Erasmus Mundus MSc Programme

Coastal and Marine Engineering and Management
CoMEM

Impact of Climate Change on Trans-Arctic Navigation; A Northern Sea Route Case Study

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Extract:

This thesis reviews Arctic development, and industrial responses to changing climate-driven, geospatial, and economic environments. First, the optimization of trans-arctic navigation was addressed in light of the global warming impact on Arctic sea ice. In this regard, a central consideration was given to the Northern Sea Route (NSR), such that its history, characteristics and future interests were addressed. Following, an environmental management scheme was developed in line with today's sustainable development principles. Advanced mitigation measures were proposed for the proposed development, in consistence with the most recent recommendations of international regulations. Finally, the thesis quantitatively scrutinized the comparative environmental profiles of NSR passage and Suez Canal transit. Environmental mapping was used for this purpose such that carbon foortprint estimates formed the basis for comparing generated emissions as a result of shipping activities of the case study in question. The synergy between fuel consumption, energy consumption and generated emissions was reflected in the model. Further, the role of slow steaming was highlighted in terms of reducing emissions for all considered cases. The study also recommended several areas of research in respect to the investigated impacts. In conclusion, the thesis notes that the NSR, despite its ice-infested waters, presents the most environmentally feasible routing out of the presented alternatives. A question worth investigating then: how will trans-arctic navigation in an ice-free Arctic interact with the existing impacts of climate change?

Key words:

1. Arctic Transformation
2. Arctic Sea Ice
3. Sustainable Development
4. Carbon Footprint

(sign.)

PREFACE

This Master of Science (MSc) thesis was researched through and written at the Norwegian University of Science and Technology's Department of Civil and Transport Engineering through supervised self-tuition in the spring of 2010. The thesis forms the basis for the grading of TBA4920 Marine Civil Engineering Master Thesis, in partial fulfillment of the MSc degree requirements for the Erasmus Mundus Coastal and Marine Engineering and Management (CoMEM) Programme.

Just like any other scientific research, it always starts with a blink and a bit of curiosity. At the beginning of my research I had enormous energy for analyzing operational, technical, commercial, political and environmental issues of Arctic shipping. As I proceeded with my research, I decided to streamline my thesis towards research into shipping along the Northern Sea Route (NSR): for both the idea and its realization, I thank the following mentors, supervisors and fellow researchers.

I begin with respectful appreciation for the comments and critical guidance of my scientific supervisor: Eivind Dale. Next, I appreciate the efforts of Tor Wergeland at MARINTEK, whose structured feedback brought this thesis towards its core subject matter and its fruitful completion, in addition to his assessment of environmental mapping results and his continued assistance in modifying the adopted methodology.

Turning to the thesis itself, my study evolved from an inspiration provided by the work of two MSc students with the NTNU Department of Industrial Economics: Marte S. Ellingsen and Stine M. Hodøl. On March 4th, 2010, I had the opportunity to observe Ellingsen and Hodøl's rehearsal of their client presentation re: the economic viability of Arctic shipping. Involved with the same industrial case study, which I was also researching, and inspired by the Ellingsen/Hodøl model, I decided to direct my thesis towards a complementary comprehensive environmental analysis. Thereafter, my scientific supervisor and I agreed to discuss this with the client to harmonize my research with the economic viability study.

It is worth noting ex ante that the implemented tasks have deviated from the descriptions given in the thesis proposal due to lack of data and the complexity that emerged during the mapping of alternatives. The thesis initially planned to analyze two traditional shipping routes as comparators: the Suez Canal and the Cape of Good Hope. However, I was wisely advised to focus on the Suez Canal; essentially due to ship size restrictions around the African passage since, during the analysis, an assumption of similar ship capacities would provide more realistic. Furthermore, the trans-shipment alternative was also eliminated since the industrial case in question has not yet been launched, and the present unavailability of basic information from port operators, such as gaps in input requirements. These changes in the scope of work were approved by the scientific supervisor prior to performance.

Additionally, it must be noted that the Ellingsen and Hodøl's specialization project remains unpublished and subject to client confidentiality agreements. Given the courtesy to employ certain findings in relation to my work, I proceed to present relevant findings sensitive to such existing binding agreements. Likewise, background information about the Kirkenes-Qingdao case study referenced herein was extracted from workshops, the reports and findings from which also remain unpublished. I will therefore provide a list of suggested readings for materials utilized in the research that are either unpublished or not referred to in the text.

I hope that the readers of my thesis will admire a fresh perspective of our world's Arctic, respectfully presented to you by a dedicated young researcher from the desert.

Nancy Haitham Haddaden
Trondheim, 05.07.2010

ACKNOWLEDGEMENTS

I would like to extend my sincere appreciation to my scientific supervisor: Eivind Dale for his guidance and the resulting efforts. Likewise, I wish to thank the following persons: my programme coordinator and professor in charge; Øivind Arntsen for his follow-up and dedication for resolving administrative issues. Tor Wergeland, (a former member of the INSROP committee) for his critical feedback and comments to my work, in addition to his generosity in providing me with essential INSROP working papers, which formed the pillars of my qualitative assessment.

Finally, I will seize this opportunity to express my gratitude to the CoMEM board for their endless efforts in facilitating the CoMEMers stay in Europe during the past two years. I wish to express my admiration to each coordinator among the consortium of the five universities involved; for endeavoring to make this 2-year MSc programme a successful experience on an academic, intellectual and a cultural level.

DEDICATION

To my cherished Parents; for indulging me
with their love & guidance

To a special starsharer: Anita;
for inspiring me in so many ways

To all Arctic explorers

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LIST OF ABBREVIATIONS

CO_2	Carbon Dioxide
ACIA	Arctic Climate Impact Assessment
NSR	Northern Sea Route
DNV	Det Norske Veritas
LOGIN	Logistic Operations in the High North
IPCC	Intergovernmental Panel on Climate Change
AR4	Fourth Assessment Report
GHG	Greenhouse Gases
AMAP	Arctic Monitoring and Assessment Programme
CAFF	Conservation of Arctic Flora and Fauna
IASC	International Arctic Science Committee
NSIDC	National Snow and Ice Data Center
PAME	Protection of the Arctic Marine Environment
EPPR	Emergency Prevention, Preparedness and Response
AMSP	Arctic Marine Strategic Plan
AMSA	Arctic Marine Shipping Assessment
NWP	Northwest Passage
NEP	Northeast Passage
nm	Nautical Mile
INSROP	International Northern Sea Route Programme
ARCOP	Arctic Operational Platform
UNCLOS	United Nations Convention on the Law of the Sea
AEPS	Arctic Environmental Protection Strategy
UD	Norwegian State Department
EIA	Environmental Impact Assessment
IMO	International Maritime Organization
HFO	Heavy Fuel Oil
NOx	Nitrogen Oxides
SOx	Sulphuric Oxides
PM	Particulate Matter
SECA	Sulphur Emission Control Area
CSR	Corporate Social Responsibility
EU	European Union
WRI	World Resources Institute
WBCSD	World Business Council for Sustainable Development
Knot	Nautical Mile per Hour
DWT	Deadweight

EXECUTIVE SUMMARY

This thesis reviews Arctic development, and industrial responses to changing climate-driven, geospatial, and economic environments. First, trans-Arctic navigation promises distance reductions via top of the world routing, and is therefore attracting industry interest. Moreover, as commodity exchange between continents increases in the global economy, traffic congestion is becoming a serious issue witnessed by traditional transportation routes. In this regard, the Centre for High North Logistics is looking at the potential for unlocking the NSR for transporting iron ore between Kirkenes/Norway and Qingdao/China. Further, such routing must look to and integrate climate change's visible impact on today's Arctic, already a principal driver of foreseeable regional developments.

First, this study addresses trans-Arctic navigation optimization in light of the climate change impact on sea ice. The methodology therefore analyzes the interaction between sea ice reduction progression in the Arctic and ensuing developments, with comprehensive treatment and central consideration of the NSR's history, characteristics and future interests. In light of the foregoing, the state of sea ice extent, Arctic climatic conditions (still at an early stage of investigation) and political constraints pose critical impediments to the development of trans-Arctic shipping. In its conclusions on optimization, this thesis therefore recommends postponement of trans-arctic developments until both proper risk management and the interaction between sea ice extent and shipping routes are well understood.

Next, this thesis qualitatively inspects the impediments associated with a NSR transit. For this purpose, an environmental impact assessment was conducted, using an industrial (iron ore) case study as a comparator and in line with sustainable development principles. The assessment concluded that identified negative impacts adjoining the trans-arctic passage development may be avoided with advanced environmental management measures through a developed environmental management scheme consistent with IMO, AMSA and INSROP recommendations. However, some impacts cannot be managed at this point due to limited knowledge and responsive resources. The analysis therefore suggests further research in relation to certain investigated impacts.

Finally, this thesis quantitatively scrutinizes the comparative environmental profiles of NSR passage and Suez Canal transit. Environmental mapping was used for this purpose, such that carbon footprint estimates formed the basis for comparing generated emissions as a result of shipping activities of the iron ore case study. The

utilized model reflected the synergy between fuel consumption, energy consumption and generated emissions.

In order to employ the model effectively, different ice scenarios were developed for the projected years 2030 and 2050, whereas the Suez Canal transit formed the baseline case of the analysis. The mapping revealed the efficiency of the NSR in terms of fewer generated emissions and, higher capacity such that the annual transported volume significantly exceeded the baseline case. Further, generated emissions generated in the 2030 ice scenario were fewer than in the 2050 scenario, reflecting the impact of the slow steaming predominantly employed in the 2030 scenario. Sensitivity analysis then confirmed the impact of slow steaming in reducing emissions, which was significantly highlighted in case of a Suez Canal transit; conversely, a slow steaming operation resulted in increased voyage times. Additionally, it was argued that slow steaming operation might promote other GHG emissions, such as NOx. In this regard, this thesis recommends further research into means of improving vessel design parameters, such that vessels are functioned to cope with the proposed mitigation measure for reducing emissions.

In conclusion, this thesis notes that the NSR, despite its ice-infested waters, presents the most environmentally feasible routing out of the presented alternatives. A question worth investigating then: how will trans-arctic navigation in an ice-free Arctic interact with the existing impacts of climate change?

1 INTRODUCTION

The planet 'Earth' is only a small fraction of the universe; yet it is deemed as a complex system with plenty of mysterious phenomena. One of these phenomena is water. Water is an astonishing matter on earth. It is the most unstable substance of all; taking various forms: liquid as running water, gaseous as water vapor and, solid as ice. The earth's water is also an outstanding substance, such that it follows a cycle of constant renewal; engaging several appearances: waterfalls, water vapor, clouds, rains, springs, rivers, seas, oceans and glaciers. This cycle is never broken; there is always the same quantity of water on earth (Bertrand, 2009). Water; the source of life, also plays a major role in plenty of the earth's inexplicable phenomena, one of which is the "Climate System", which outlines the starting point of this study.

Two major substances affecting our climate are: air and water. These are intimately linked; water and air are inseparable and, this linkage forms the engine of life (Bertrand, 2009). However, since the beginning of the industrial era, transport, industry, deforestation and agricultural activities have released gigantic quantities of carbon dioxide (CO_2); without realizing, molecule by molecule, we have upset the earth's climate balance. Additionally, it had been reported that human action interrupted the harmony between air, water and soil. Humanity has never lived in an atmosphere like this before. The life of many species is threatened today due to excessive exploitation of our natural resources; this threat is emphasized by climate change. It is even anticipated that by 2050, one fourth of the world's species could be intimidated by extinction (Bertrand, 2009); one evidence already taking place can be observed in the destruction occurring in the Polar Regions, where the effects of global warming are most visible.

Under the effect of climate change, the Polar ice cap has lost 40% of its thickness in only 40 years. This can be best justified by the fact that the sun beams of the ice sheets that previously reflected back are now penetrating the dark water surface, thus, heating it up; global warming is gaining pace. Furthermore, this ice contains the records of our planet; it is the methane that is contained in the sea ice that scientists are most concerned about. Moreover, it had been already reported that the concentration of CO_2 today is the highest record among the past several hundred thousand years (IPCC, 2007).

'SEA ICE' has been defined by various sources as a fragile part of the Earth which plays a dominant role in affecting our climate and biodiversity, consequently reflecting upon our economy and society. One of the aims of this thesis is to explore some of the unprecedented impacts that will be imposed on our world due to the future of the Arctic Sea ice. Igor et al. (2002) describe the Arctic sea ice as a controlling agent for the high-latitude heat balance moderating heat exchange between the ocean and the atmosphere. Furthermore, the important role that the Arctic sea ice plays in the global climate system is reflected in the export of ice to lower latitudes such that the intensity of large-scale ocean overturning is regulated, with significance for the thermohaline[1] circulation (Aagaard et al., 1994).

In the context of the global warming debate - one of the most challenging issues of the 21st century - many climate research reports have clearly shown the alteration that will strike the Arctic region due to climate change and temperature rise. The Arctic Climate Impact Assessment (ACIA), (2004) report discusses the clear evidences of the melting of the ice cover and its impacts on flora and fauna. The report also argues how the ice melt is in fact transforming the Arctic region, thus warning about the dreadful future that is facing all ice-dependent species. Simultaneously, opportunities for economic developments arise from this anticipated climate change effect. Rob Huebert (2008) recognizes three major new developments: (1) a vision of new trans-arctic shipping routes, (2) expansion of oil and gas developments and (3) commercial fishing. In this regard, further exploration will be allocated for the impact of climate change on trans-arctic shipping routes.

To this end, it is worth mentioning that the potential of utilizing the “Arctic” as an alternative shipping route essentially evolved due to the enormous reduction in distance it can achieve if compared with the existing shipping lanes. Ragner (2000) estimates a reduction in distance as much as 40% for some destinations in comparison to traditional routes. This thesis will focus on distance savings mainly between Northern Europe and Northern Asia.

1.1 MOTIVATION & AIMS OF THIS STUDY

The past two decades have witnessed steep acceleration in internationalization of trade and production. Additionally, the world’s transport networks are continuously improving due to the world’s commerce evolution (Grigentin et al., 2009). Ohmae (1985) describes the economy drive between North America, Europe and Asia as “the triad”. It is recorded that 80% of exports and 83% of imports are in fact confined to the northern hemisphere, such that most of the traffic generated is between the regions referred to earlier as “the triad” (Knowles et al., 2008).

[1]Thermohaline circulation: ‘When currents are driven by differences in ocean temperature and salt concentration, water would naturally mix to try and even out the distribution of heat and salt. Circulation then occurs as the denser colder, saltier water drops below the warmer, fresher water. These differences drive the “thermohaline circulation” or what is often called the “ocean conveyor belt”.’ (Dow and Downing, 2006)

Two major commercial maritime routes, through which transportation of commodities takes place today, are the Suez Canal and Cape of Good Hope. However, these commercial lanes are currently experiencing large flow of vessels. Therefore, leading to traffic congestion and long waiting times, in addition to the piracy witnessed during some journeys. Accordingly, ship owners are urged to envisage alternative routes to smooth the circulation of commodities; with the Arctic providing a possible option. Nowadays, the main viable alternative Arctic route is deemed to be the "*traditional interface between Northern Asian and Northwestern European markets*" as defined by the Organization for Economic Cooperation and Development (2004); the so-called Northern Sea Route (NSR).

In line with the ongoing research for investigating new trans-arctic routes, MARINTEK[2] and Det Norske Veritas (DNV)[3] are currently undergoing a comprehensive research under the Logistic Operations in the High North (henceforth, LOGIN) project; looking at possibilities of unlocking the trans-arctic route for transporting dry bulk commodities. The particular article of trade under research is iron ore, such that transportation is taking place between Kirkenes/Norway and Qingdao/China.

The motivation behind this project arises from the need to create efficient logistics[4] solutions for the High North region; reducing the shipping distance between the markets under consideration. It is worth mentioning that the NSR trans-arctic passage was proposed as an alternative shipping route for further investigation, since the iron ore deposits are close to the NSR, consequently providing a shorter sailing distance.

1.2 RESEARCH PROBLEM

The LOGIN project aims at carrying out a feasibility study for several alternative maritime logistics systems, each of which represents a shipping transport mode for the iron ore from Kirkenes to Qingdao. In line with today's increasing demand for maintaining a sustainable environment, the present thesis will choose to focus on investigating the environmental aspects of the LOGIN industrial case study. In order to carry out a concrete analysis, the research will address the environmental aspects in a qualitative and quantitative manner. The qualitative aspects will be studied through a comprehensive environmental assessment methodology, whereas

[2]MARINTEK: is a Norwegian Marine Technology Research Institute that provides technical consultancy for developing maritime solutions of both industry and public sectors.

[3]DNV: is a global provider of services for managing risk. It is an independent foundation with the objective of safeguarding life, property and the environment.

[4] Logistics: is the management of the flow of goods, information and other resources between the point of origin and the point of consumption in order to meet the requirements of consumers. This involves the integration of information, transportation, inventory, warehousing, material handling and packaging.

environmental mapping will inspect the carbon footprint produced by the iron ore transportation activities, such that the study area is represented by the transit routes of the Suez Canal and the NSR. To the author's knowledge, this is the first time in history that carbon footprint inspection will be carried out for bulk carriers, targeting the NSR as a trans-arctic passage. Hence, implementing this research is highly remarkable.

1.3 RESEARCH OBJECTIVE

The main objective of this study is to evaluate the soundness of transportation along the NSR in comparison with the currently existing traditional route; Suez Canal. The research also aims at scrutinizing the robustness of the attained results through performing a sensitivity analysis. Furthermore, the thesis attempts to tackle the following research questions, which form a complementary feature of the research problem:

- Is it possible to exploit the changing-climate driven impacts on arctic sea ice for optimizing trans-arctic navigation?
- How will the evolving obstacles be conquered in accordance with today's vision of maintaining a sustainable environment?
- Is it environmentally sound to convert shipping routes from the traditional into the proposed trans-arctic route?

1.4 RESEARCH OUTLINE

As the proposed Northern Sea Route option - the main core of this study - has gained more attention through recent climate change studies, it is worth including an overview of the climate change debate, which resulted in the advancement of further Arctic climate assessments. Therefore, Chapter 2 will take you through a quick journey to explore the 'Climate Change Debate' in the context of the Arctic transformation.

Chapter 3 aims at presenting technical facts and figures illustrating the state of 'Arctic Sea Ice' and weather conditions in an Arctic environment.

Chapter 4 will uncover the secrets of 'Arctic Shipping', such that it deals with the evolving role of the Northern Sea Route, discusses negotiation initiatives between the involved Arctic governments and, reveals the obstacles that might encounter future developments in the Arctic.

Chapters 5 and 6 will be focused on the LOGIN industrial case study, such that an environmental impact assessment will be conducted in Chapter 5, whereby Chapter 6 will be dedicated for environmental mapping where the proposed alternatives are tackled quantitatively. A sensitivity analysis will also be carried out in order to ensure the credibility of the mapping results. Chapter 7 will discuss the findings of the mapping methodology. Finally concluding remarks will be addressed in Chapter 8.

2 CLIMATE CHANGE DEBATE

Our earth is a miracle, and life on earth remains a mystery that appeared four million years ago. It had been scrutinized that the earth is characterized by a dense, thick atmosphere filled with water vapor, and CO_2; a furnace. This water vapor drop remains in balance, and this carbon which made our atmosphere, was the reason for the initiation of life on earth and allowed life to develop partially. Life occurred at the instance when carbon drained from the atmosphere and other life forms were able to develop. Every specie of those existing life forms has its own role and place, none is harmful, they all balance out and, each being depends on another being for its continuation; it is the reliance on this balance that keeps the subtle fragile harmony of our earth going. However, it is life that altered the atmosphere and, today it is argued that we humans or “Homo Sapiens” who appeared only 200,000 years ago have disrupted the balance that is essential for life on this planet, by pumping back out the carbon and increasing the heating up process of our planet (Bertrand, 2009). This chapter aims at stroking the basic disputes of climate change and, presenting brief scientific and sociological facts that deal with the complexities of global warming.

