal conduction | 7 | 6 |
| | | Heavy demand and load of air conditioning in summer | 6 | 3 |
| | | Damage of infrastructure (turbines, transmission lines, etc.) | 5 | 4 |
| | | Increasing cost of infrastructure maintenance and repair | 9 | 9 |
| | | Both types of companies: | | |
| | | Decrease of death rate among the employees | 5 | 5 |
| | | Increased disease rate among the employees caused by contaminants etc. | 6 | 7 |
| Winter temperature | Increasing | Impacts on Oil & Gas companies: | | |
| | | Shorten ice roads transportation time | 7 | 7 |
| | | Declining duration and demand of heating fuel in winter | 5 | 4 |
| Frequency and length of heat | Increasing | Impacts on Energy (utilities) companies: | | |
| | | Damage of infrastructure (transmission lines, power plants, etc.) | 6 | 6 |

| | | | | |
|---|---|---|---|---|
| waves | | Increasing cost of infrastructure maintenance and repair | 8 | 8 |

If possible, please elaborate on your rating.

*Response: The infrastructure effects and costs are the most dramatic ones and may be hard to predict. Actual energy consumption will probably not go as dramatically in terms of everyday use in relation to rising temperature.*

**Main climate driver: Precipitation**

*Since precipitation frequency varies on location, both trends have been included

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| Precipitation Frequency* | Decreasing | Impacts on Oil & Gas companies: | | |
| | | Chance of fires can halt production and cause severe damage | 3 | 2 |
| | | Droughts can effect current oil deposits and slow down machining Droughts can effect current oil deposits and slow down machining | 3 | 2 |
| Precipitation Frequency* | Increasing | Impacts on Oil & Gas companies: | | |
| | | Flooding could slow down search for new deposits, production, and transportation | 6 | 6 |
| | | Avalanche slow down transportation and halt production | 7 | 7 |
| | | Ice can slow down transportation and damage equipment | 7 | 8 |
| Storm Seasons | Increasing | Both types of companies: | | |
| | | Storm seasons may become longer | 5 | 5 |
| | | More frequent storms effect transportation and production | 5 | 5 |
| Rate of Evaporation | Increasing | Impacts on Oil & Gas companies: | | |
| | | More storms can effect production, transportation and deposits | 2 | 2 |
| | | Dries out land can effect oil deposits | 2 | 2 |
| Wind | Varies | Both types of companies: | | |
| | | Change in direction can effect transportation | 2 | 2 |

If possible, please elaborate on your rating.

*Response:*

**Main climate driver: Sea level / sea ice / snow cover / permafrost change**

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| Snow cover thickness | Increasing | Both types of companies: | | |
| | | Increased maintenance costs (snow cleanup) | 4 | 4 |
| | | Increased risk of structural failure (from increased snow on roofs) | 5 | 5 |
| | | Impacts on Oil & Gas companies: Increased operational cost (snow cleanup) | 5 | 5 |
| | | Specialized equipment for dealing with the higher amount of snow | 5 | 5 |
| Sea level | Rising | Both types of companies: | | |
| | | Flooding of coastal sites | 6 | 6 |
| | | Impacts on Oil & Gas companies: | | |
| | | Potential change in resource access | 7 | 7 |
| | | Impacts on Energy (utilities) companies: | | |
| | | Higher potential for hydro-electric (more power) | 5 | 5 |
| Sea ice | Decreasing | Both types of companies: | | |
| | | Increased ice road failure (melting) | 8 | 8 |
| | | Increased maintenance costs (icebergs, beached ice, waves, storm surges) | 8 | 8 |
| | | Impact on Oil & Gas companies: | | |
| | | Increased mobility through arctic waters | 6 | 7 |
| | | Increased wave strength | 6 | 7 |
| | | Increased water traffic through the Arctic | 8 | 5 |
| | | Impacts on Energy (utilities) companies: | | |
| | | Increased percentage of reservoir availability during the winter | 5 | 5 |

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| Sea chunks/ icebergs | Increasing | Impacts on Oil & Gas companies: | | |
| | | Increased operational risk | 8 | 9 |
| | | Increased platform cost to protect against icebergs | 8 | 9 |
| | | Impacts on Energy (utilities) companies: | | |
| | | Potential hydro-electric failure due to clogging | 7 | 5 |
| | | Increased maintenance costs (to clean ice chunks) | 7 | 4 |
| Ocean variability | Increasing | Impacts on Oil & Gas companies: | | |
| | | Increased survey / exploration cost and time | 5 | 5 |
| | | Decreased reliability of ocean transportation | | |
| Average sea ice age | Decreasing | Impacts on Oil & Gas companies: | | |
| | | Easier water transportation | 5 | 7 |
| | | Lighter ice, meaning increased ice mobility and speed | 6 | 7 |
| | | Impacts on Energy (utilities) companies: | | |
| | | Increased percentage of reservoir availability during the winter | 7 | 7 |
| Ground solidity | Softening | Both types of companies: | | |
| | | Increased chance of structural / foundational failure (for buildings that rely on permafrost as a foundation) | 9 | 9 |
| | | Impacts on Oil & Gas companies: | | |
| | | Potential pipeline failure (due to support failure) | 8 | 9 |
| | | Decreased land transportation reliability | 7 | 8 |
| | | Decreased time for asset exploration | 5 | 5 |

| Climate effect | Trend | Impact | Probability | Significance |
|---|---|---|---|---|
| | | every year | | |
| | | Increased building costs (different type of foundation) | 7 | 8 |
| Ground warping | Increasing | Both types of companies: | | |
| | | Increased chance of structural failure | 6 | 7 |
| | | Impacts on Oil & Gas companies: | | |
| | | Increased chance of pipeline failure (due to support failure) | 7 | 8 |
| Ground drainage | Increasing | Impacts on Oil & Gas companies: | | |
| | | Sump failure | 6 | 6 |
| | | Increased contamination risk | 7 | 8 |
| | | Impacts on Energy (utilities) companies: | | |
| | | Potential lake and river drainage (damage to hydro-electric potential) | 7 | 8 |

If possible, please elaborate on your rating.

*Response: I know less about these probabilities*

[10] Is there anything that you think we missed, or want to go further into detail? If so, please describe it below.

*Response: Alternative energy and other sustainable development?* “