2.1 EVOLUTION OF THE DEBATE

The United Nations Framework Convention is an international treaty that initiated the publishing of a series of reports that technically tackled the threat of climate change; known under its famous name: the Intergovernmental Panel on Climate Change (IPCC). The thrill behind IPCC publications is that it engaged hundreds of scientists from dozens of countries trying to resolve the scientific uncertainties associated with global warming theories. These reports include the largest and most detailed summary of climate change situation undertaken, thereto received a global attention and, attracted the insight of plenty of writers and media.

2.2.1 Latest IPCC Findings

The IPCC most recent publication is the Fourth Assessment Report (AR4) entitled *Climate Change 2007*, which is the fourth report in series that intends at assessing the scientific, technical and socio-economic information concerning climate change: its potential effects, and choices for adaptation and mitigation. The AR4 concluded that “warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" and, furthermore, the report concludes with "very high confidence" (at least a 9 out of 10 chance of being correct) that the globally averaged net effect of human activities since 1750 has been one of "warming" of the Earth's climate system. Furthermore, the report states that a 0.75°C rise in global temperatures and a 22cm rise in sea level during the 20th century are evident. The IPCC also predicts that by 2100 global temperatures could rise further in the range between1.1°C and 6.4°C, and if combined linearly with additional melting of the ice sheets of Greenland and Antarctica, the sea level could rise between 28cm and 79cm. Another prediction shows that global warming impacts are going to be irreversible, and that Greenland's ice cover will melt in 1000 years.

2.2.2 Diverging Opinions

While plenty of researchers are indulged with the scientific facts of global warming, Maslin, (2009) reveals the complexities of both science and politics of climate change. It had been stated that the problem of global warming is not confined to scientific concerns only, rather it wraps within it the personal choice of individual's life style. Therefore, reflecting upon the economics, sociology, geopolitics and local politics world-wide. It had been also clarified that the importance of understanding climatic conditions is reflected in our dependence on local climate knowledge in order to operate in our lives; for example, communities build their houses, buildings, and transport systems in a manner that suits their local climatic conditions.

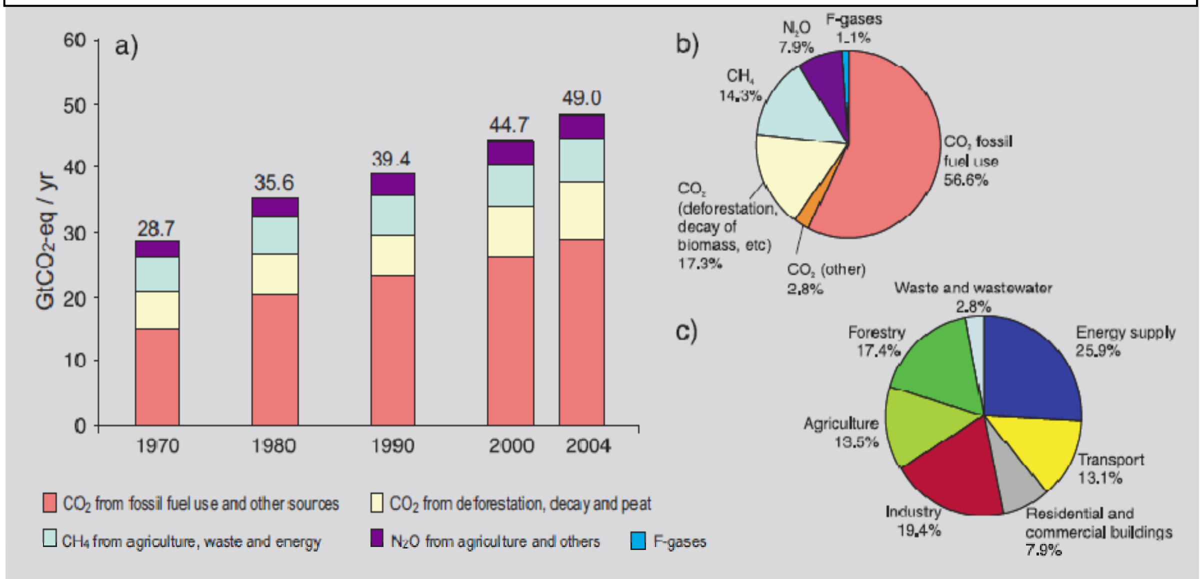
From this point, it can be concluded that the jeopardy of climate change impacts can be overlooked if and only if the models and assessments that we develop are reliable, such that necessary precautions are being taken. Nevertheless, the foremost ongoing climate change debate is concentrated on how skeptics are continuously questioning the validity of the available models, and the unknown phenomena between the physical parameters that influence our climate; an issue that creates an obstacle against our preparedness for any abrupt climatic consequences.

2.2 NATURAL AND ANTHROPOGENIC IMPACTS ON THE CLIMATE SYSTEM

Greenhouse gases (GHG) are those atmospheric gases that are critical to the temperature balance of the Earth; which occurs as an exchange between the input energy from the Sun and the reflection of some of this energy back into space. Naturally occurring greenhouse gases include water vapor, carbon dioxide, ozone, methane and nitrous oxide, all combined create a natural greenhouse effect such that they trap and re-emit some of the long-wave 'infrared' radiation which was absorbed by the atmosphere, land and oceans. The long-wave radiation originates from the warming of the earth's surface due to the absorbance of 2\3 of the short-wave Sun radiation. This natural greenhouse effect, which is also known as the blanket effect, is in fact essential to maintain the temperature of the Earth; without it the Earth would be at least 35°C colder (Maslin, 2009). However, it is believed that human activities have interfered in the natural amounts of GHG present in the atmosphere (Figure 2.1) and the resulting effects. The IPCC scientists found that increases in carbon dioxide, methane, and nitrous oxide resulted in a combined radiative forcing[5] such that it can be identified today as the largest climate driver and, the industrial era had *very likely* led to an increase in its rate to an unprecedented value in more than 10,000 years. Additionally, the largest change for any decade in at least the last 200 years can be referred to the increase of the carbon dioxide radiative forcing by 20% from 1995 to 2005.

Figure 2.1: Global anthropogenic GHG emissions

(a) Global annual emissions of anthropogenic GHGs from 1970 to 2004 (b) Share of different anthropogenic GHGs in total emissions in 2004 (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq



(Source: IPCC, 2007)

The IPCC, (2007) also identified the 'global dimming' as the aerosols in the atmosphere which are produced from anthropogenic contributions, consequently leading to cooling effects. However, it is found that the cooling effects resulting from human-caused aerosols correspond to about half of the warming effects, due to the combined radiative forcing of human-produced greenhouse gases, hence, causing a net warming. Several other anthropogenic sources that also impose radiative forcing

[5] Radiative forcing: is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the surface while negative forcing tends to cool it (IPCC, 2007).

effects include tropospheric ozone changes, resulting from emissions of ozone-forming chemicals, changes in halocarbons resulting in direct radiative forcing, and changes in surface albedo[6] due to land-cover changes and deposition of black carbon aerosols on snow. Finally, the solar irradiance increase since 1750 was estimated to have caused a forcing which also contributed to the recent Earth Warming. Nevertheless, the impact of this increase of sunlight which stroked the Earth each year during this ~250 year time span was estimated to constitute only about 1/20th of the warming impacts resulting from anthropogenic greenhouse gas emissions (Nodvin et. al., 2009).

To this end, it is worth mentioning that the IPCC have developed climatic models run against different scenarios due to the fact that future human activity is a factor upon which climate change is highly dependable. Assumptions in the IPCC scenarios were made for future greenhouse gas pollution, land-use and other driving forces. Thus, each scenario involved assumptions about future technological development as well as the future economic development such that the consumption of fossil fuels varied from one scenario to another. Additionally, in line with the IPCC postulations, it can be stated that future human GHG emissions are not necessarily fixed as they depend on many variables, such as the global economy, technological development, political agreements and individuals' lifestyles. Furthermore, it is argued that of all the systems that are used in the emissions climate models of the future, humanity is the most unpredictable. For example, population growth, economic growth, fossil fuel usage, rate of deforestation, rate of switching to alternative energy, third-world development and effectiveness of international agreements to cut off emissions, are all factors that will highly affect the amount of CO_2 produced (Maslin, 2009).

2.3 ARCTIC TRANSFORMATION

Due to the significant role that the Arctic plays in global climate, and since the climatic changes experienced in the Arctic are particularly intense; the first comprehensive integrated assessment of climate change across the entire Arctic region was called for by the Arctic Council[7], such that several working groups were

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[6] Albedo: "The fraction of solar energy (shortwave radiation) reflected from the Earth back into space. It is a measure of the reflectivity of the Earth's surface. Ice, especially with snow on top of it, has a high albedo: most sunlight hitting the surface bounces back towards space. Water and ground not covered by ice or snow are much more absorbent and less reflective" (Koc et. al., 2009).

[7] The Arctic Council: is a high-level intergovernmental forum that provides a mechanism to address the common concerns and challenges faced by arctic people and governments. It is comprised of the eight arctic nations (Canada, Denmark/Greenland/Faroe Islands, Finland, Norway, Russia, Sweden, and the United States of America), six Indigenous Peoples Organizations, and the official observers

involved with its implementation. The Arctic Climate Impact Assessment (ACIA) was first published in 2004, reflecting the efforts of an international team of over 300 scientists, experts and knowledgeable members of the indigenous communities. Leading authors of this massive report were being selected from the two working groups entailed: the Arctic Monitoring and Assessment Programme (AMAP) and the Conservation of Arctic Flora and Fauna (CAFF), along with the International Arctic Science Committee (IASC). The report attracted global interest as it clearly illustrated the ongoing climate change condition in the Arctic and its rapid and severe impacts.

The major finding of the ACIA is that the Arctic is experiencing today some of the most rapid and severe climate change on Earth, and will experience an accelerated climate change in the 21st century; turning the Arctic into a vulnerable region in accordance with the projections, many of which have already begun. Those climatic changes will also affect the rest of the world over the next 100 years, embodying widespread physical, ecological, social and economic changes through rising sea levels and increased global warming.

2.4 THE ARCTIC REGION

The term Arctic comes from the ancient Greek word *Arktikos,* which means the country of the Great Bear. Above the North Pole, lies the North Star; Polaris, with the constellation of the Ursa Major stars surrounding it, also known as the Great Bear (ACIA, 2004). In everyday use, “the North Pole” is associated with the entire Arctic region. However, when “the North Pole” is discussed by scientists, it is generally meant to include a single point on the globe located at 90 degrees North (NSIDC, 2009). In this thesis, the term “Arctic” will commonly refer to a much larger region that encompasses the northern latitudes of our globe (Figure 2.2), with a main focus on the Norwegian and Russian Arctic.

(including France, Germany, the Netherlands, Poland, United Kingdom, non-governmental organizations, and scientific and other international bodies)

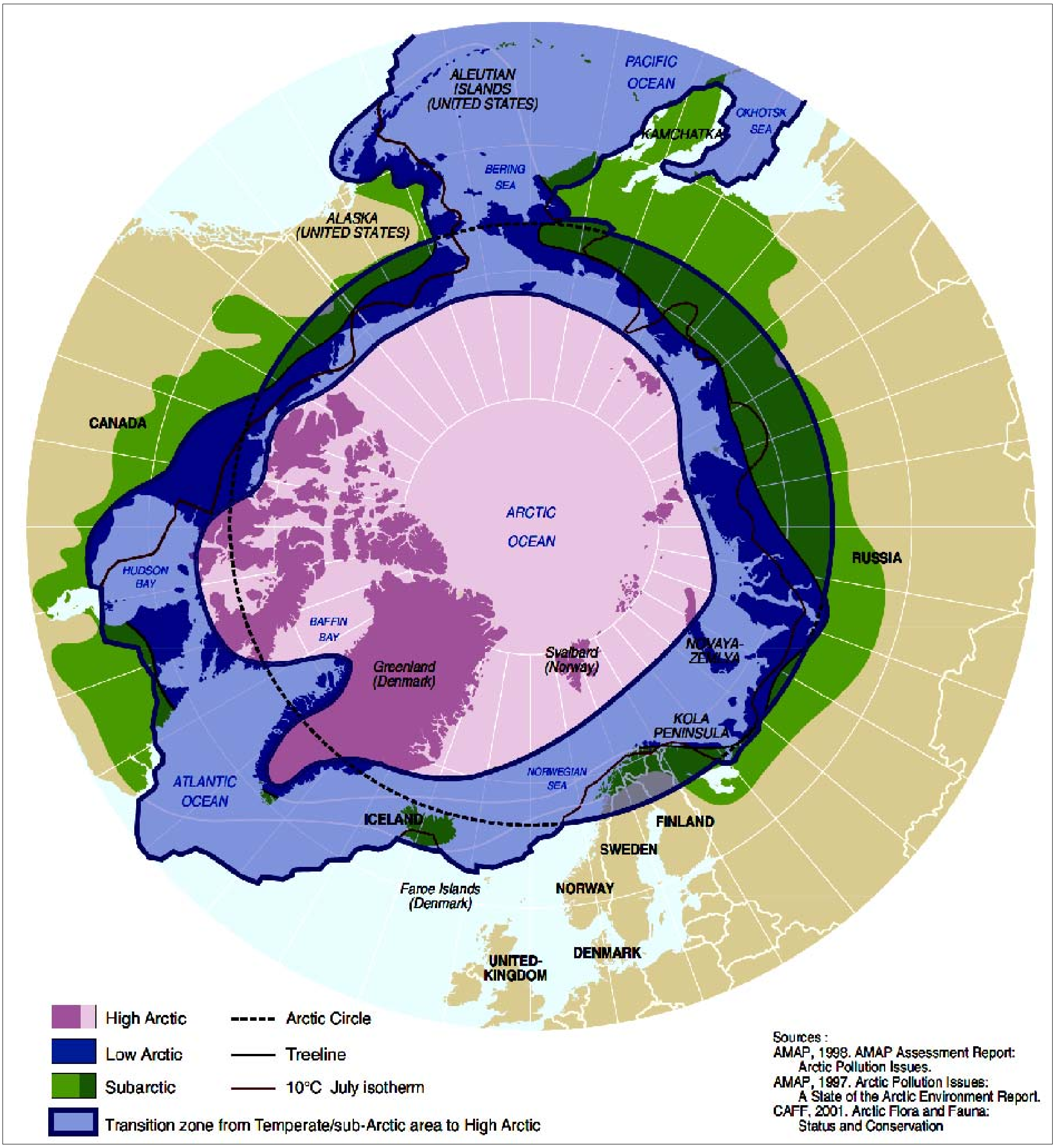

Figure 2.2: Boundaries of the Arctic (Source: AMAP, (1997); AMAP, (1998); CAFF, (2001))

In the Arctic Marine Shipping Assessment Report (AMSA 2009), the Arctic Circle is defined as "the circle of latitude at 66 degrees 33 minutes N (2606 kilometers from the North Pole) that encloses a northern area about 8 percent of Earth's surface. The Arctic Circle is the southern limit of the midnight sun, where north of the circle there is at least one day each year when the sun does not set". In contrast to the Southern

Polar region; which is an ice-covered continent surrounded by ocean, the Northern Polar region of the Earth (i.e., the Arctic) is comprised of a vast ocean surrounded by land (ACIA, 2004).

The Arctic's physical geography is mainly characterized by the sea ice, permafrost, glaciers, ice sheets, and river and lake ice (ACIA, 2005). It is also the legendary home of the polar bear, the walrus, ringed seal, murre, ivory gull and the intrepid Inuit hunter, in addition to the four million people who live on the margins of the Arctic Ocean, with traditional communities deriving their continuation from the Arctic's marine mammals and fisheries (Huebert, 2008).

The Life in the Arctic had always been described as both vulnerable and resilient. Vulnerable due to the short growing season and extreme climatic events if compared to temperate regions, however, the populations recovering after climatic variations is an evidence of the adaptation of Arctic species to its living conditions (ACIA 2005).
Unfortunately, new challenges to the resilience of the Arctic life are currently being compelled due to the climate change impediment. A question worth boosting at this point would be '*why does the Arctic warm faster than lower latitudes?*' The ACIA (2004) report distinguishes five major justifications in this regard:

1. *Melting of ice and snow will cause the resulting darker land and ocean surfaces to absorb more solar energy.*
2. *Extra trapped energy goes more into warming rather than evaporation as is the case in the tropics.*
3. *The atmospheric layer that has to warm in order to warm the atmosphere is shallower in the Arctic.*
4. *The retreat of the sea ice causes the solar heat absorbed by the oceans to be transferred into the atmosphere more easily.*
5. *Warming can be caused by alterations of atmospheric and oceanic circulation.*

In view of that, it is anticipated that accelerated global warming will radically alter the fundamental living conditions in the Arctic over the next few decades and, developing new mitigation measures for adapting to this change has become inevitable.

2.4.1ACIA Findings

It is agreed that climatic changes will have huge impacts on human societies and economies as well as ecosystems and, with the Arctic perceived as significant; it has become an essence to further examine the consequences of global warming on this spectacular region.

The ACIA (2004) key findings concerning the impact of climate change on the Arctic are listed below:

- *Arctic Climate is now warming rapidly and greater changes are projected.*
- *Arctic warming and its consequences have worldwide implications.*
- *Arctic vegetation zones are likely to shift, causing wide-ranging impacts.*
- *Animal species' diversity ranges, and distribution will change.*
- *Many coastal communities and facilities face increasing exposure to storms.*
- *Reduced sea ice is very likely to increase marine transport and access to resources.*
- *Thawing ground will disrupt transportation, buildings, and other infrastructure.*
- *Indigenous communities are facing major economic and cultural impacts.*
- *Elevated ultraviolet radiation levels will affect people, plants, and animals.*
- *Multiple influences interact to cause impacts to people and ecosystems.*

From the findings listed above, it can be seen that the climate change dilemma is not only confined to the Arctic region, but rather how the Arctic transformation will swing the natural systems and society's lifestyle worldwide.

2.4.2Major Arctic Alterations

As mentioned earlier, the Polar Regions are the most susceptible to change (IPCC, 2001). Comiso, (2002) foresees a significant loss in ice cover in the coming decades. He states that a rate of melt of about 3% per decade was recorded since the 1970s, and that the most recent satellite study of Arctic ice cover revealed a 9% loss per decade. Even though the pace of melt is still argued, northern people's observations and scientists confirm that wide-scale impacts in the region are evident as a result of increasing temperatures (Moritz et. al., 2002). Thus, the structure of the entire polar region is altering due to the impacts of climate change.

The 2004 and 2005 ACIA reports and even more climatic research have tackled the consequences of rising temperatures on the Arctic. It is clearly shown that temperatures in the Arctic are even rising at a faster rate than any other place on earth. To mention but a few evidences related to temperature rise include: the warming of the permafrost under previously stable tundra by up to 2°C in the recent decades and the transformation of the tundra surface by the bushy vegetation. As for the marine environment, the thinning and receding of the formerly stable ice pack is proceeding due to sea temperature rise, it is even predicted that in the summer of 2050 the Arctic Ocean could be practically ice-free. The severe impacts of this ice melt are essentially transforming the Arctic ecosystem, such that ice-dependent species which are indigenous to the region are encountering an outrageous future (Washington Post, 2006). Other side effects emerging in the Arctic region are represented by the immigration of subarctic species northward; indicators are already evident for the salmon and puffins' movements (Huebert, 2008).

Simultaneously, pack ice recession will expand opportunities for economic developments in the Arctic, where the region's natural resources undergo further exploitation. Three major divine developments defined by Huebert (2008) and others are: (1) the view of new shipping routes (2) enlarged oil and gas development and (3) new commercial fishing. These potentials will certainly pose new management challenges among the Arctic nations.

To this end, it is worth mentioning that various surveys and research are still required to conquer the challenges ahead of us in light of the Arctic transformation. With the Arctic defined as a "*remote and a previously inhospitable region*" and, currently characterized with its harsh environment; the impediments become even more durable.

3 ARCTIC CONFIGURATION

While global warming is imposing severe climatic consequences world-wide, it is enhancing the Arctic's ice conditions. Climate models confirm that the high northern latitudes will be even more improved due to anthropological warming and as a consequence of complex feedback[8] mechanisms in the atmosphere-ocean-ice system (IPCC, 2007). A simple example of a positive feedback mechanism is the ice-albedo loop whereby more dark ground is being exposed due to melted snow; this exposed ground of lower albedo will in turn absorb more heat and causes more snow to melt (Koc et.al, 2009). This describes the ongoing situation in today's Arctic, and it is predicted that over the next 50 years the Arctic warming due to GHG accumulations would be in the range of 3-4°C, which is more than twice the global average (IPCC, 2007). Thus, the physical environment of the Arctic can be identified as challenging and distinctly different from mid latitude regions. This section aims at demonstrating significant Arctic characteristics, of which some are undergoing dramatic changes.

3.1 STATE OF ARCTIC SEA ICE

From a climatic point of view, it is known that air temperature, prevailing winds, sea currents and fresh water flow from large rivers, are all factors that determine the season's length. Speaking of the Arctic, passages are in fact open from late September; which is the end of the melt period. The warm water that is supplied by the Gulf Stream, fresh water that is made available from large rivers and, with ice being transported by the sea current, all jointly provide dynamic features that lenient navigation through the Arctic, also during winter seasons (Laulajainen, 2009). However, ice covered waters in the Arctic remains a winter as well as a summer phenomenon. From this point, it is worth addressing the importance of a navigation season, which has been defined as *"the number of days per year with navigable conditions, generally meaning days with less than 50% sea ice cover"* (Liu and Kronbak, 2010). By this means, it is anticipated that any reduction in sea ice cover is likely to improve access along the shipping routes in the Arctic.

The National Snow and Ice Data Centre (NSIDC) define several ice characteristics that are essentially worth differentiating over navigation periods. Three important features of sea ice include: multiyear ice, leads and ridges as illustrated in Figure 3.1.

[8]Feedback: "In a feedback process, some of the output of a system returns as input. Climate feedback processes are positive when they amplify climate change and are negative when they diminish change" (Koc et. al., 2009).

Figure 3.1: Vital features of sea ice: multiyear ice, leads and ridges (Source: NSIDC, 2009)

Multiyear ice can be distinguished from first-year ice based on its distinct properties and processes that occur mainly during the summer melt. One major property for multiyear ice is that it contains more air pockets and less brine than first-year ice, thus making it a stiffer ice that is harder to break. On the other hand, *leads* can be defined as linear narrowed features that are formed by the motion of ice. These are the regions of open water where it is normally expected to find sea ice, and hence important to note upon choosing shipping routes. Contrary to Leads are *ridges;* which are defined as layers of ice which collide and break such that areas of thicker and harder ice are formed. It is worth noting that sea ice not only outlines a key characteristic of the Arctic environment, but also makes trans-arctic shipping fundamentally different from traditional routes.

3.2 CLIMATE CHANGE AND ARCTIC SEA ICE

The Arctic Ocean has been greatly affected by climate change (Liu and Kronbak, 2010) and, up to one-half of Arctic Sea ice declination is credited to atmospheric greenhouse gases. It has been illustrated by satellite observations (Figure 3.2) that Arctic Sea ice extent has declined by 9% per decade since 1979 (Laulajainen, 2009). The significant reduction of Arctic polar ice caps in just 20 years is evident from Figure 3.2; and it can be said that melting is proceeding at an accelerated pace. An even more drastic reduction of the ice caps is projected and believed to be opening new areas for maritime transportation (Global Environment Outlook Year Book, 2004).

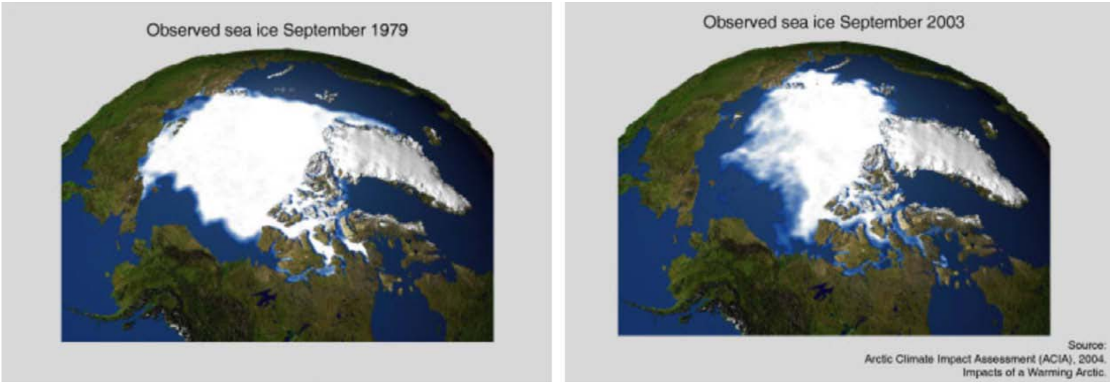

Figure 3.2: Comparison of polar ice cap satellite observations (left: 1979, right: 2003) (ACIA, 2004)

Furthermore, as Arctic sea ice reflects sunlight, it is capable of moderating the global climate and cooling the Polar Regions. However, the dramatic declination in its extent over at least the past thirty years, with an utmost extreme decline over the summer melt season will induce impacts that are still vague; hence, triggering world-wide curiosity (NSIDC, 2010). Additionally, over the last hundred years, ice extent had been decreasing at a rate of 3-5% per decade, with older multi-year ice decreasing twice as fast; leading to increased river discharge, thawing of the tundra permafrost and a decrease in snow cover on land (Bobylev et.al, 2004).

3.3 POLAR DARKNESS AND COLDNESS

The advantage of the midnight sun during the Arctic summer is reflected in its impact on ice in every hour of the day, such that the ice melts down to its minimum level by September. However, the time frame between the midnight sun and the polar night is quite short, such that darkness replaces the favorable light days; bringing the temperatures down to an average of -30°C in January, or even lower to -70°C sometimes, as indicated by recorded levels.

Figure 3.3 demonstrates historical records of Arctic temperature anomalies between 1880 and 2000. It is clearly shown that the Arctic was relatively cold in the late 1800, and temperatures started to warm by about 0.7° over the 20th century. It is also worth noting that warm periods existed between the 1920s and 1940s, and cold periods in the early 1900s and 1960s. As for the last decade it is apparent that temperatures were constantly more than 1.0°C above the 20th century average value (Liu and Kronbak, 2010). Other observations also confirm that air temperature has increased at a rate that is double the global average over the last hundred years (Bobylev et.al, 2004). Therefore, Arctic temperature trends are essentially worth tracking, as they represent a solid indicator for the impacts of climate change. This is a significant issue for predicting the future of Arctic shipping routes.

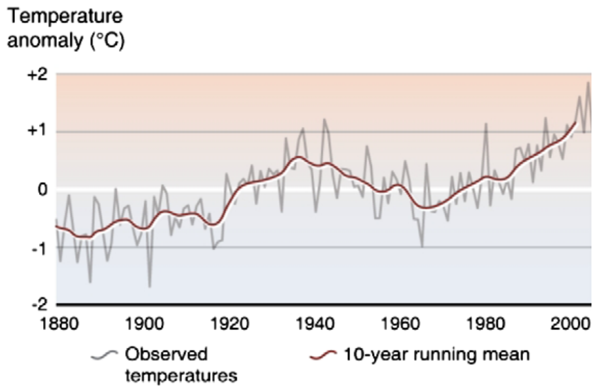

Figure 3.3: Trends in Arctic Temperature (Source: CRU, 2007)

3.4 REMOTENESS OF THE ARCTIC

An additional aspect to the Arctic's harsh environment is its remoteness and the associated challenge adjoining such trait. The fact that the Arctic is distant from trivial portal infrastructure and emergency assets raises the risk for any future sailing activities. Therefore, dealing with rescue incidents in the Arctic is an obstacle that is worth resolving.

4 POTENTIALS FOR ARCTIC SHIPPING

Climate change, natural resource development, governance challenges and marine infrastructure concerns in the Arctic, are all issues powering current and future uses of the Arctic's marine environment. This has urged the Arctic Council[9] to demand a comprehensive Arctic marine shipping assessment, which was conducted by the Protection of the Arctic Marine Environment (PAME), in collaboration with the Emergency Prevention, Preparedness and Response (EPPR) working groups, as outlined under the Arctic Marine Strategic Plan (AMSP). Consequently, "The Arctic Marine Shipping Assessment" report was released in 2009, and is known today as The AMSA 2009 Report. It is worth mentioning that the Council's decision of releasing AMSA followed the synthesis of two relevant Arctic Council reports, namely: the ACIA 2004 Report; which was conferred earlier in Section 2.3, and the AMSP Report which presented the strategic goals of the Council for protecting the Arctic marine environment (AMSA, 2009).

In relation to marine shipping activities in the Arctic, the ACIA (2004) sixth Key Finding states that "Reduced sea ice is very likely to increase marine transport and access to resources." In this regard, dedication will be made for the evolution of marine transport in the Arctic Ocean.

4.1 HISTORY OF ARCTIC SHIPPING

The original explorers of the Arctic were the indigenous people. They have searched the Arctic seeking food, resources and for settlement purposes. The indigenous people can also be described as the founders of the Arctic region (AMSA, 2009).

Investigating the Arctic was not confined for seeking shipping routes only; rather it involved developing the explored routes as well. Two main Arctic routes known today include: (1) the Norwest Passage (NWP), which runs through the Canadian Archipelago and the (2) Northeast Passage (NEP), of which the NSR comprises a main part of; stretching along the northern coastline of Russia (AMSA, 2009; Østreng et.al, 2010). The NSR will be the focal point of the present study; analysis will be made for the advancement of this shipping route.

[9] Please refer to Section 2.3 for the 'Arctic Council' definition.

4.1.1 Promising Arctic Routes

Laulajainen (2009) defines four main Arctic routes. These are exemplified in Figure 4.1; which are known as "the Arctic Sea Routes" and can potentially be utilized as paths for trans-Arctic transportation.

Figure 4.1: Possible Sailing routes in the Arctic; 1: Northwest Passage, 2: Transpolar Route, 3: Russian Economic Zone, 4: Northeast Passage.
(Developed after Ellingsen and Hodøl, (2009)).

Two major routes of global interest nowadays are those depicted in Figure 4.1 as numbers 1 and 4. Route number 1; the Northwest Passage; which goes through the Arctic Ocean, via waterways amidst the Canadian Arctic Archipelago and alongside the northern coast of North America. The apparent obstacles in the form of islands, along with depth restrictions and extreme weather conditions limit the attractiveness of this route if compared to other shipping routes at the eastern side (Eger, 2009). This route will not undergo further investigation in this thesis.

Route number 4 is the Northeast Passage; connecting the Atlantic and Pacific Oceans along the entire length of the northern coast of Eurasia. Of relevance to the present study is the NSR, which is part of the NEP and, runs along the coast of the Russian Arctic from the Novaya Zemlaya in the west to the Bering Strait in the east. Lengths of this route can extend from about 2,200 nautical miles (nm) up to 2,900 nm; depending on the chosen sailing paths. Furthermore, - the Kara Sea, the Laptev Sea, the East Siberian Sea and the Chukchi Sea- all together form a series which makes up the NSR with its ice-infested waters (Østreng, 2010). Additionally, the route offers up to 40% reduction in distance from Northern Europe to Northeast Asia in comparison to traditional lanes; a fact that expanded the international interest in its utilization (INSROP,1999). The core of the present study will be focused on analyzing the environmental feasibility of trans-arctic navigation along this route.

Finally, routes 2 and 3 represent sailing paths that run outside the Russian economic zone. With route 2 portrayed straight across the Pole and, route 3 depicted in a location just outside the Russian territorial waters. It is worth mentioning that these two additional routes have emerged as an alternative to the NSR due to depth restrictions along the NSR; they will not hinder vessel size requirements. Routes 2 and 3 are generally referred to as the trans-polar routes and, are still undergoing further commercial research as a consequence of the rapid ice melting conditions in the Arctic (Ellingsen and Hodøl, 2009). However, these routes will not be further addressed in this thesis.

To this end, it is worth realizing that all possible trans-arctic routes that will one day provide a "short-cut" across the top of the world, share a common crossing point; the Bering Strait.

4.1.2 History of the NSR

Shortening the distance between Northern Europe and Northeast Asia through utilizing the NSR had been the dream of traders for centuries. Nevertheless, it was not until 1879 when the Swedish scientist Adolf Erik Nordenskiöld was able to overcome the harsh ice and cold weather conditions; achieving the triumph of navigating the whole NSR with the ship Vega (Figure 4.2). Vega navigated all the way through the Northeast Passage from Europe to the Bering Strait, after having spent 10 months trapped in the ice (Leslie, 1879), hence, proving the possibility of sailing through a trans-arctic route between Europe and Asia.

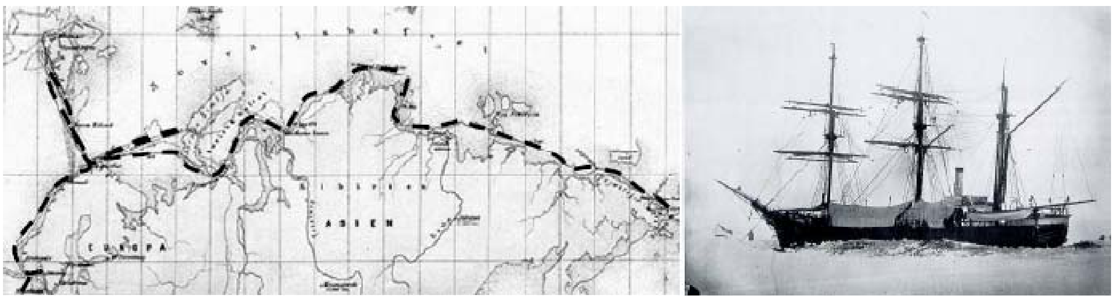

Figure 4.2: Vega sailing through the NSR in 1878-1879 (Source: Tromsø University Library of The northern lights route , 1999)

Previous attempts to discover the passage were made by the Dutch navigator and explorer Willem Barentsz, who in 1594 articulated that the NSR can exist as an open water route north of Siberia, believing that the 24-hour sun is capable of melting any potential ice. However, at that time, he only managed to reach the west coast of Novaya Semlya with his 3 unsuccessful trials (Leslie, 1879).

4.1.3 Characteristics of the NSR

According to AMSA's (2009) definition, the Northern Sea Route, or NSR, stretches from "the Kara Gate in the west to the Bering Strait in the east". It was originally initiated by the Soviet Union in order to serve as a national waterway, and was officially opened and exploited in 1935. The Arctic fleet carried a range of 100,000 to 300,000 tons of cargo annually, employing about 40-150 ships per year. The maximum number of voyages on this route reached its climax in 1987 with a 1,309 trips performed by 331 vessels, amounting to 6.6 million tonnage capacity (Frolov and Krutskih, 2008).

The NSR acted as a preliminary route that has served year-round navigation in ice-covered waters since 1978-79. Historical records exist for Arctic marine transport around the ice-free periphery of the Arctic Ocean. This is represented by the western ends of the route, i.e. the Kara Sea, thereby, providing a passage for ships sailing between the port of Dudinka on the Yenisei River and Murmansk (AMSA, 2009).

Due to political constraints embodied by the Russian Revolution in 1917, the NSR was practically inaccessible to non-Soviet vessels; an issue that limited the international interest in the route at that time (Ragner, 2000). Only on July 1st, 1991 was the NSR open to non-Russian ships, along with the approval of the "Regulations for Navigation on the Seaways of the Northern Sea Route"; a document that regulates shipping through the NSR for all commercial vessels of any nation and without discrimination.

Today, the route is deemed as technically feasible due to the availability of the most powerful ice-breaking ships – of the Russian fleet - worldwide, in addition to ice-strengthened ships for various cargo types, specialized ice navigation skills and a highly developed infrastructure (AMSA, 2009). Moreover, global warming and the polar ice caps melting are introducing a new itinerary in the High North; permitting maritime transport between the markets of Northern Asia and Northwestern Europe, especially that it is thought by 2015 the Arctic Ocean is anticipated to be navigable year-round, particularly along the Russian coast (Verney and Grigentin, 2009 ; Valsson, 2006).

4.1.4 International Interest in the NSR

The opening of the NSR in 1991 resulted in a worldwide attention; recognizing the saving in distance this route can achieve by offering the shortest connection between Northeast Asia and Northern Europe, in a range between 2100 to 2900 nautical miles (Wergeland, 1992). Consequently, the multidisciplinary International Northern Sea Route Programme (INSROP) evolved to investigate all aspects of the potential increased international use of the route. This research programme served as an extensive NSR database, and was primarily a joint Norwegian-Japanese-Russian venture, that lasted for 6 years between 1993 and 1999 and, enrolled more than 450 scholars in 14 countries. Since then, the published material of the INSROP results covered all topics concerning the route comprehensively, such as: natural conditions, ice navigation, environmental factors, trade and commercial aspects, and political and legal aspects (Liu and Kronbak, 2010).

Other relevant studies include: the *Arctic Demonstration and Exploratory Voyage* conducted in *1997,* which aimed at taking a test voyage for Russian and European vessels to verify whether year round navigation around the NSR was by any means achievable (European Commission, 1999). A third follow- up study was the *Arctic Operational Platform* (ARCOP) undertaken in 2002, however, it focused at oil transportation including the maritime dimension (Finnish Ministry of Trade and Industry, 2003). The fourth study in series was announced by the International Arctic Science Committee (IASC) in 2003, and targeted a new Arctic marine transport project titled *Marine Transport and Changing Access in the Arctic Ocean*. Its intention was to assess the changing Arctic ice conditions and its impact on maritime transport routes for both the Arctic Ocean and the Baltic Sea. This study focused on both the NSR and the NWP (IASC Project Catalogue, 2003).

Essentially, the major international interest in the NSR is reflected upon the distance saving the route can propose if compared to traditional shipping routes; Suez Canal and Cape of Good Hope. Figure 4.3 better illustrates this; taking the example of distance reduction between the ports involved in the case study in question. However, the reduction in distance that can be achieved through utilizing the NSR varies since the determining factor is the distribution of ice, which controls the exact choice of routes. That is so because the route is not a single passageway, rather regarded as all possible routes between the Atlantic Ocean and the Pacific Ocean using the eastern part of the Arctic Ocean (Liu and Kronbak, 2010).

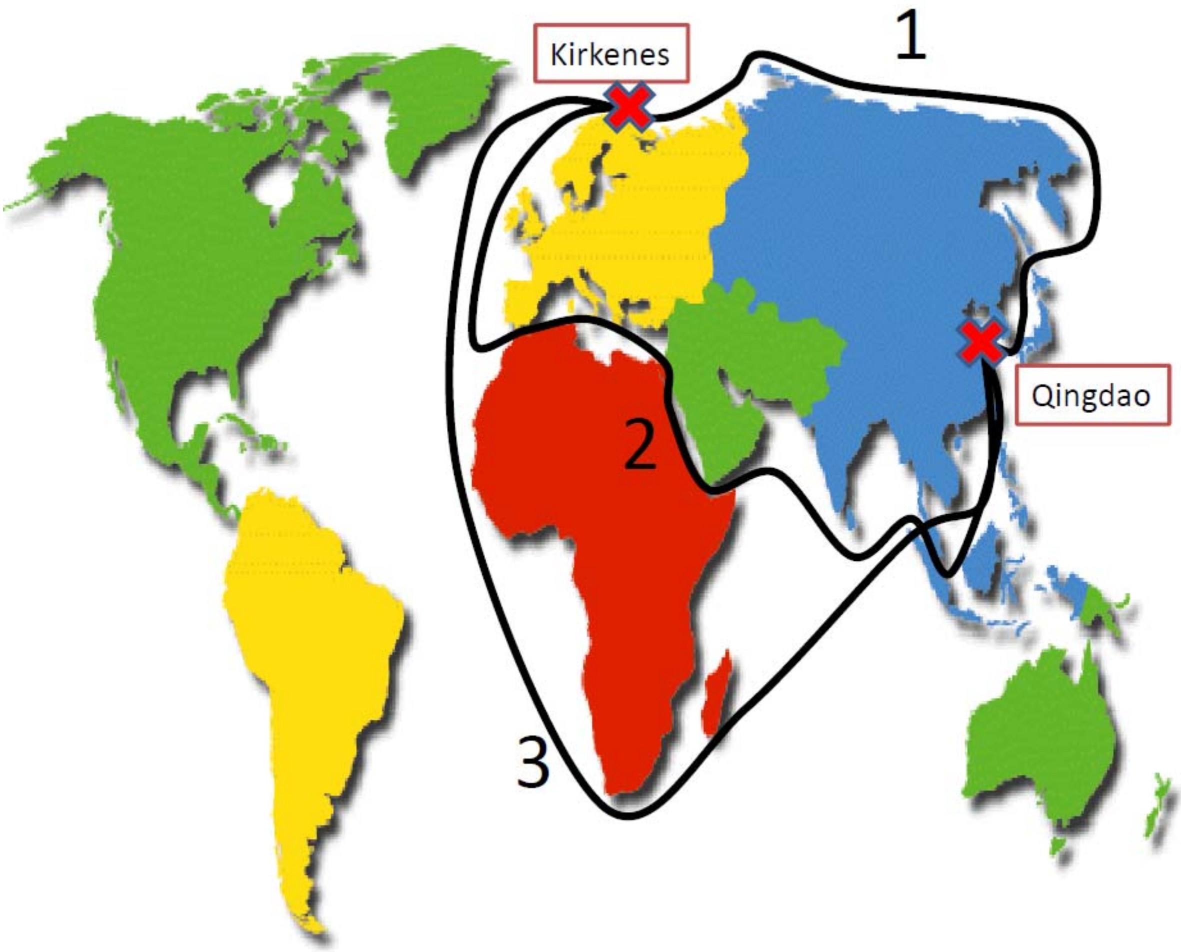

Figure 4.3: Main global route alternatives for maritime transportation; highlighting possible Asian-European trade routes for the Kirkenes-Qingdao case study. The NSR (no. 1), the Suez Canal (no. 2) and Cape of Good Hope (no. 3).

Last but not least, it is worth mentioning that the peaceful growth of the geopolitical climate since the opening of the NSR in 1991, when the dissolution of the Soviet Union opened the Arctic Ocean to international traffic; made the exploitation of the NSR in light of the climate change phenomena more favorable (Brubaker, 1999).

4.2 CROSS BORDER AND LEGAL CONCERNS

As long as the territorial water to be sailed through by future Arctic vessels is under the sovereignty of an assortment of countries; international customs and practices of shipping and merchant communities will have to be operated in order to govern the movement of goods in the Arctic, in addition to the international maritime law

(AMSA, 2009). Hence, the competition of maritime shipping in the Arctic will urge a need for an international treaty, such that the conservation of the Arctic marine environment and the legal responsibility is being administered among the eight Arctic countries involved. These Arctic Countries include: Canada, Denmark/Greenland/Faroe Islands, Finland, Iceland, Norway, Russia, Sweden, and the United States of America.

Huebert, (2008) discusses the need for a cooperative management in the Arctic region, such that sustainability is maintained. The question that Dr. Rob raises in the context of sustainability is *"whether the Arctic Nations are willing and able to strengthen their existing cooperative arrangements to manage the Arctic's transformation conserve the critical resources of the Arctic marine environment, while ensuring that northern peoples can benefit from the new opportunities and at the same time protect their traditional way of life."*

It can be stated that sustainability in the Arctic can only be managed through international treaties imposed equally on all beneficiaries involved. In this regard, the most relevant international treaty that serves for the protection of the Arctic marine environment is the United Nations Convention on the Law of the Sea (UNCLOS). Other international agreements include: the Arctic Environmental Protection Strategy (AEPS), Arctic Council, and the Polar Code for Ships Operating in Arctic Ice-Covered Waters. However, these agreements are only deemed as cooperative and fall under the definition of "soft law" agreements; a voluntary approach.

The fact that the existing cooperative structure among the eight Arctic nations has been developed under a voluntary approach reflects the lack of eagerness of some of the Arctic governments to follow more strenuous treaty bargains. This way it is almost impossible to conduct direct counteractive measures that must deal immediately with any developments taking place in the Arctic (Huebert, 2008). Therefore, a stronger management outline for governing the Arctic has become an essential challenge. In order to create an effective, strengthened management framework, Huebert (2008) suggests three main criteria the framework should meet: (1) It must be comprehensive (2) It must effectively conserve the region's unique living resources and (3) It must assure sustainable development.

It can be concluded, that the determination for utilizing the NSR as a trans-arctic passage will demand a strong cooperation among the Arctic governments involved and their concerned citizens, in addition to external beneficiaries. Apparently, the opposition of only one involved Arctic state will restrain the development of a collective political will towards signing an official Arctic pact and, with the clash of interests in the High North, it is vital that all key participants agree on a stable management regime; tackling the significance of sustainability in the Arctic.

4.3 CLIMATIC CONCERNS

"Future Arctic navigation and all marine activity will depend on more frequent, reliable and near real-time sea ice thickness measurements." AMSA, 2009

Improved access along the Northern Sea Route is highly dependable upon the reduction in sea ice cover. The projected reduction is essentially associated with increased days of navigation (Liu and Kronbak, 2010). Figure 4.4 below clarifies the projected extension in navigation season through the NSR up to year 2100. The figure clearly shows how increased days of navigation are attained towards the end of the century. A terminology worth mentioning in this regard is the "sailing-window". *"The sailing-window denotes what parts of specific year the vessel is theoretically capable of sailing in the respective Arctic conditions of that year"* (Ellingsen and Hodøl, 2009). Relating this terminology to the NSR, it can be said that the sailing-window is the number of days per year when sailing is possible along the route. Nevertheless, ice conditions in the Arctic Ocean are not consistent from year to year, even though the total area of the Arctic Ocean is diminishing. From what has been reported recently, it is anticipated that in some years the NWP will be the virtually ice free route (as in the summer of 2007) and in other years the NSR will be virtually ice free (as in the summer of 2006) (Liu and Kronbak, 2010).

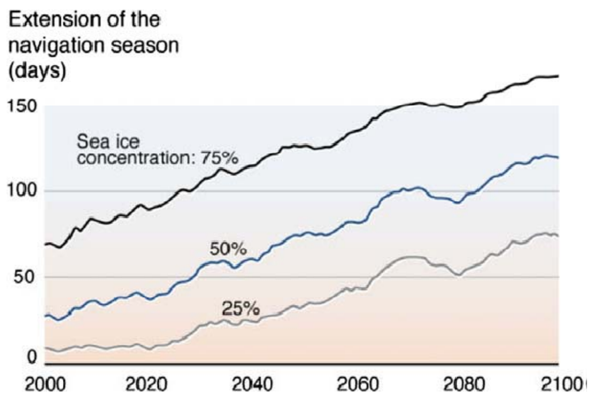

Figure 4.4: Projected increase in days of navigation season through the NSR.
(Source: ACIA, 2004)

As for the navigation season, it was projected that in 2004, navigation along the NSR will increase from 20-30 days per year up to 90-100 days per year by 2080. However, this might be deemed as a conservative estimate since the sea ice melting has increased dramatically between 2004 and 2007 (Liu and Kronbak, 2010). Thus, extreme melting values must be accounted for.

The predictions made by the National Snow and Ice Data Center (NSIDC) for Arctic Sea Ice Extent reveal a rapid growth in melting (Figure 4.5), and confirm that the summer of 2007 reflects the anticipated 2050 scenario of sea ice extent as predicted by the ACIA report (Moe, 2009). Even though the extreme melting reached in summer 2007 is not expected to continue in this trend, the modest rate of ice melting in the summers of 2008 and 2009 are indicators that the sea ice melting phenomenon will continue. Furthermore, the minimum level of ice melting reached in 2009 is in fact much lower than the average 1979-2000.

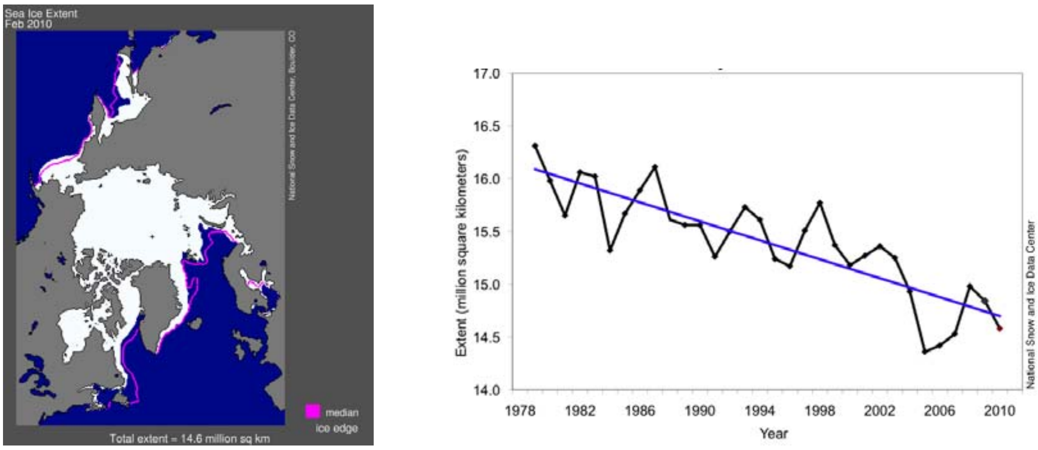

Figure 4.5: A satellite image of the all time low ice extent, taken February 2010 (total extent area of 14.6 million Km^2) and the average monthly Arctic sea ice extent February 1979-2010. (Source: NSIDC, 2010)

To this end, it can be concluded that the climatic conditions in the Arctic are a determining factor for future sailing-window of vessels, with sea ice extent being the most significant. Hence, in order to regard future shipping in the Arctic as feasible, it is vital that climate databases are enhanced and updated such that climatic data is attainable for those showing interest in the region. Meanwhile, major efforts are required to start the phase of collecting relevant data and establishing bench marks for measurement equipment, such as: wind speed and direction, waves, temperature and ice. However, it is worth realizing the challenge that is imposed by the Arctic's climate on the installation of necessary equipment.

4.4 HINDRANCE OF ARCTIC GROWTH

With the Arctic being the world's last undeveloped and unexploited marine region; characterized with its exclusivity in provisions of its landscape, ecosystems and fragile ice environment, it has become more of a challenge to start any industrial development in the marine Arctic, adding to that the vulnerability arising from climate change transformation (Vital Arctic Graphic, 2005). This implies that various coping mitigation measures are required to overcome the impending changes and, cooperation among nations at a governmental level has become inevitable. This section will touch upon determining factors that shape the future of Arctic developments.

4.4.1 Impact of Ice

Regarding ice conditions in the Arctic, it is worth mentioning that the dominant ice type along the NSR is thick, first-year ice (BIMCO, Ice Handbook, 2005), this implies that future shipping in this region will be highly dependable upon the support of ice breakers (Liu and Kronbak, 2010). Additionally, the potential for trans-Arctic navigation raises a concern for a new ship technology where the hulls of the ships are devised to withstand ice forces; ensure safe navigation through ice-infested waters.

Until recently, all ice breaking vessels have had a total efficiency in open waters that is 20-40% less than regular vessels. Electric plodded propulsion devices were introduced in the 1990s and, the new concept of double acting tankers commenced at the beginning of the present century (Juurma et. al., 2001). The principle of a double acting ship allows operation for both conditions of open water and ice covered waters. The design incorporates a highly hydrodynamic shaped bow and sides, such that the ship travels astern in ice covered waters where the strengthened stern hull is employed for breaking the ice (Shi, 2009). The double acting tanker Tempera is illustrated in Figure 4.6 as an example of this technology.

Figure 4.6 Tempera Double Acting Tanker travelling astern to break the ice and, to the fore proving its efficiency in open water (Source: Shi, 2009)

Even though the flexible design of a double acting ship makes it capable in sailing through traditional open water routes; competitive routes of trans-arctic passages, restrictions remain in terms of the high construction cost of the vessel. This new technology proved to be more expensive than traditional ice breakers; however, it still offers fewer shortcomings than traditional ice strengthened vessels (Ellingsen and Hodøl, 2009). In addition to that, plenty of research nowadays stresses the impact of ice not only on ship design in terms of special requirements for hull enforcement, but also regarding the implications that ice has on ship performance, such as reduction in speed due to declination in the propulsion power where more power is diverted for ice-breaking.

4.4.2 Impact of Arctic Climate

The Arctic's harsh environmental conditions and the required ice-breaking technology all demand a qualified crew that can handle navigation difficulties. Additionally, updated navigation equipment and portal infrastructure are essential for any future shipping expansion in the Arctic. In this regard, Mejlænder, (2009) defines four vital features that a vessel sailing in the Arctic will convene; these are shown in Figure 4.7 below.

Figure 4.7: Icing, darkness, remoteness and ice breaking in an Arctic environment (Source: Mejlænder, 2009)

4.4.3 Political Impacts

The High North started gaining strategic importance in the geopolitical and geo-economic agenda due to functional impacts of climate change. The reduction in sea ice cover attracted the attention of both Arctic states and other powerful nations (Heininen, 2008). The sea ice melting phenomenon had opened the eyes of investors into the potentials that the Arctic region can offer to a world where global economy is growing. However, this global interest will essentially demand a coalition between science and politics and will most likely transform geopolitical schemes. In this regard, Heininen (2008) anticipates major indicators of a geopolitical nature. These are clarified in Table 4-1 below. From the listed indicators, it can be stated that climate change is a novel factor that is imposing a new global problem, particularly with the allure of utilizing the Arctic's natural resources and the opportunity of a shortcut access between Europe and Asia. Thus, the potentials for Arctic shipping strongly depend on political negotiations among the Arctic states, in addition to trans-national and international agreements.

Additionally, as the UN Convention of the Law of the Sea is currently undergoing a delimitation process for the outer continental shelf in the Arctic Ocean, distinctive challenges and unusual geopolitics are foreseen to add complexity to the future of maritime Arctic (Brigham, 2009). The changes taking place in the Arctic due to climate change will require a new legal and regulatory structure that is able to meet the needs for enhanced marine safety and to maintain sustainability. A new environmental protection scheme is achievable only if the Arctic states are determined to cooperate and, possibly engaging other non-Arctic stakeholders and actors related to the global maritime industry (Brigham, 2009). Therefore, international cooperation forms the mean for a sustainable utilization of the Arctic, such that the Arctic people and the Arctic marine environment are sufficiently protected during future Arctic developments; efficiently avoiding the negative impacts of natural resources' extraction and extended shipping activities.

Table 4-1: Main indicators of the changing geopolitics of the High North

Factors	Phenomena
National Sovereignty	**Physical space**
Military presence	**National security** **Power**
Utilization of natural resources and new claims	**Resource models** **Jurisdiction**
Strategic (energy) resources	**Energy Security**
Transportation	**Logistics**
Technological development	**Modernization** **Faith of Technology**
Global (security) problems	**Globalization** **World order (models)**
Flows of globalization	**Geo-economics**
International cooperation and dialogue (building)	**Integration** **Governance**
Education, science and traditional knowledge	**Human capital** **Interdisciplinary** **Interplay**
Climate Change	**Uncertainty** **Epistemic community**

(Source: Heininen, 2008)

Speaking of the Northern Sea Route in particular, political stability is essentially required for better utilization of this route. According to the Norwegian State Department (UD), there currently exists a low tension environment between the Arctic nations that have genuine interest in the route (Walaas, 2009). However, this might be due to lack of activity in the region. However, increased international interest in the Arctic is increasing. So far, Russia, the United States, Norway and the European Union have presented strategies for the Arctic to emphasize the significance of the region (GeoPolitics, 2008).

It can be concluded that diverging interest in the region is reflected by the role that politicians play in drawing Arctic regulations and shaping the future of Arctic shipping. Additionally, environmental pressure from concerned organizations will also arise and interfere in the guidelines to be inflicted. For the time being, environmentalists are mainly concerned about type of fuel to be used for ships; heavy oil vs. natural gas. With the Arctic perceived as a fragile environment, it is paramount to conduct further research for determining the most suitable fuel type for the Arctic. Furthermore, certain restrictions are opt to be imposed for ensuring the safety of mammals and other marine creatures in the Arctic, in addition to precautionary measures necessary for safe sailing activities and to efficiently respond to accidents. Clearly, those environmental restrictions are pertinent to political negotiations; future legal agreements will have to account for the norms of environmental protection measures and should essentially be contemporary to meet exclusive Arctic conditions.

5 ENVIRONMENTAL IMPACT ASSESSMENT

It would have been inconceivable to spot a boat in the Arctic only few years ago. Under the effect of global warming, the Arctic ice cap has lost 30% of its surface area in 30 years, and its shrinking is ensuing fast year by year. It is even believed that the ice cap around the North Pole could disappear by summer months in 2030, others say 2015. Today, all eyes are open on the poles, where the effects of global warming are most observable. The Northwest Passage and the Northern Sea Route are opening up very rapidly (Bertrand, 2009). However, any shipping activities in the subtle Arctic cannot be deemed as efficient if it threatens the environment in which it occupies and, with climate change accentuating the intimidation of the ecosystems worldwide; the Polar Regions have already witnessed a disrupted balance of its nature, an issue that raises the concern of sustainable development. Clearly, the alteration of the Polar physical and biological setting is becoming a serious concern requiring alarming calls for action; growth of awareness in sustainability and the necessity of developments being managed in harmony with the environment (Glasson et. al., 1999) have become inevitable. This chapter will focus on analyzing the environmental impacts that are predicted to arise once shipping activities along the Northern Sea Route commence, and where crucial, adaptive mitigation measures will be proposed to outline a framework for an environmental management scheme.

5.1 BASIC DEFINITION OF EIA

A broad definition of Environmental Impact Assessment (EIA) was drawn by Munn (1979), which referred to the need: “to identify and predict the impact on the environment and on man’s health and well-being of legislative proposals, policies, programmes, projects and operational procedures, and to interpret and communicate information about the impacts”. In general, an EIA study serves as a tool for decision makers.

Regarding the Arctic, and since it is deemed as a region with unique features; requiring special attention, the Arctic Environment Protection Strategy (AEPS) produced guidelines for EIA in the Arctic in collaboration with all the eight Arctic countries. Under the AEPS Sustainable Development and Utilization Programme, the Arctic EIA “aims at avoiding deleterious effects on the arctic environment, including all its fauna and flora, abiotic components, natural resources, and human health, security and well being” (Finnish Ministry of the Environment, 1997).

The effectiveness of EIA lays in its ability to highlight the most significant issues from an assortment of components. This is achieved through a scoping phase; where a wide range of potential problems are screened orderly such that a number of priority issues are finally defined and addressed by the EIA (Beanlands, 1988). Furthermore, since political decisions follow a human oriented process; an "intelligent simplification" is essential for setting priorities (Thomassen et. al., 1995). At this instance appears the significant role of EIA, which serves as a systematic process to examine the environmental consequences of development actions in advance (Glasson et. al., 1999); aiming at depicting objective decisions.

5.2 PUBLIC PARTICIPATION: AN INTER-DISCIPLINARY APPROACH

A key feature of EIA is that it involves public participation throughout the whole process. Another imperative asset of an EIA is that it should be a cyclical activity, with continuous feedback and interaction between the various parties involved and at an assortment of phases (Glasson et. al., 1999). Therefore, the nature of an EIA entitles an inter-disciplinary approach and, demands cooperation between different stakeholders: experts, individuals, indigenous people, groups, organizations, or interested communities who could be affected by the proposed action (Finnish Ministry of the Environment, 1997). It is worth noting that the stakeholders involved share varying values, this stresses the importance of integration and communication on different levels (Thomassen et. al., 1995), such that all parties involved are capable of exchanging ideas and are given equal opportunities for contribution. This implies communication across borders (for international developments) and from high political levels down to local community level.

Relating public participation to future developments in the Arctic, it is evident that the complex nature of the Arctic will demand efforts for resolving the conflicts and clash of interests among involved stakeholders, especially with the allure of expanding industrial developments. Hence, fostering common understanding will be an essential facet for successful environmental management planning.

5.3 FUNDAMENTAL FEATURES OF EIA

The utmost contribution that EIA studies provide to any environmental management scheme is the flexibility in adjusting plans at an early phase in the project\process (Thomassen et. al., 1995), such that the proposed solutions or mitigation measures are ensured to be acting effectively in combating any negative impacts. Accordingly, EIA is capable of achieving its chief role of maintaining sustainable development. Sustainable Development intends at striking all detrimental effects acting against the natural and human environment; a concept that gained additional attention in the

21st century in response to the intensification of the negative consequences of climate change.

5.3.1 Sustainable Development

According to the Bruntland Commision (1987), "Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future". The capability of maintaining the needs of future generations requires careful planning for any industrial development, especially when the exploitation of resources is involved or biological, physical, social, cultural and economical environments are threatened. Thus, in order to achieve the objectives of sustainability, a thorough planning approach is essentially required, such that environmental integrity is maintained at tolerable levels of development.

5.3.2 Main EIA Components[10]

Environmental Assessment studies entail the following components: Screening, Scoping, Baseline Information Studies, Impact Prediction and Evaluation, Mitigation, Auditing, Monitoring and Follow-up. These are briefly discussed below.

EIA studies essentially start with a *Screening Phase*, where a decision is made whether the project under consideration requires an EIA or not. This necessitates the use of certain environmental lists. Then comes the *Scoping Phase* where different environmental impacts are identified for further analysis, impacts are also classified into certain categories. Additionally scoping aims at addressing the project alternatives in terms of technology to be used, location, etc, and states the mitigation[11] measures that should be further analyzed later on in the process.

A comprehensive EIA process also calls for available *Baseline Information Studies*, such as existing records of air emission values, or soil and water conditions. This is an essential component since the analysis will be based on comparison with reference to these values; the environmental situation before implementing the project weighed against the predicted impacts arising during different project phases.

Regarding *Impact Prediction and Evaluation*, the identified impacts during the scoping phase will be further analyzed and classified according to their type, magnitude, probability of occurrence, extent and significance. In accordance with the

[10] This subsection was formulated based on the author's previous experience in working with EIA.
[11] "Mitigation is the action taken to avoid or lessen the adverse effects of an activity." (Finnish Ministry of the Environment, 1997)

predicted impacts, suitable solutions to mitigate the detrimental effects will be presented. Therefore, *Mitigation Measures* are essentially case sensitive; such that they comply with the specific environmental conditions of the project. This involves for example, climatic conditions: wind speed and direction, temperatures, waves, etc., social conditions: solutions that are suitable to indigenous people's values, physical conditions: terrain, soil type, etc. and so on.

In order to check the validity of the proposed mitigation measures -after commencing the project - *Auditing* will act as an assessor to the proposed mitigation measures; ensure that the previously proposed measures are meeting their purpose in combating the negative effects. Last but not least, *Monitoring and Follow-up* will guarantee an effective continuity of the process, such that authorized agencies and governmental sectors in charge of inspecting the performance of the project will be documenting the resulting outcome.

It is worth mentioning that the components described above must be executed in a cyclical manner, such that feedback from any phase is not overlooked. Also, *Public Participation* remains a significant component in this cycle. At this point, it is worth noting that the traditional knowledge is a valuable source of information and can only be attained from indigenous and local residents. Speaking of the Arctic, acknowledging the opinion of local residents should be given high priority, not only due to lack of scientific data for that region, but essentially due to the crucial Arctic nature, whom mostly indigenous people are aware of.

5.4 SPECIAL ARCTIC CONSIDERATIONS

Special attention must be given to special Arctic features and to areas of specific interest. Special Arctic features include mainly climate, socio-cultural conditions and the unique functioning of the ecosystem. As for the areas of specific interest, these can be identified in relation to predicted area of potential impact (Finnish Ministry of Environment, 1997).

To this end, it can be realized that a comprehensive EIA requires the knowledge and effort of experts in various fields. Furthermore, EIA is a lengthy process and, must be implemented at an early stage of a project development such that it becomes influential. In this thesis, the EIA methodology adapted for analyzing the iron ore case study slightly deviates from regular EIA analyses, mainly due to lack of time and experience. Hence, attention will be given only for basic shipping impacts relevant to the development project in question.

5.5 METHODOLOGY: A UNIQUE NSR ANALYSIS

Major EIA analyses addressing the Arctic region were conducted through the AMSA and the INSROP research programmes. Both studies had a singular focus on the NSR, which is also the route in question. In this thesis; evaluation of the environmental aspects of the iron ore case study will rely to a large extent on the scientific knowledge stemming from the IMO, AMSA and INSROP recommendations. However, the analysis will be simplified and, will not include all EIA components. Moreover, the criteria will basically deal with predicted impacts of the proposed project on the surrounding environment and vice versa; which is the chief aim of an EIA. Following that, appropriate mitigation measures will be proposed.

In the following sections, a brief description will be given to the bulk logistics case study that was developed by the Centre for High North Logistics. Additionally, details concerning the project owner and the need behind implementing the project will be mentioned. It is worth mentioning that the present thesis will predominantly focus on environmental issues; economical and logistical details will be ignored to some extent and, only raised up if found relevant to the examined issues. Moreover, the analysis will choose to focus on shipping impacts along the NSR. Details relevant to the commodity to be transported or ports, railways and roads that complete the case study's objectives will not be addressed.

5.5.1 Project Description

The Logistic Operations in the High North (LOGIN): is a practical oriented research project attached within the needs of industry and business. The project was initiated as a resultant of an international cross disciplinary network consisting of companies, research institutions and public authorities. The scope of LOGIN is focused on developing and analyzing maritime logistics system for three different industrial categories: (1) Field Logistics, (2) Bulk Logistics, and (3) Project Logistics. LOGIN also considers the need for an efficient and sustainable logistics infrastructure; which calls for a cross disciplinary attention (Det Norske Veritas AS, 2010).

This thesis aims at analyzing the environmental aspects for a case study that falls under the second industrial category of LOGIN; Bulk Logistics. The proposed development aims at unlocking the potential for bulk transportation from northern Scandinavia (Kirkenes/Norway) to the Far East (Qingdao/China) through envisioned trans-arctic routes. As the mining site of iron ore in Kirkenes reopened recently after decades of closure, a new theme that shapes the challenge of opening the northern sea route for iron ore transportation evolved. The NSR was proposed as the alternative among other trans-arctic and traditional routes, mainly because it is very close to the mining site. The present analysis will chiefly assess environmental issues and associated risks adjacent to this development.

5.5.2 Project Proponent

The project proponent is the Centre for High North Logistics[12] whose vision is to create and develop efficient and sustainable solutions for the High North's logistical systems. This is achieved through interaction between business sectors, academic institutions, organizations and public authorities, such that an international knowledge network is created (Det Norske Veritas AS, 2010). Hence, the Centre represents a single unit that combines different stakeholders together.

It can be concluded that the structure of the Centre integrates within its vision a fundamental EIA requirement; Public Participation. This confronts a primary component that serves scoping objectives. However, in the present analysis, screening and scoping components will be ignored due to lack of resources. The following sections will address the most essence components of an EIA; selection of study area, in this case choosing a suitable shipping lane alternative and tackling significant environmental issues.

5.6 DETERMINATION OF STUDY AREA

The proposed development is confined to shipping lanes connecting two ports: Kirkenes in Norway and Qingdao in China. The novel area of interest is represented by the NSR. Speaking of its characteristics, 'Arctic Climate' reflects the preeminent depiction. Chapter 3 of the present study thoroughly discussed the Arctic's distinctiveness. It can be concluded that the major climatic feature that highly impacts the transportation activities and, consequently the route selection criteria is the state of the sea ice.

Determining the project's specific study area is also intriguing, as this depends on the markets involved; relationship between commodity surplus in Norway and steel demand in China (Fearnley Consultants, 2010). If the end user's destination was represented by another continent, a different trans-arctic route would have been considered. Furthermore, since shipping forms 40% of the price of the transported iron ore (Sanderson, 2010), the main target would be to illustrate a shipping route

[12] The Centre was launched as part of the Norwegian national research initiative; i.e. "The Global Maritime Knowledge Hub", which was initiated by the Norwegian Ship-owners' Association and Oslo Maritime Network.

that is shorter, faster and cheaper than the traditional Suez Canal preference; baseline case. Figure 5.1 below shows several operational areas of the NSR along with the Russian Economic Zone.

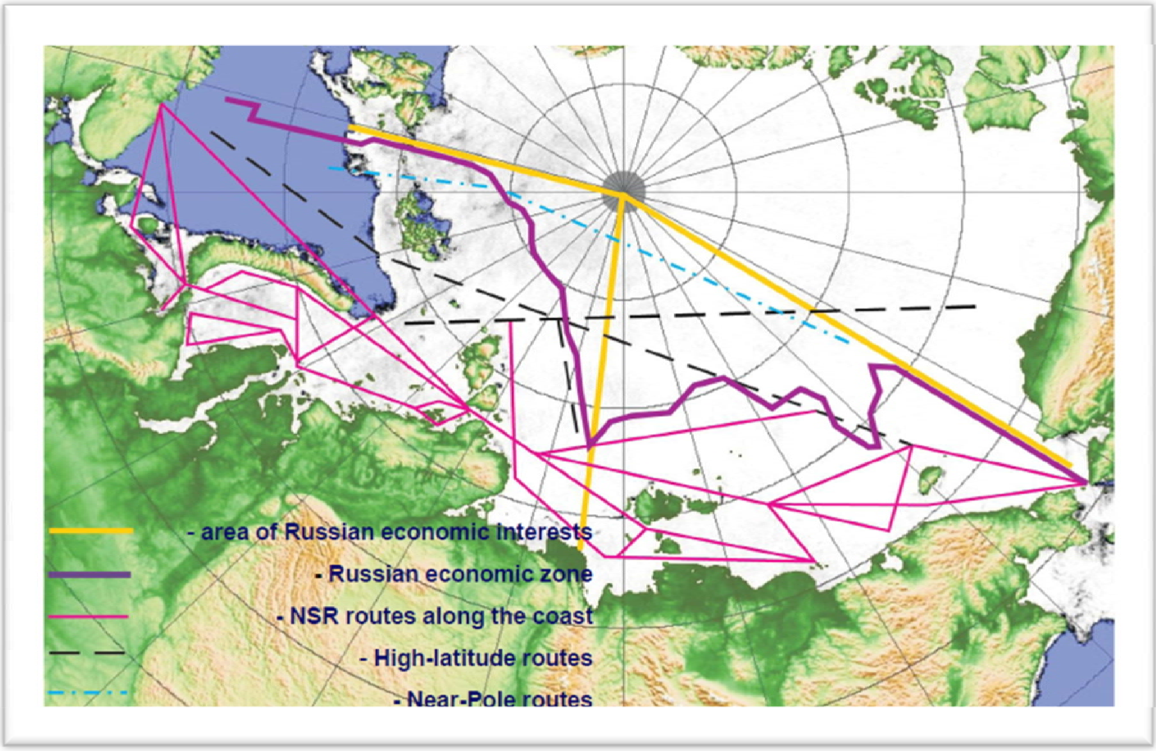

Figure 5.1: Russian economic zone and operational areas of the NSR
(Source: Vyacheslav, 2010)

From Figure 5.1, it can be realized that the foremost concern in the route selection is not only confined to ice-covered areas, but also encloses depth limitations especially around the landmasses involved. In relation to this, Figure 5.2 demonstrates an example of depth restrictions for several shipping lanes around the Laptev Sea.

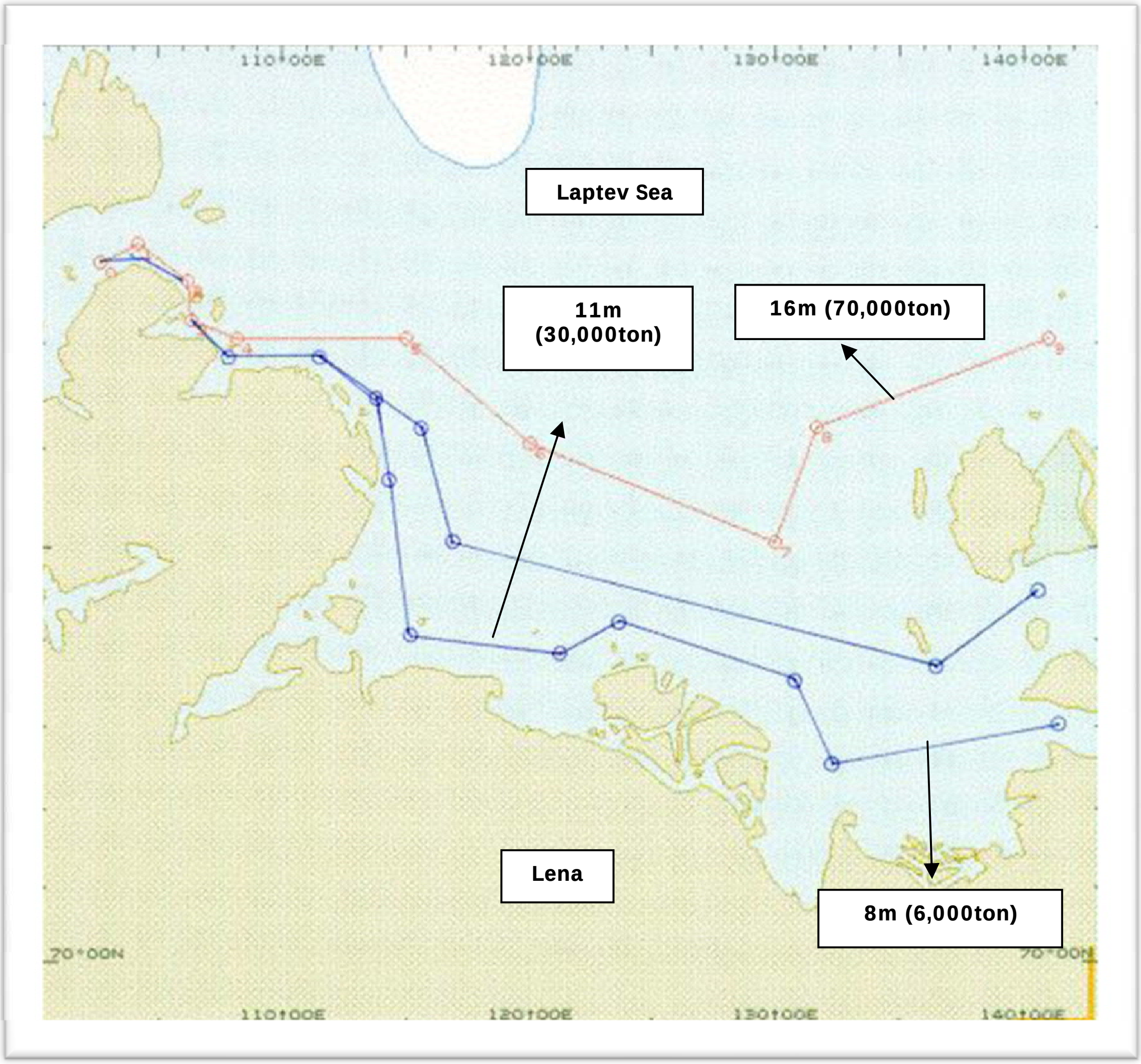

Figure 5.2: Depth Restrictions around landmasses in the Laptev Sea
(Source: Norvald Kjerstad, 2010)

When speaking of route selection, one cannot ignore the correlation to economical point of views. The route selection remains a multifaceted concern, making the overall economics of trans-arctic navigation more challenging. At this point, it must be noted that Arctic shipping is not the same as trans-arctic navigation. In AMSA report it was concluded that nearly all Arctic shipping is destinational today and in the future. One of the real challenges is whether any trans-arctic navigation can be viable from an economic standpoint if it cannot be conducted year-round; reflecting on the costs of icebreakers when not used in ice. Since there will not be very lengthy seasons without some ice somewhere along the NSR passage, polar class ships will still be required (Brigham, 2010). This reveals the complexity of factors interfering with the selection of a proper shipping alternative. And since the baseline case to which the developed alternatives are compared to is the existing Suez Canal; with contradictory climatic concerns, the economical aspect will remain a robust factor that must be adjoined with environmental considerations. However, this issue will not be addressed in the present thesis, though it is an interesting issue for further research.

As shown earlier, there are several alternatives for shipping lanes along the NSR and with varying depths. The present study will assume that the northernmost lane with the 16m depth can serve as a possible option for the iron ore vessels under consideration, mainly because it has the only suitable draught for the proposed vessels' size. However, further details for technicality and impacts of depth limitations on shipping activities will not be addressed. Rather, the assessment will be carried out in a qualitative manner, such that the impacts and proposed mitigation measures are conferred generally. This enables expanding the assessment for future shipping developments in the same study area.

5.7 BASIC SHIPPING IMPACTS

Ships and the environment interact in so many ways. Substances are released to the environment either deliberately or accidently (Talley, 2003). Oil spill accidents are fatal to plants, fisheries, birds and mammals. An example of a disastrous Arctic incident is the Exxon Valdez; an oil tanker that ran aground in the Alaskan waters in 1989. This section aims at addressing common shipping impacts that must be managed through precautionary environmental measures.

5.7.1 Fuel Impact

Fuel impact is twofold: oil spill; with consequences depending highly on type of fuel used and, accidental discharge. Regarding oil spills, Dicks (1998) states that because of the interaction of a great number of factors, two oil spills in the same place may have very different environmental effects, as this depends on the time of year, weather conditions and success of clean-up. As the vessel in question is transporting iron ore, this impact may be deemed as irrelevant in respect to cargo carried. However, concerns remain regarding spills occurring from ship collisions or leakage of fuel. A Possible mitigation measure to this issue would be the prohibition of the use of heavy fuel oil (HFO), taking the example of the Norwegian Government which prohibits the use of heavy oil outside the shores of Svalbard (Svalbard, 2009). Another impact imposed by HFO is its contribution to ship air emissions by being a source of nitrogen oxides (NOx), sulfur oxides (SOx) and particulate matter (PM). Measures to be taken could include converting into cleaner distillate oil, however, this process is gradual and will require sometime before it can be adapted by the shipping sector. However, the International Maritime Organization (IMO)[13] commenced the concept of Sulphur Emission Control Areas (SECA); a binding agreement under which the assigned regions can only introduce lower allowable sulphur content (1.5%) in the fuel oil used. The North Sea; which is part of the study area considered, is already covered by this initiative (Mortensen, 2010). Alternatively, heavy oil can be replaced with a less polluting fuel, such as natural gas which is depicted as the cleanest type of fossil fuel (World Natural Gas Production, 2010). However, even though utilizing natural gas will be considered as a convenient measure to protect Arctic waters, studies revealed that it is mainly composed of methane. Methane has a high radiative forcing effect, twenty times greater than carbon dioxied (US EPA, 2010); introducing an additional air pollutant. The overweighing of the impacts of different types of fossil fuels is beyond the scope of this study. Nevertheless, this is an interesting issue for further research.

Regarding oil spill accidents, this impact can pose a great threat on marine birds and mammals. In this regard, the Norwegian Coastal Administration had adopted an integrated environmental risk management plan, such that valuable and vulnerable areas were identified across the Norwegian part of the Barents Sea. Furthermore, information on risk trends in the area was addressed in relation to oil pollution from ships. In accordance with this effort, the International Maritime Organization (IMO) established new regulations for vessels transiting the Norwegian coast of the Barents Sea such that the Norwegian coastal environment and resources are protected. It was stated that large cargo vessels should operate further away from the coast than in the past; allowing longer response time in case of accidents (AMSA, 2009). This mitigation measure can be further developed to include the Russian coasts along the NSR; nevertheless, this requires an administrative Russian initiative. Other mitigation measures include the compliance to environmentally friendly clean up processes, such as in situ burning. The weight of this impact can be evaluated through environmental risk assessment; demonstrating the manageability of the resulting effects.

5.7.2 Ballast Water Disposal

The process of vessels taking on and discharging ballast water is vital for their stability. It is a common practice that may disrupt the natural marine system (Talley, 2003). In the AMSA report, this issue was raised under the topic of introduction and spreading of alien invasive species. The main concern was essentially the loss of the Arctic's biological diversity, primarily due to changing climate and increased

[13] IMO: Is a specialized agency of the United Nations, established in 1948. Its main task has been to develop and maintain a comprehensive regulatory framework for shipping and its remit today includes among others also environmental concerns of shipping.

shipping (AMSA, 2009). Long-term solutions for innovations in the treatment of ballast water such that non-indigenous species are killed or removed is a possible mitigation measure (Talley, 2003). Furthermore, the IMO addressed the issue of ballast exchange and treatment in its *International Convention for the Control and Management of Ships Ballast Water & Sediments*. Norway is already one of the countries who has endorsed this convention, under which only a small percentage of viable organisms are allowed to be discharged (AMSA, 2009). In this regard, this impact can be deemed as manageable.

5.7.3 Regular Discharges to Water

Regular discharges to water include: bilge water, oily water from tank washings, oily sludge which accumulates in fuel tanks and constitutes 1-5% of the amount of fuel consumed, sewage, garbage and, grey water. The IMO's *International Convention for the Prevention of Pollution from Ships, 1973, as Modified by the Protocol of 1978 Relating Thereto (MARPOL 73/78)* and other relevant conventions, in addition to national regulations of coastal states, all have made efforts to regulate regular ship discharges. Restrictions exist for maximum allowed concentrations of these discharges. For example, oily sludge is not allowed to be released in waters and according to the international standards, it is mandatory to store it onboard and disposed of only in reception facilities at ports (AMSA, 2009).

INSROP thoroughly discussed the requirements to NSR shore reception facilities. A relevant mitigation measure to the iron ore case study is that shipping operators that are targeting the NSR as a trans-arctic passage should equip their ships with installations such that the amount of waste generated is reduced as much as possible. This is so since waste treatment will be done merely at central reception sites, such as the ports of Murmansk, Archangel and Nahodka. Other ports on the NSR will be responsible for only collecting the waste and transferring it to the central sites (Semanov et. al., 1994). Thus, this impact is manageable.

5.7.4 Hull Fouling Impacts

Fouling is defined as "*the unwanted growth of biological material*" (Talley, 2003). A serious threat to subarctic waters today, is the transfer of aquatic invasive species on ship hulls (AMSA, 2009). However, hull fouling is normally dealt with through the application of antifouling agents, since vessel hulls must remain free of fouling to prevent their speed reduction. This introduces another unavoidable impact to adjacent waters of the NSR; effective antifouling agents used for hull coating (AMSA, 2009).

Another possible mitigation measure to prevent fouling is to dry dock vessels, which is a process that occurs every 2-5 years (Talley, 2003). Therefore, this impact is significant and manageable to some extent. However, innovative measures for mitigation are still required.

5.7.5 Ship Air Emissions

AMSA disclosed that shipping activities contribute significantly to global climate change through GHG emissions. Ship air emissions include carbon dioxide, methane (CH4), Chlorofluorocarbons (CFC), aerosols, nitrogen oxides, sulfur oxides, carbon monoxide (CO) and particulate matter. Chemical processing and atmospheric transport of those emissions result in significant air quality impacts (AMSA, 2009). Activity-based estimates of Arctic marine shipping emissions were developed by AMSA. However, the attained figures reveal the total amount generated from international shipping and do not allocate the share produced along the NSR. In the present study, CO_2 emissions allocated for the iron ore vessels in question will be analyzed quantitatively.

The above mentioned pollutants are directly linked with specific environmental effects and, complex interactions among these substances can occur in the regional and global atmosphere (AMSA, 2009). Since the climatic effects of those emissions are still at the beginning of their understanding, the present study will not go into the details of their global impacts. Nevertheless, it must be stated that AMSA mapped the amount of CO_2 emissions according to location of activities; assigning emissions resulting from different routes for various vessel types. The mapping revealed that CO_2 emissions are heaviest in the Bering Sea region, along the Norwegian coast and in the Barents Sea, which is also part of the study area in question. In AMSA report, it was advised that further research on the trend of ship-based emissions would be conducted. Furthermore, as the current climate change's policy focuses on CO_2 emissions, Chapter 6 of this study will map CO_2 emissions generated by the proposed development; iron ore transportation along the NSR. It is worth mentioning that a significant mitigation measure for managing CO_2 emissions is the potential for slow steaming. Slow steaming denotes sailing at reduced speeds in parts or whole of the voyage (Penfold, 2008). However, this will result in longer time spent at sea. In this regard, Lloyds Register warns of side effects such as an increase in NOx emissions, loss in propeller efficiency and loss in heat recovery systems since the engine is driven at a speed extremely lower than the design speed (Lloyds Register, 2010). Further research is still required in this regard. The present study also aims at scrutinizing the impact of slow steaming on generated emissions.

To this end, it can be concluded that ship air emissions are highly significant and, advanced mitigation measures require novel efforts to combat the negative impacts. A possible starting point would be the compliance with the existing IMO regulations under the MARPOL annexes for reducing global emissions; serious efforts must be allocated for adapting proper precautionary measures.

5.8 IMPACTS RELEVANT TO ARCTIC SHIPPING

"Many environmental effects resulting from ship disturbances can be effectively mitigated through the use of best practices and the implementation of management measures" AMSA, 2009

5.8.1 Sound and Noise Disturbance

Sound is a by-product of a vessel's operation requirements, such as low frequency sound generated by the machinery onboard. Also the dominant source of noise is the hydrodynamic flow noise around the hull resulting from propeller cavitation. The produced sound is relevant to ship size, speed, load, condition, age and engine type. The larger and faster the ship is, the more noise it produces (AMSA, 2009).

Relating sound impact to marine species, it can be stated that in general, making, hearing and processing sound serves their fundamental biological functions. And introducing noise to those species' environment will adversely impact their ability in using sound for meeting necessities of surviving. Proposed mitigation measures include rerouting from sensitive areas, lower speed (which is already an option in this study for a slow steaming operation) and improved hull and engine designs such that noise of ships is reduced (AMSA, 2009). Furthermore, the IMO is currently undergoing a phase of developing guidelines for innovating ship-quieting technologies targeting commercial shipping industry. Therefore, this impact is manageable.

5.8.2 Impact of light

The primary concern of this impact is the risk of bird species' collision with lighted structures. This highly depends on weather, season and the age of birds. In the Arctic, most collision incidents occur in the fall migration season. However, generally speaking, light collision can be deemed as an insignificant issue for the Arctic during the summer months, since there is little or no darkness; also due to the fact that Arctic-breeding birds are less active at night (AMSA, 2009). Nevertheless, this impact becomes significant during non-breeding periods; late summer and early fall, as the presence of lighted ships increase in ice-free waters; the risk becomes prominence (AMSA, 2009). As for the NSR case study, avoiding the breeding regions is a possible mitigation measure.

5.8.3 Impact of Icebreakers

Icebreaking operations will pose two fold disturbances; generated noise and the path of open water left astern. Furthermore, the technique of an icebreaker functioning promotes louder and more variable voices than other vessel types; this is best clarified with the process of ramming forward into the ice and then reversing to start again (AMSA, 2009).

Sources of noise are created from the bubbler systems that icebreakers are equipped with for ice clearing operations and, the propeller cavitation associated with the icebreaker movement, hence, disrupting the hearing ability and vocalization of marine mammals. Nevertheless, some Arctic species have proved to exhibit strong avoidance and awareness response (AMSA, 2009).

As for the channel openings, this will have a negative impact on Arctic residents, thus, altering animals' behavior. Additionally, open water channels will certainly interrupt the mobility of people and animals over the ice, especially if it takes long time to freeze up again. Another significant impact arising from open water operations is the confusion those channels will pose for marine mammals and other Arctic species, who will be deceived to replace channels for polynyas[14] and eventually get trapped when the channel refreezes again, whilst they have gone too far from the ice edge (AMSA, 2009).

The case study under consideration (iron ore transportation along the NSR); will assume a nuclear icebreaker for opening water operations. The aim of this choice is to cut off CO_2 emissions. However, icebreakers introduce radiation concerns that will impact ecological systems in the Arctic Basin (Pravdin et. al., 1997).

In this regard, INSROP developed Environmental safety measures, where it discussed technical and organizational measures and, elaborated on emergency plans in relation to radiation effects of nuclear icebreakers. The main precautionary measure recommended is to ensure that radiation levels are kept to acceptable low levels. Additionally, under this safety programme, a Marine Radiation Monitoring System intended for providing necessary data and managing accidents subsists; however,

[14] Polynyas: The only naturally occurring ice opening in the Arctic winter caused by wind or ocean currents (AMSA, 2009).

improvements are still required such as linguistic issues and routing information flow. Therefore, this impact can be better mitigated if international cooperation is enhanced and transparency ensured.

5.8.4 Vessel Collisions on Marine Species

Marine organisms colliding with vessels will encounter death or serious injuries. Vessel collisions are a main concern when large species are involved, such as large whales or cetaceans (i.e. narwhal, beluga whales) (AMSA, 2009). In the Arctic and along the NSR, when traffic flow increases, this impact is likely to become significant. In this regard, AMSA reported that vessel speeds in the range of 10-14 knots, increase the probability of a whale being survived a collision in the order of one-half or greater. Therefore, speed restrictions can serve as a convenient mitigation measure for protecting cetacean aggregations. Since the case study in the present analysis will assume a speed of 14.5 knots in open water, this impact becomes less significant. Routing measures are another effective appraise for avoiding areas with vulnerable Arctic species. Some Arctic regions have already adapted measures that included shifting of shipping lanes and have established the “Area to be Avoided” (AMSA, 2009) vessel. Moreover, a guideline for minimizing the risk of collisions on cetaceans is currently being developed by the IMO.

To this end it can be stressed that shipping impacts, whether relevant to Arctic operations or basic impacts will both be encountered by future activities along the NSR. However, the IMO proposes and is still developing plenty of mitigation measures for managing those effects. The ambiguity remains in the willingness of ship operators to abide by the recommended measures of the IMO. Furthermore, the INSROP and AMSA findings both provide extensive solutions that are specific and directly deal with the NSR developments. Essential databases for information relevant to trans-arctic navigation along the NSR already exists and should be utilized by the operators of the proposed development; iron ore case study.

6 ENERGY AND EMISSION MAPPING

"In a world where the cost of fuel and subsequent carbon emission is increasing at an accelerated pace, having full control of the factors affecting an organization's GHG emissions and energy consumption is paramount." ~DNV ProNavis

As discussed in earlier chapters, the world's changing climate is forcing an urgent demand for sustainability. Maintaining sustainable development is no longer confined to the agenda of environmental activists; rather it has become a competent component in today's industry. With the ongoing debates around the severe impacts of climate change, most industries are sprinting to prove that their systems are functioning in accordance with the environmental standards. Furthermore, the pressures from customers who are concerned about GHG emissions have resulted in the commitment of the private sector towards Corporate Social Responsibility (CSR)[15], where carbon footprint records are exposed.

Even though international environmental standards are still disputable, the fact that the non-renewable energy resources are diminishing implies an increase in their prices and, in the long run governments will start imposing environmental taxes or regulations to account for this increased cost on one hand, and to eliminate emissions on the other. For example, heavy oil is already prohibited within the European Union (EU) region and, it can be assumed that more countries will adhere to this trend in the future. In this regard, this chapter will briefly present a methodology aimed at inspecting GHG Emission and Energy Consumption for a transport system. Following that, an illustration will be presented for the Kirkenes-Qingdao case study, in order to scrutinize the environmental soundness of shifting the transit shipping route from the traditional; Suez Canal into the proposed trans-arctic; Northern Sea Route.

6.1 GHG PROTOCOLS

Standardization methods of GHG emissions have been taken by plenty of stakeholders. For example, the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) have created the GHG Protocol Initiative which assesses performance of maritime logistics chains.

The GHG Protocol Initiative identifies three levels of scope to account for sources of emissions. These include: (1) Direct GHG emissions from sources owned by a certain

[15] CSR: In the private sector, a commitment to corporate social responsibility implies a commitment to some form of the Three Bottom Line (TBL) reporting. This is distinct from the more limited changes required to deal only with ecological issues. TBL captures an expanded spectrum of values and criteria for measuring organizational (and societal) success: economic, ecological and social; it is also known as 'the three pillars' or 'people, planet and profit'.

firm, (2) Indirect GHG emissions generated from electricity purchased by a firm and, (3) Other indirect GHG emissions, such as activities that arise as a consequence of a firm's existence or intended to meet the necessities of a firm's functioning; for instance construction of infrastructure (roads, railways), mining activities and emissions produced during ship manufacturing as applies for the Kirkenes/Qingdao case study. However, the third scope of this protocol is normally eliminated due to the complication in defining the various sources of emissions and, subsequent data collection, mapping and calculations. Regardless of the neglection of this scope in most developed mapping models, it remains an integral part of a mapping process when CO_2 estimates are required on a life cycle basis.

In the present study, the model used is that developed by MARINTEK. The model maps CO_2 emission and energy consumption. The input requirements utilized were those employed in one of MARINTEK's projects, which mapped emissions for sea transport activities. It is worth mentioning that the model's calculations were based on the IMO Protocol: Study of Greenhouse Gas Emissions for ships (2008), which is one of the most detailed protocols available. The main parameters required by this protocol include type and size of ship, cargo capacity, capacity utilization, service speed and transport work.

6.2 METHODOLOGY: CARBON-FOOTPRINT MAPPING

In general, all carbon footprint estimates of a supply chain[16] are derived from energy consumption calculations. A means for arriving at a reasonable energy consumption figure is by looking at amount of fuel consumed. In most cases fuel records or invoices are used as a starting point for calculating the actual fuel consumption and then the mapping protocols can be used for recalculating the consumed fuel into energy consumption and associated emissions. As the aim of the present analysis is to hypothesize future transport chains, simplified assumptions are used to describe fuel consumption. Therefore, estimates will rely on work performed by the chain instead, such that transported cargo volume and the travelled distance form the basis of these assumptions.

[16] A supply chain is a system of organizations, people, technology, activities, information and resources involved in moving a product or service from supplier to customer. Supply chain activities transform natural resources, raw materials and components into a finished product that is delivered to the end customer.

6.2.1 Baseline Case & Proposed Alternatives

The present analysis will compare the energy consumption and generated emissions for three logistics solutions. The baseline alternative is identified as activities associated with supplying the iron ore from Kirkenes to Qingdao via the traditional sea route; Suez Canal. Modeling of a single ship will be conducted in this case. It is worth mentioning that mapping will be dedicated only for energy and emissions produced as a result of time spent at sea, in addition to port operations such as loading and unloading. Road or rail transportation of cargo will not be taken into account.

At this point, it must be recalled that one of the objectives of the present thesis is to scrutinize the environmental soundness of converting the shipping itinerary from the traditional mode to the trans-arctic: NSR. Therefore, the analysis will compare the foreseen emissions generated from transportation activities of both logistical solutions. Furthermore, the present study also aspires to predict the long-term impact of climate change on a NSR transit. For this purpose, two different ice scenarios will be proposed, such that assumptions are made for the development of sea ice conditions along the trans-arctic passage. The projected years assumed for the analysis are 2030 and 2050, such that ice conditions are more favorable in 2050, where more open water distance is presumed for this year. On the other hand, the proposed logistical solution for year 2030 will assume that the ship will be serving in a convoy journey due to a necessity for ice-breaker assistance. Whereas in year 2050 scenario, a single ship assumption is made. However, the only difference between the proposed alternatives will be an additional waiting time for the convoy scenario. This is so because in a convoy journey all vessels must wait until being assembled, such that the cost of an ice-breaker assistance is shared among ship operators. In this case, it will be assumed that a nuclear ice breaker will provide assistance when needed, mainly to eliminate generated carbon emissions. It is understood that a nuclear icebreaker will pose a higher risk than regular icebreakers; this issue was discussed earlier in Chapter 5 where appropriate mitigation measures for managing associated risks were proposed.

Therefore, mapping will involve the sea waters of the NSR; starting from Kirkenes port, crossing the Norwegian Arctic then transiting through the Russian Arctic until the Qingdao port is reached. Additionally, as the baseline case forms the bench mark for comparison, the modeling will also involve a case where transit takes place through the Suez Canal. Figure 4.3 demonstrates those transit routes.

To this end, the logistical solutions to be mapped can be summarized as follows;

- Baseline Case: Single ship via the Suez Canal
- Alternative One: 2030 ice scenario / Ship in convoy via the NSR
- Alternative Two: 2050 ice scenario /Single ship via the NSR

6.2.2 Data Assembly & Associated Assumptions

In order to simplify the comparison, it will be assumed that the bulk carriers used along both routes are of a Panamax type with the same deadweight (dwt). According to IHS Fairplay's database sea-web[17], bulk carriers of this size are available for both ice class and non-ice class vessels. Even though both vessel types comprise the same average speed and average dwt, an ice class vessel remains heavier and this is reflected in a higher engine power (Wergeland, 2010). Tables 6-1 and 6-2 present the specifics for each ship type as reasoned throughout the analysis.

Table 6-1: Ship specifics for a Regular Panamax

DWT	70,000
Service speed (knots)	14.5
Engine power in (kW)	9,100
Fuel consumption at service speed (g/kWh)	190
Fuel consumption in port (g/kWh)	20

Table 6-2: Ship specifics for an Ice Class Panamax

DWT	70,000
Service speed (knots*)	14.5
Engine power in (kW)	9,700
Fuel consumption at service speed (g/kWh)	190
Fuel consumption in port (g/kWh)	20

*1 knot = 1 nautical mile per hour

An online calculator[18] will be used to estimate distances between operational ports. Table 6-3 illustrates main operating distances assumed. The breakdown details of each route specifics clarifying the time spent at sea, transported volume and distances between ports are provided in the appendix.

[17] http://www.sea-web.com
[18] http://e-ships.net\dist.htm

Table 6-3: Main operating distances between Kirkenes and Qingdao

	Via Suez	Via NSR
Total Distance (nm)	12,221	8,160
Open water distance in 2030 (nm)	-	5,360
Open water distance in 2050 (nm)	-	8,000

(1 nm = 1.852m)

The total distance given in Table 6-3 is that attained from the online calculator. Whereas the open water distance is an arbitrarily value chosen for the analysis. It was not possible to base the open water distance assumption on any ice model since these are still in their infancy. However, most conclusions made by the NSIDC, ACIA and IPCC predict that the surface area of ice in the Arctic Ocean could contract between 15% and 40% by the end of summer 2050. This contraction is also anticipated to be accompanied by reduction in thickness of up to 30%, in addition to the probability of the ice being drifted by the ocean currents, thus, easing the sailing conditions. From this point, it was assumed that the ice conditions in 2030 will be more challenging than in 2050, such that an assumption of a longer ice-covered water distance was made for the 2030 scenario and, accompanied by a requirement of an ice-breaker assistance to force the passage through the thin layer ice in this year scenario.

A chief equation exploited throughout the analysis was:

$$\boldsymbol{Time = Distance/Speed}$$

As the distance remained the only constant parameter; ship speeds highly impacted the time spent at sea and consequently the final emitted carbon. This issue forms the underpinning of the present analysis. Furthermore, additional waiting and port times were attained from port operators. These are shown in Table 6-4. Speed and distance for waiting and port times are essentially zero since the ship is not moving at those times. Time spent for port operations at Kirkenes and Qingdao is assigned for loading and unloading of cargo respectively. Whereas waiting time is the time wasted while ship is either waiting in a queue, as is the case of a Suez Canal passage, or for ice-breaker assistance, as is the case for a NSR transit. It is worth noting that the transit time which was assumed for the case of a Suez Canal passage, is the time associated with the ship sailing at a speed of 8 Knots, due to traffic congestion witnessed at the Canal. Additionally, the 48 hours allocated for the NSR transit is the additional time assumed for the ship while waiting for other vessels to be joined for the convoy voyage.

Table 6-4: Additional waiting, transit and port times

	NSR	Suez Canal	Kirkenes	Qingdao
Waiting time	48 hours (only for convoy)	16 hours	-	-
Port operation (hour)	-	-	120	120
Transit Time (hour)	-	14 hours	-	-

6.2.3 Fuel Consumption vs. Carbon Footprint

All carbon footprint estimates address the proportional relationship between fuel consumption and CO_2 emissions. Hence, the methodology adopted in the present study was based on this hypothesis, such that the final estimate for emissions was derived from amount of fuel consumed. The procedure for determining the final carbon footprint is demonstrated hereunder:

$$\boldsymbol{Ton\ fuel\ consumption} = \frac{(\boldsymbol{hours\ spent\ at\ sea}) \times \big(\boldsymbol{fuel\ consumption\ (g/kWh)}\big) \times (\boldsymbol{Engine\ Power(kW)})}{\mathbf{10^6}}$$

$$\boldsymbol{Total\ yearly\ fuel\ consumption} = \boldsymbol{fuel\ consumption\ per\ trip} \times \boldsymbol{no.\ of\ trips\ per\ year}$$

Such that; $\boldsymbol{Hours\ spent\ at\ sea} = \boldsymbol{Distance\ /Speed}$

$$\boldsymbol{Trips\ per\ year} = \frac{(\mathbf{365 \times 24})}{\boldsymbol{Time\ spent\ for\ each\ trip}}$$

$$\boldsymbol{Total\ tons\ transported\ per\ year} = \boldsymbol{no.\ of\ trips\ per\ year} \times \mathbf{70,000}$$

Finally, the total emissions for all cases were calculated as follows;

$$\boldsymbol{Total\ Emission\ per\ year} = \boldsymbol{Ton\ CO2\ per\ ton\ fuel} \times \boldsymbol{Total\ yearly\ fuel\ consumption}$$

At this point is, it is worth addressing a significant correlation between speed and fuel consumption. This is described by the Admiralty formula, which states that the consumption of fuel is proportional to the cube of speed. This relation will be highlighted in the impact of slow steaming on generated emissions, since in a slow steaming operation vessels are sailing at a very reduced speed. Slow steaming operation was assumed for sailing in ice-covered waters as well as for the transit distance through the Suez Canal.

Furthermore, the volume of transported cargo was calculated as the total number of trips that can be performed per year multiplied by the dwt of the ship. Therefore, the analysis assumed a cargo volume of 70,000 instead of dwt. As for the Ton-Miles estimate, this only accounted for one-way travelled direction, assuming that the vessel will return with ballast.

6.3 SENSITIVITY ANALYSIS

Generally, a sensitivity analysis aims at apportioning the uncertainty of an output to different inputs of a model. The technique aims at systematically changing the parameters of the model in order to determine the effects of such changes (Cruz, 1973). In the present analysis, the purpose of applying this technique is to validate the robustness of the attained results and to examine the fundamental factors that are deemed as effective in carbon footprint computations. Two fundamental factors to be inspected are: Speed and transported Cargo Volume.

6.3.1 Impact of Cargo Volume

According to the assumptions made, the baseline case itinerary via the Suez Canal has a capacity for transporting a volume of 308,815 tons. However, in order to create a lucid base for examining the impact of cargo volume on generated emissions, the assumptions will be based on a fixed number of trips performed. As the transportation via the Suez Canal has a maximum capacity of 4 trips per year; carbon footprint inspection for each alternative will be based on this figure. Hence, it is assumed that the total cargo volume to be transported is 280,000 ton. This allows unifying the tons of transported cargo for all alternatives, such that all cases are - to a certain extent- placed on a similar scale of comparison.

6.3.2 Impact of Speed

The Admiralty equation discussed earlier reveals the significant impact that sailing speed has on fuel consumption. And since CO_2 emissions are proportional to amount of consumed fuel; the study will aim at inspecting the impact of speed on amount of emitted carbon. For this purpose, it will be assumed that vessels sailing via both routes are slow steaming at a speed of 10 Knots.

7 ANALYSIS & DISCUSSION

The main purpose of the environmental mapping was to scrutinize the potential for rerouting the iron ore transportation towards a NSR transit. Accordingly, the performance of the alternatives developed for the 2030 and 2050 ice scenarios will be inspected in respect to the baseline case. Additionally, the analysis will also tackle the impact of ice condition development on the proposed scenarios.

7.1 MAPPING RESULTS

Table 7-1 summarizes the output of the carbon footprint mapping. The table is valid for comparison on a year round basis. It is clearly shown how all cases perform different amount of work per year. For example, the total time for one roundtrip in a 2030 ice scenario was calculated as 66 days, whereas in 2050 it was only 57. This is so because the 2030 scenario assumed a case where the ship will be sailing in a convoy voyage due to ice conditions in that year and, the need for ice-breaker assistance; an additional 48 hours of waiting time for a convoy service was required for each direction in this case. Furthermore, as sailing in ice water was assumed to be dominating in the 2030 scenario, this required accounting for slow steaming operation of vessels, an issue that certainly prolonged the total time of the journey as vessels were sailing at a speed much lower than the design speed.

As for the baseline case, the total length of a roundtrip was calculated as 83 days. The longer conveying length of the Suez Canal passage is reflected in its least capacity for roundtrips and, consequently lesser volume of transported cargo. The table also shows the total energy consumption which led to the final value of the total generated emissions. It is interesting to note the 33.5% reduction in total emissions upon comparing the two ice scenarios together, even though the numbers of trips performed in those projected years are somehow comparable. The impact of slow steaming operation is apparently reflected in the high savings of consumed fuel. On the other hand, even though the total amount of emissions for the baseline case and the 2050 ice scenario appear to be comparable, it must be realized that in this case the NSR is actually transporting more volume; performing more work and hence, more generated emissions.

Table 7-1: Comparison of output for the proposed cases

	Trips/year	Tons / year	Mill ton-miles per year	Total yearly fuel consumption (ton)	Total Emissions (ton)	Number of days per trip
Baseline	4.41	308,815	3,774	13,086	40,437	83
NSR-2030	5.53	387,023	3,158	10,056	31,072	66
NSR-2050	6.38	446,763	3,646	13,426	41,486	57

7.1.1 Annual Carbon Footprint per Roundtrip

It was recognized that a roundtrip for a baseline case generates more emissions in the order of ca. 63% and ca. 41% in comparison to the 2030 and 2050 ice scenarios, respectively. Figure 7.1 illustrates this. And the most environmentally feasible round trip appeared to be the case of a ‘ship in convoy’ sailing via the NSR in 2030. This confirms the role of slow steaming in reducing the amount of energy and emissions. However, the carbon footprint for the roundtrip estimates was concluded from the total number of trips performed per year. Hence, those values only reflect a different representation of the original mapping results and, may include a certain marginal error since each case had its distinctive number of performed trips per year. At this point it must be stated that the calculation being conducted on a yearly basis was only a subjective choice such that it is eventually possible to calculate emissions per transported ton, since this will form the most reasonable base for comparison.

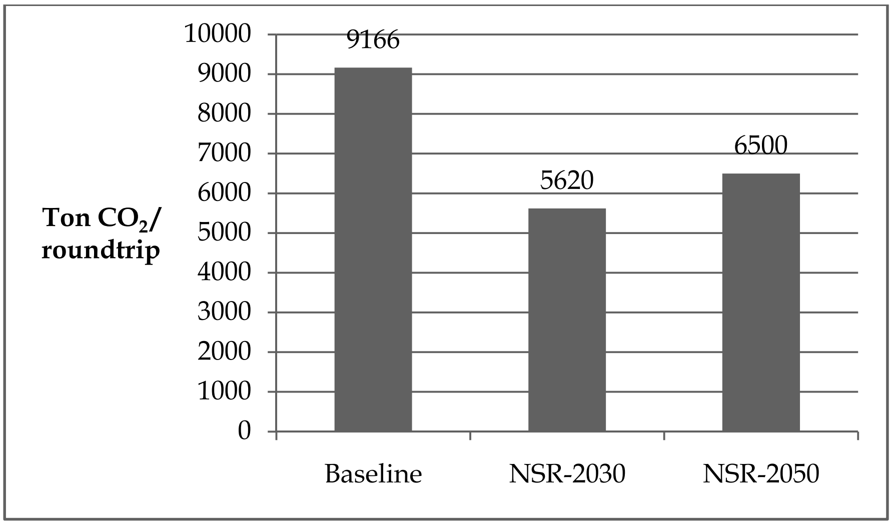

Figure 7.1: A comparison of emissions as quantified per roundtrip

7.1.2 Annual Carbon Footprint per Transported Ton

Speaking of annual generated emissions per transported ton, it can be observed from Table 7-2 that both ice scenarios generate fewer emissions than the baseline. This proves the efficiency of the NSR as a shorter transport route. The reduction is in the order of ca. 38% and ca. 31% from the baseline for the the 2030 and 2050 scenarios, respectively. The Table also reflects the substantial role of slow steaming operation in year 2030, such that fewer emissions are generated per transported ton in comparison to a 2050 scenario. This proves that performance in ice-water tends to be more environmentally efficient. However, the achieved reduction is in the order of only 12.5% since in the model, the distance assumed for ice-covered water for the 2030 scenario accounted for 2,800 nm. If more distance was allocated for ice-covered waters, the results may have shown even further reduction in emissions.

Table 7-2: A comparison of emissions as quantified per transported ton

Case	Emission per ton carried
Baseline	0.13
Ship in Convoy- 2030 scenario	0.08
Single Ship-2050 scenario	0.09

7.2 RESULTS OF SENSITIVITY ANALYSIS

7.2.1 Uniform Cargo Volume

The aim of unifying the transported cargo volume for all cases was to create a reliable base of comparison where the same amount of work is being performed by all alternatives. Table 7-3 demonstrates the results of this assumption. The results ensure the considerable role of slow steaming when operating in ice-covered waters. However, in contrast to an annual-based comparison where the deviation between the ice scenarios accounted for ca. 33.5% reduction in emissions (Section 7.1); the assumption that the transported volume is similar for both ice scenarios resulted in a deviation in the order of 12.5%. This error in the attained values can thus be allocated to the additional cargo carried in case of a 2050 scenario when comparison was conducted on a year performance basis. Regardless of this variation, Table 7-3 also shows that both years 2030 and 2050 will emit less carbon than a baseline case. This reduction in emissions interestingly coincides with the percentages attained earlier for an annual-based analysis. The reduction in emissions for a NSR passage is in the order of ca. 38% and ca. 31% for the 2030 and 2050 ice scenarios, respectively. Therefore, the methodology adopted for obtaining the carbon footprint estimates can be deemed as reliable.

Table 7-3: Total generated emissions for the transport of 280,000 ton of iron ore

	number of trips/year	Total transported cargo (ton)	Emission per trip (ton)	Emission per ton carried (ton)	Total emissions for total carried tons	Total Emissions for all trips performed
Baseline	4	280,000	9,166	0.13	36,400	36,664
NSR-2030	4	280,000	5,620	0.08	22,400	22,480
NSR-2050	4	280,000	6,500	0.09	25,200	26,001

7.2.2 Impact of Slow Steaming

Table 7-4 below shows the results of mapping when an assumption of slow steaming at 10 Knots speed is made for the three logistics cases. It is interesting to see the significant changes that a slow steaming operation poses on logistical and environmental conditions.

Table 7-4:Output of mapping where slow steaming conditions apply

	Trips per year	Tons per year	Mill ton-miles per year	Total yearly fuel consumption	Total Emission	Emission per ton carried (ton)	Emission per trip	Emission per mill ton-mile
Baseline	3.19	223,453	2,731	4,590	14,184	0.06	4,443	5.2
NSR-2030	4.45	311,585	2,543	4,599	14,210	0.05	3,192	5.6
NSR-2050	4.68	327,564	2,673	4,835	14,939	0.05	3,192	5.6

Apparently, a lower speed will reduce the number of trips that can be performed per year. Table 7-5 demonstrates the deviation in the length of each roundtrip for a slow steaming operation, in contrast to regular sailing conditions. Hence, a year in case of a slow steaming vessel will accommodate less cargo volume for transportation.

Table 7-5: Time-span required for each roundtrip

	Trip length for basic assumptions (days)	Trip length for slow steaming conditions (days)	Increase in trip length due to slow steaming operation
Baseline	83	114	+37%
NSR-2030	66	82	+24%
NSR-2050	57	78	+37%

Additionally, Tables 7-6 and 7-7 represent deviation percentages for carried tons and cargo transportation volume for each compared case separately. Both figures show that the tons that can be carried for the baseline case will be reduced in the order of 27.6 % when a slow steaming operation is proposed. Deviation figures for the 2030 and 2050 ice scenarios are in the order of -19.5% and -26.7% respectively. The reason that year 2030 had the least amount of deviation from its regular conditions is that slow steaming was already proposed for most parts of the journey in the first place. It can be said that the impact of slow steaming on transported volume and ton-miles travelled is not much significant.

Table 7-6: A comparison of route capacity for slow steaming conditions

	Annual transported Tons for basic assumptions	Annual transported Tons for slow steaming conditions	Deviation from basic assumption
Baseline	308,815	223,453	-27.6%
NSR-2030	387,023	311,585	-19.5%
NSR-2050	446,763	327,564	-27.7%

Table 7-7: A comparison of million ton-miles travelled for slow steaming conditions

	Million ton-mile travelled per year (basic assumptions)	Million ton-mile travelled per year (slow steaming conditions)	Deviation from basic assumption
Baseline	3,774	2,731	-27.6%
NSR-2030	3,158	2,543	-19.5%
NSR-2050	3,646	2,673	-27.5%

However, the most considerable variation between regular conditions and slow steaming operation was recognized in the amount of fuel consumed. Table 7-8 shows an enormous reduction in amount of fuel consumed for all cases. The achieved reduction is in the order of 54% and 64 % for the 2030 and 2050 ice scenarios respectively, and 65% for the baseline scenario. As fuel consumption estimates lead to the final values of generated emissions, the most significant observation to be correlated to this is the vast drop in emissions, especially as witnessed for the baseline case. Reductions in generated emissions per transported ton were in the order of 54% for the baseline case, 37.5% for the 2030 scenario and 44.4% for the 2050 scenario. Figure 7.2 illustrates this.

Table 7-8: A comparison of ton fuel consumption for slow steaming conditions

	Annual ton fuel consumption (basic assumptions)	Annual ton fuel consumption (slow steaming conditions)	Deviation from basic assumption
Baseline	13,086	4,590	-65%
NSR-2030	10,056	4,599	-54%
NSR-2050	13,426	4,835	-64%

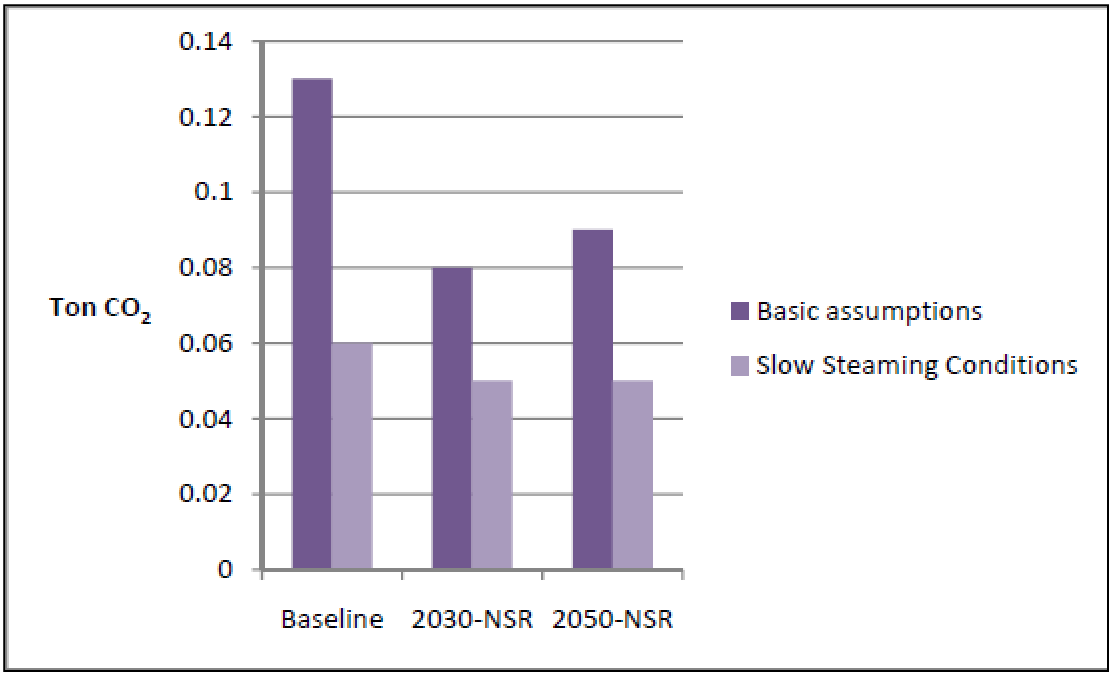

Figure 7.2: A comparison of generated emissions per transported ton for slow steaming conditions

Additionally, an alluring observation can be made in terms of how emission values for all cases converge when employing a slow steaming operation. Figure 7.2 clearly contrasts the annual emissions as generated per transported ton. The figure shows that regardless of the immense variation in the travelled distance between the baseline and the proposed alternatives; carbon footprint becomes comparable for all cases of slow steaming conditions. In fact, the CO_2 emitted for both ice scenarios becomes essentially identical due to similar sailing conditions in this case and, deviates in the order of only -16% from the baseline. At this point, it must be recalled that the basic assumption mapping revealed an increase in emissions for the baseline in the order of ca. 62% and ca. 44% as compared to the 2030 and 2050 scenarios respectively. Therefore, the figures attained for a slow steaming assumption outline the substantial impact that slow steaming operation has on amount of fuel consumed and consequently associated carbon footprint. This can be best explained by the Admiralty formula which states that amount of consumed fuel is not only proportional to the speed, rather to the cube of the speed. Thus, a proposed measure for eliminating generated emissions can be achieved through savings in consumed energy; applying slow steaming conditions. It must be recalled though that slow steaming of vessels promotes NOx emissions. However, NOx are considered as short-lived emissions that last for only 1 or 2 days and, can be reduced basically by in-engine measures. An interesting area of research would be weighing the impacts of different emissions. As for efficient slow steaming technologies, a closer surveillance on engine performance, power-speed conditions and other operating parameters are essentially worth investigating.

8 CONCLUDING REMARKS

- The present study aimed at examining the interaction between pertinent climate change impacts and the potential for trans-arctic shipping as a consequence. The analysis showed that the potential of trans-arctic navigation had been recently highlighted due to enhanced Arctic sea ice conditions in recent years. This implies that stakeholders perceiving the Arctic as a “shortcut across the top of the world” wouldn’t have considered this possibility if it were not for the visible effects of climate change. Climate change is the major driver for foreseeable regional developments in the High North.

- While climate change poses severe impacts at low lying areas of the world, in terms of varying sea levels and temperatures; the Arctic is one of the areas which are magically transformed into a rich resourceful area due to climate change impacts and, planning for foreseeable developments is already taking place.

- ACIA’s sixth finding of anticipating increased shipping activities in the Arctic is already translated into action. Industrial interests are already emerging and, development projects have started to launch gradually. One of which is the iron ore case study analyzed in the present thesis.

- The foreseen future shipping activities are anticipated to promote feedback processes, which will in return speed up ice retreat. It can be concluded that the correlation between the effects of climate change on trans-arctic navigation and vice versa is very complex. This interaction between the environment and the proposed development can be best understood and managed through an environmental impact assessment study.

- In line with today’s vision of maintaining sustainable development, it is best to utilize the Arctic only when the physical phenomena of the sea ice and other Arctic features are fully understood. As sea ice studies are still in its pioneering phase, it is recommended that proposed development projects targeting the Arctic as a trans-arctic passage are postponed until their interaction with the Arctic Environment becomes implicit. The only way to conquer the obstacle’s emerging during developments of trans-arctic navigation is to be fully aware of its characteristics, functioning and interaction with other variables. In this manner associated shortfalls can be immediately dealt only if an effective environmental management plan is achievable.

- It can be concluded that optimizing trans-arctic routes in light of the changing-climate driven effects can be best attained with increased dedication for sea ice measurements and studies. In this regard simulations for integrating the impacts of sea ice retreat and future shipping routes are recommended. This implies that the behavior of sea ice along Arctic coastal cities is continuously detected, since it will essentially form the basis for portal infrastructure. Additionally, it is paramount to note the importance of risk management measures such as 'search and rescue' and 'response to accidents'. These issues were note addressed in the present study but are anticipated to form a vital foundation for any future shipping expansion and were thoroughly tackled by AMSA and INSROP. It is recommended that these are given major attention for future development studies.

- A major factor that will highly impact the proposed development (iron ore case study) is the political aspect and international cooperation. Speaking of environmental soundness and viability, one cannot ignore the impact of environmental standards and regulations that are controlled by national governments. In this regard, negotiation initiatives between and Russian and Norwegian governments shape the future of the proposed development. Additionally the UNCLOS convention will play a significant role in posing future standards for trans-Arctic shipping.

- In line with the significance of sustainability, the adopted EIA methodology suggested mitigation measures that were deemed as proper for an Arctic environment. It was concluded in some parts of the qualitative analysis that severe negative impacts as a result of the proposed development can be avoided through proper management schemes. However there remains plenty of area of research and uncertainty, especially regarding baseline studies requirements along the NSR; which are a basic requirement for EIA analyses. INSROP and AMSA GIS databases can serve as a starting point.

- Throughout the analysis, questions emerged in terms of choice of fuel for an Arctic environment. As plenty of the Arctic's characteristics remain vague, a concern was raised as whether HFO or natural gas should be used for operating in an Arctic environment. The concern from a HFO focused on its polluting effects to Arctic waters and its generation of several GHG emissions, whereas the natural gas, which is deemed as the cleanest fuel type also emits methane with a radiative forcing twenty times higher than CO_2. Fuel types to be used in the Arctic are worth investigating, as these are responsible for all ship GHG emissions. It is recommended that further research is undertaken in this regard.

- Throughout the mapping analysis, all attained results reflected upon the optimal role of a NSR passage, whether in its greater capacity for accommodating cargo or in terms of less generated emissions. This optimality was replicated in the relationship between carbon footprint and fuel consumption. It was realized that less carbon emissions are generated in case of the proposed NSR logistical alternatives; 'single ship' or a 'ship in convoy'. Furthermore, year 2030 proposed a significant reduction in emissions, which was paradoxically justified by the longer 'ice water' sailing distances. The recommended solution of vessels slow steaming for part of the journey in ice-covered waters is a fundamental operational requirement. Fortunately, this necessity outlined an equilibrium point where reduction in emissions and decreasing fuel consumption convened, such that operation in ice-covered waters proved to be more environmentally feasible in terms of carbon emitted.

- At the beginning of the research, it was intended to map the GHG emissions and energy consumption using a tool developed by DNV ProNavis. The GHG Emission and Energy Consumption (GEEC) tool also maps emissions for a transport system. However, the obtained output figures from GEEC were not consistent with the input data, mainly because the tool was not acting dynamically. For example, as it was aimed to analayze the impact of speed variation on generated emissions, the tool did not reveal accurate figures that correspond to the relationship between consumption and speed. Therefore, a different calculation sheet was developed such that the correlation between the input and the output data was achieved. The utilized sheet was based on a model developed by MARINTEK.

- At this point of research, it is hard to get reliable figures for sea ice extent predictions, as these are still undergoing their preliminary stages of development. Therefore, the analysis argued that the projections made by the

NSIDC, ACIA and IPCC models for reduction in sea ice cover at the marginal regions of the Arctic Ocean, of which the NSR is part of can be used as a starting point for the examination. From this point, it was assumed that the NSR will witness a certain reduction in its cover in the projected years that were covered throughout the mapping analysis. However, the exact extent was not accurately calculated. Rather, the present study arbitrarily divided the NSR into open and ice water areas for the purpose of developing the 2030 and 2050 ice scenarios. In this manner, it was possible to inspect the impact of sea ice variability on future generated emissions. It is recommended that future studies utilize the evolving ice models that are being developed by different scientists around the world such that more accurate figures are attained.

- A sensitivity analysis was performed such that emissions were calculated based on a similar scale.The analysis showed that the developed model is reliable to some extent, as the deviation between the proposed alternatives and the baseline case were similar to the initial mapping results.

- All results obtained from the mapping tool proved that a NSR passage will always emit less emissions per transported ton and, have additional capacity for accommodating additional cargo if compared to a baseline case. It can be concluded that the shorter distance of the NSR was reflected in fewer generated emissions due to less work performed; less spent time at sea.

- The 2050 ice scenario proved to be more efficient in terms of work performed such that it was able to accommodate more cargo with less emissions as compared to the baseline case. However, the 2030 scenario proved to be the most environmentally feasible solution mainly due to employing a slow steaming operation for the majority of its journey. It can be concluded that the differences between the 2030 and 2050 scenarios represented only slight variations, since the 2050 scenario also involved a certain travelled distance with slow steaming.

- It was concluded that a slow steaming operation can propose a suitable mitigation measure for eliminating emissions. Slow steaming mapping showed an enormous reduction in emissions for all cases especially for a Suez Canal transit. However the analysis also showed that a slow steaming will result in more days spent at sea, thus, a reduction in volume of transported cargo. Furthermore, recent research warns of associated NOx emissions as a downside effect to slow steaming, in addition to losses in operational efficiencies since the engine is driven below the design speed. Therefore, it is recommended that the impact of slow steaming on engine performance is assessed and further investigations are dedicated for revealing the most suitable fuel type for such operation.

- Finally, a general conclusion to be drawn is that the state of arctic sea ice will remain a dominant factor in terms of future utilization of the NSR. The analysis showed that the capacity of the NSR to accommodate more trips per year will increase as we move towards an ice-free Arctic. It was observed that in 2050 as more open water distances become accessible, vessels will be able to operate at the average service speed; eliminating the need for a slow steaming option. This finding declares the 'feedback' impact that an ice-free Arctic poses on the environment; the opening of Arctic waters will be the major driver for its utilization. Furthermore, the analysis revealed that an ice-infested NSR passage proved to be the optimal environmental solution as long as slow steaming is employed for operation for the majority of the journey. The question is: will ship operators still want to slow steam in an ice-free Arctic in order to cut off carbon emissions?

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APPENDIX

Baseline Case: Suez Canal Transit

Ship Particulars	
DWT	70000
Service speed in knots	14.5
Engine power in kw	9100
Fuel consumption at service speed g/kWh	190
Fuel consumption in port g/kWh	20
Constant in fuel consumption function	567.140924

Suez route particulars		Hours spent	Ton fuel consumption
Port time Kirkenes - hours	120	120.0	21.8
Distance Kirkenes - Suez nm	4831	333.2	576.1
Waiting time Suez	16	16.0	0.0
Transit time Suez	14	14.0	4.1
Distance Suez - Qingdao nm	7390	509.7	881.2
Port time Qingdao - hours	120	120.0	21.8
Distance - Qingdao - Suez	7390	509.7	881.2
Waiting time Suez	16	16.0	0.0
Transit time Suez	14	14.0	4.1
Distance Suez - Kirkenes nm	4831	333.2	576.1
	Totals	1985.7	2966.3

Output	
Trips per year	4.41
Tons per year	308815
Mill. Ton-miles per year	3774
Total yearly fuel consumption	13086
Ton CO2 per ton fuel - residual fuel #5	3.09
Total emission	40437
Emissions per trip	9165.89273
Emission per million ton-mile	10.7
Emission per ton carried	0.13

2030 Ice Scenario: Ship in Convoy – NSR Transit

Ship particulars	
DWT	70000
Service speed in knots	14.5
Engine power in kw	9700
Fuel consumption at service speed g/kWh	190
Fuel consumption in port g/kWh	20
Constant in fuel consumption function	604.534831

Assumption: Speed in ice water = 11 knots

NSR route particulars		Hours spent	Ton fuel consumption
Port time Kirkenes - hours	120	120.0	23.3
Open water sailing - nm	5360	369.7	681.3
Waiting time ice-breaker hours	48	48.0	0.0
Ice water sailing - nm	2800	254.5	204.8
Port time Qingdao	120	120.0	23.3
Open water sailing - nm	5360	369.7	681.3
Waiting time ice-breaker hours	48	48.0	0.0
Ice water sailing - nm	2800	254.5	204.8
		1584.4	1818.7

Output	
Trips per year	5.53
Tons per year	387023
Mill. Ton-miles per year	3158
Total yearly fuel consumption	10056
Ton CO2 per ton fuel - residual fuel #5	3.09
Total emission	31072
Emissions per trip	5619.91206
Emission per million ton-mile	9.8
Emission per ton carried	0.08

2050 Ice Scenario: Single Ship – NSR Transit

Ship Particulars	
DWT	70000
Service speed in knots	14.5
Engine power in kw	9700
Fuel consumption at service speed g/kWh	190
Fuel consumption in port g/kWh	20
Constant in fuel consumption function	604.534831

Assumption: Speed in ice water = 11 knots

NSR route particulars		Hours spent	Ton fuel consumption
Port time Kirkenes - hours	120	120.0	23.3
Open water sailing - nm	8000	551.7	1016.8
Waiting time ice-breaker hours	0	0.0	0.0
Ice water sailing - nm	160	14.5	11.7
Port time Qingdao	120	120.0	23.3
Open water sailing - nm	8000	551.7	1016.8
Waiting time ice-breaker hours	0	0.0	0.0
Ice water sailing - nm	160	14.5	11.7
		1372.5	2103.6

Output	
Trips per year	6.38
Tons per year	446763
Mill. Ton-miles per year	3646
Total yearly fuel consumption	13426
Ton CO2 per ton fuel - residual fuel #5	3.09
Total emission	41486
Emissions per trip	6500.19433
Emission per million ton-mile	11.4
Emission per ton carried	0.09

Slow Steaming Results

Baseline Case – Suez Canal Passage	
Trips per year	3.19
Tons per year	223453
Mill. Ton-miles per year	2731
Total yearly fuel consumption	4590
Ton CO2 per ton fuel - residual fuel #5	3.09
Total emission	14184
Emission per trip	4443.470612
Emission per million ton-mile	5.2
Emission per ton carried	0.06

2030 Ice Scenario- Ship in Convoy	
Trips per year	4.45
Tons per year	311585
Mill. Ton-miles per year	2543
Total yearly fuel consumption	4599
Ton CO2 per ton fuel - residual fuel #5	3.09
Total emission	14210
Emission per trip	3192.46701
Emission per million ton-mile	5.6
Emission per ton carried	0.05

2050 Ice Scenario- Single Ship	
Trips per year	4.68
Tons per year	327564
Mill. Ton-miles per year	2673
Total yearly fuel consumption	4835
Ton CO2 per ton fuel - residual fuel #5	3.09
Total emission	14939
Emission per trip	3192.46701
Emission per million ton-mile	5.6
Emission per ton carried	0.05

MASTER THESIS

TBA4920 Marine Civil Engineering, master thesis

Spring 2010
for
Nancy Haddaden

Impact of Climate Change on Shipping Routes in the Arctic

Konsekvenser av Klimaendringer på Shippingruter i Arktis

BACKGROUND: On why and how

"The world can tell us everything we want to know. The only problem for the world is that it doesn't have a voice. But the world's indicators are there. They are always talking to us" Quitsak Tarkiasuk

The Arctic Climate Impact Assessment Report (2004) concluded in its sixth finding that marine transport will be increased in the Arctic Ocean due to reduced sea ice. It is paradox how what is perceived as a severe impact on the arctic indigenous nations and ecosystem, can be deemed as a possible solution to reduce the increased congestion in shipping routes world-wide.

As the global economy is demanding more exchange of commodities between the nations of western/Northern Europe and the Far East; the need for investigating alternative maritime routes became a must. The Centre for High North Logistics, which was launched as a part of the Norwegian National Research initiative, aims at developing efficient and sustainable maritime logistical solutions that meet the rising demands of the High North countries, under the LOGIN project. Several industrial cases emerged for further exploration in the High North Region, one of which is the Bulk Logistics; a case themed at unlocking the trans-arctic challenge, as an alternative for transporting dry bulk commodities. The case study tackles the feasibility of transporting iron ore from deposits in Kirkenes/ Norway to customers in China. This thesis will be focused on analyzing this industrial case with the role of the Northern Sea Route in the maritime logistical operations as the main hub.

TW A.A.

Perceiving the arctic as a multi-national area, it is apparent that the clash of interest is a serious factor that will evolve during any stages of development in this spectacular region of the earth. For example, the indigenous arctic communities which have been residing there for many ages cannot be ignored regarding any measures to be taken for 'open water' operations. A Canadian Inuit describes the sea ice as his highway. On the other hand, the governance of the arctic will not be a simple issue of concern; rather, it should include the consensus of the eight arctic countries involved. This implies that for any treaty to be officially deemed as a binding agreement, the voluntary approval of each country engaged must be attained.

It can be seen that the Arctic is a challenging spot of the earth, with so many factors to be considered, of which plenty of area of research is still required. Therefore, this thesis arises from the urgent need to resolve the complexity of the ongoing debate concerning the Arctic; and with the unprecedented surprises of climate change, further research for this region is inevitable.

TASK DESCRIPTION: (Tentative work for the thesis)

In order to create a reliable base of examination, several shipping scenarios in the arctic, each of which represents a maritime logistics system will be inspected in terms of its performance. The 'AS-IS' alternative will also be included, such that it resembles the baseline logistics solution. The shipping scenarios to be investigated are as follows:

1. Baseline Solutions -'AS-IS': traditional transportation via the Suez Canal and Cape of Good Hope.
2. Alternative one: Northern Sea Route; which is also known as the North East Passage. Several scenarios to be developed with trans-shipment condition included.
3. Alternative two: Also Northern Sea Route, but the scenarios developed will assume no trans-shipment involved.

Due to the time limit of this thesis, the major criteria for comparison will be based on a feasibility assessment of the environmental issues, even though it is believed that operational, technical, commercial and political issues can also serve as assets for supporting the analysis of the proposed alternatives.

GHG Emission and Energy Consumption (GEEC) mapping will provide a quantitative tool to compare the emissions, green house gases (GHG), fuel consumption and carbon footprint for each scenario developed, whereas other related impacts will be addressed qualitatively based on an Environmental Assessment Methodology.The reliability of the results will be inspected via a Sensitivity Analysis

Description of tasks:

1. A brief description of the different parties involved in the LOGIN project.
2. A presentation of the **Iron Ore, Sydvaranger - China** project illustrating the need behind implementing it.
3. A short introduction of climate change debate in the context of the arctic transformation.
4. Feasibility assessment of the proposed trans-arctic shipping scenarios; this will include environmental modeling for quantitative comparison, and a qualitative evaluation through an environmental assessment methodology.
5. Sensitivity Analysis to inspect the robustness of the results.

Aims and purpose: The purpose of this dissertation is to examine the feasibility of future trans-arctic shipping routes; predominantly assessing the impact of climate change on maritime logistics systems and vice versa.

Subtasks and research questions:

The following research questions are raised as a complementary part of the thesis:

- Is it possible to utilize the impact of climate change on arctic sea ice through optimizing possible trans-arctic routes?
- Is it environmentally sound to convert shipping routes from the traditional into the proposed trans-arctic routes?
- How will the evolving obstacles be conquered in accordance with today's vision of maintaining a sustainable environment?

A scientific methodology will be implemented such that the above research questions are resolved, in line with today's global debate around the Arctic's mystery.

GENERAL ABOUT CONTENT, WORK AND PRESENTATION

The task description for the master thesis is meant as a framework for the work of the candidate. Adjustments might be done as the work progresses. Tentative changes must be done in cooperation and agreement with the supervisor and professor in charge at the Department. (Also including external cooperative partners where this is applicable).

In the evaluation thoroughness in the work will be emphasized, as will be documentation of independence in assessments and conclusions. Furthermore the presentation (report) should be well organized and edited; providing clear, precise and orderly descriptions without being unnecessary voluminous.

The report shall include: (templates are found on http://www.ntnu.no/bat/skjemabank)

- Standard report front page.
- Title page with abstract and keywords (signed by the student).
- Summary and acknowledgement. Table of content including list of figures, tables and enclosures. If useful and applicable a list of important terms and abbreviations should be included.
- The main text.
- Clear and complete references to material used, both in text and figures/tables. This also applies for personal and/or oral communication and information.
- Text of the Thesis (these pages) signed by the professor in charge.
- The report must have a complete page numbering.
- The thesis may possibly be written as a scientific article. The report must come with report front and title pages and, if necessary, with appendices that document the work performed in the process of writing of the article.

Submission procedure

- The complete, original report (un-bounded).
- Two copies (bounded).
- If applicable: X additional copies if agreed upon for instance with external partner (to be paid for by the Department or the external partner)
- CD with the complete report (pdf-format) and all assisting or underlying material.
- A brief (one to two A4 pages including possible illustrations) popular science summary of the work, aiming at publication on the Department's web-site. Include a copy of this html document on the CD. Template is found on: http://www.ntnu.no/bat/skjemabank

The summary shall include the objectives of the work, explain how the work has been conducted, present the main results achieved and give the main conclusions of the work.
Advice and guidelines for writing of the report is given in: "Writing Reports" by Øivind Arntsen. Additional information on report writing is found in "Råd og retningslinjer for rapportskriving ved prosjekt og masteroppgave ved Institutt for bygg, anlegg og transport" (In Norwegian). Both are posted on http://www.ntnu.no/bat/skjemabank

Documentation collected during the work, with support from the Department, shall be handed in to the Department together with the report.

According to the current laws and regulations at NTNU, the report is the property of NTNU. The report and associated results can only be used following approval from NTNU (and external cooperation partner if applicable). The Department has the right to make use of the results from the work as if conducted by a Department employee, as long as other arrangements are not agreed upon beforehand.

Tentative agreement on external supervision, work outside NTNU, economic support etc
Separate description to be developed, if and when applicable.

Health, safety and environment (HSE)
The health, safety and environmental (HSE) work at NTNU shall constitute continuous and systematic efforts that are integrated into the primary activities. NTNU emphasizes the safety for the individual employee and student. The individual safety shall be in the forefront and no one shall take unnecessary chances in carrying out the work. Information in English on HSE is given on: http://www.ntnu.no/hse. In particular, if the student is to participate in field work, visits, field courses, excursions etc. during the Master Thesis work, he/she shall make himself/herself familiar with the ***Fieldwork HSE Guidelines*** http://www.ntnu.no/hms/retningslinjer/HMSR07E.doc. General HSE provisions that apply in all laboratories and workshops are given on: http://www.ntnu.no/hse/labhandbook.

The students do not have a full insurance coverage as a student at NTNU. If a student wants the same insurance coverage as the employees at the university, he/she must establish an individual travel and personal injury insurance. More information about students and insurance is found on the faculty HSE page on: http://www.ntnu.no/ivt/adm/hms/. (Documents are in Norwegian only, ask the supervisor to explain).

Start and submission deadlines
The work on the Master Thesis starts on **February 8th, 2010**

The thesis report original (not bounded) and 2 bounded copies and the CD as described above shall be submitted at the latest on **July 5th, 2010 at 1500 hrs.**

Professor in charge: Øivind Arntsen 94625 / 92650455
Other supervisors: Eivind Dale 95761 / 93059822

Department of Civil and Transport Engineering, NTNU

Date: 16-03/2010

Signature:
Øivind Arntsen
Professor in charge:

Supervisor: