An environmental cost-benefit analysis of LNG as a maritime fuel in the Arctic

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LIST OF ABBREVIATIONS

ASEAN	Association of Southeast Asian Nations
BC	Black carbon
BCM	Billion cubic meters
CBA	Cost-benefit analysis
CNG	Compressed natural gas
ECA	Emissions control area
EPA	Environmental Protection Agency
EU	European Union
IEA	International Energy Agency
IMO	International Maritime Organization
JCC	Japan Customs-cleared Crude
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
MARPOL	International Convention for the Prevention of Pollution from Ships
NGO	Nongovernmental organization
NO_X	Nitrogen oxide
NPV	Net present value
O_3	Ozone
OECD	Organization for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PM	Particulate matter
PV	Present value
SO_X	Sulphur oxide

ABSTRACT

As environmental regulations continue to drive a transition away from the extremely polluting heavy oil based fuels traditionally utilized for maritime transport towards alternative fuels, liquefied natural gas is emerging as a viable compliance option. This transition is of particular importance to the Arctic region, where escalating interest in development activities pose significant risks to a relatively undeveloped, yet particularly environmentally vulnerable area. Due to the importance of the Arctic region to the global environment, the prospect of increased development activity and associated maritime traffic within the area has wide ranging implications extending well beyond the region. By taking into account the perspectives of governance actors at varying levels and through the use of cost-benefit analysis, this study will provide an evaluation of the environmental, political and economic implications of a transition towards liquefied natural gas being utilized as a maritime transport fuel in the Arctic region.

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CHAPTER 1: INTRODUCTION

The maritime transportation sector is facing an energy transition in the type of fuel used to propel ocean-going vessels. Actions and policies related to issues such as environmental protection, pollution abatement, and climate change are driving a transition away from the existing status quo of utilizing heavy fuel oil for the purposes of maritime transportation fuel towards a less polluting, more sustainable alternative. Of the alternatives to the status quo that are currently available, liquefied natural gas (LNG) is emerging as an alluring and viable option. As a unique and environmentally sensitive region in which maritime affairs are paramount, the Arctic is an ideal area in which to study this transition. This study will analyze the transition away from heavy fuel oil to LNG for the purpose of maritime propulsion in the Arctic region and the accompanying environmental, economic, and political context. Through the use of cost-benefit analysis (CBA) this study will seek to determine if society is be better or worse off as a result of this transition materializing.

A principal aspect of this study will be an exploration of governance, in particular the ways that the concepts of energy and maritime governance are associated with the transition to LNG as an alternative shipping fuel in the Arctic. Researchers (Farazmand 2013; Jordan 2008; Treib et al. 2007) describe governance as moving beyond models of traditional state controlled bureaucracy towards the inclusion of non-state actors such as societal organizations and commercial interests in the policy and decision-making process. A review of the concept of governance revels a trend towards non-state actors performing an increasingly important role in governance. As a result of increased globalization, opportunities for non-state actors such as nongovernmental organizations (NGOs) and businesses to become active participants in governance are greater than ever.

Maritime governance is managed at the international level in large part through the direction of the International Maritime Organization (IMO). As the organization responsible of regulating international shipping, the IMO uses treaties and directives to address issues such as environmental protection and safety at sea. While the IMO plays a prominent role in maritime governance, it is not exclusively responsible for maritime governance. Maritime governance at the regional and national level involves the participation of actors such as the European Union (EU), individual states, and other assorted maritime stakeholders. Contemporary stakeholders active in maritime governance include maritime related industries such as international shipping and commercial fishing, as well as establishments such as NGOs. A trend in maritime governance is an increased degree of cooperation and coordination among actors, particularly at the regional level. Another trend in maritime governance is a desire among stakeholders for an increased level of conformity in regulation and policy. This desire for consistency of regulation by maritime governance actors is reflected in many IMO directives that strive to establish global minimum standards while permitting for further national protocols.

Like maritime governance, energy governance is a complex issue involving a diverse assortment of actors. Frequently maritime and energy governance overlap or are intertwined, and often involve the many of the same actors. Due to the essential role that energy plays in the lives of humans, energy governance affects practically every aspect of society on some level. The role of private interest, particularly energy companies, is more apparent in energy governance than in maritime governance. At the international level, energy governance is often disorganized and is characterized by an uneven collection of state and non-state participants. Prominent energy governance actors include intergovernmental agencies, summit processes, multilateral development banks and public-private partnerships.

Due to the unique physical and political characteristics of the Arctic, the region has a unique governance arrangement that combines maritime and energy governance in an intriguing way. The governance of the Arctic is managed by a diverse collection of participants such as Arctic and non-Arctic states, NGOs, business interests and indigenous groups. An extremely important participant in Arctic governance is the Arctic Council. In addition to a core membership consisting of the eight Arctic states and indigenous resident associations, the Arctic Council also welcomes the involvement of non-Arctic states and NGOs through the bestowing of observer status to many such contingents. The involvement of non-Arctic state actors with the Arctic Council is indicative of the broader trend of stakeholders from outside the Arctic increasingly desiring to become engaged in Arctic governance.

Energy governance plays an important role in the Arctic due to the high level of interest in the natural resources located within the region. A large amount of the development activity proposed for the Arctic is related to the exploration and extraction of oil and gas reserves located within the region. Apprehensions of Arctic stakeholders regarding oil and gas development within the region include concerns such as environmental damage, pollution, and climate change.

Maritime governance has long played an important role within the Arctic region. The prospect of Arctic shipping routes becoming an increasingly viable option for the international shipping industry means maritime governance will play an ever more crucial role in the Arctic region in the future. Arctic shipping routes such as the Northern Sea Route and the Northwest Passage are attracting increased interest from the international shipping sector due to the prospect of considerably reduced voyage distances between Asia, Europe and North America. Navigation along these routes is now feasible for lengthier periods of the year due to the melting of Arctic sea ice.

The prospect of increased shipping activity taking place in the Arctic presents a host of concerns for Arctic stakeholders such as infrastructure requirements, safety, and environmental impacts. It is imperative that Arctic governance actors take these concerns regarding increased shipping activity being conducted within the region into consideration sooner rather than later. The prospect of heightened development in the Arctic poses serious risks to the region. As an example, increased air pollution due to an intensification of activities currently taking place in the Arctic such as shipping, oil and gas extraction, and metal smelting could escalate ecosystem damage by way of pollutant deposition, contribute to warming by decreasing surface albedo, accelerate sea ice loss, and have a detrimental effect on human health (Arnold et al. 2016; Law et al. 2017). While the prospect of heightened development activity taking place within the Arctic poses serious risks to the region, it also presents an opportunity for governance actors from the region to expand the degree of influence the Arctic region has on the global stage.

An examination of historic energy transitions provides many lessons, which are of great use for an analysis of the transition away from heavy fuel oil to LNG in the Arctic. By reviewing previous energy transitions researchers are better able to develop an understanding of the motivating factors that lead to changes in the ways in which energy is ultimately utilized. Throughout history, each notable energy transition has been characterized by underlying technological, social and cultural factors that have been linked to the transition. Throughout history, as each energy transition has progressed, the ramifications and impacts of the transition have reshaped the broader societies in which they have occurred.

The energy transition characterized by the emergence of coal as a replacement for organic forms of energy sparked the industrial revolution and saw the emergence of significant technological and social changes in society. The energy transition to coal enabled the spread of industrialization, resulting in tremendous economic and cultural changes taking place. The rapid expansion of industrialization during this age brought about not only economic advancement, but also environmental problems such as air pollution. The environmental challenges stemming from the rapid industrialization afforded by the utilization of coal, and the efforts to address it would reshape society.

The energy transition to coal brought about revolutionary changes in transportation on both land and at sea. Groundbreaking technological innovations such as rail travel and steam ships forever changed the way that humans and trade items would be transported throughout the world. The technological advancements related to the transition to coal fostered a tremendous expansion in global trade that would reshape the geopolitical landscape.

By the late nineteenth century, an energy transition began to take place that would see petroleum begin to replace coal as the dominant energy source. Once again, this transition was cultivated by a series of technological advancements and innovations. The transition to petroleum had tremendous geopolitical implications as powerful developed nations became reliant on oil for prosperity and the strategies taken by powerful nations to ensure a secure, stable, and reliable supply of the resource would have incredible ramifications, a great deal of which are still being experienced today. The transition to petroleum would eventually see global issues such as economic policies, defense strategies and trade agreements all significantly linked to the energy source.

Much like the prior transition to coal, the transition to petroleum would revolutionize transportation but this time on land, at sea, and in the air. The transition to petroleum ushered in the age of the automobile, which would transform both modern life as well as the landscape in large parts of the world. Following the transition to petroleum, aviation would forever change the way in which goods and people are transported throughout the world. The advantages that the transition to petroleum provided the maritime transportation sector saw ships be able to transport increasingly vaster cargos over greater distances in shorter periods of time than ever before.

Throughout the twentieth century, petroleum remained the dominant energy source. However, as the demand for global energy continued to grow and as issues such as energy security, pollution, and climate change increasingly became matters of concern, the opportunity of different types of energy being able to provide the energy needs of society began to be realized. The second half of the twentieth century and the start of the new millennium would see technological advancements such as nuclear and renewable energy technologies become a more viable and prevalent approach to meeting the demand for energy throughout the world.

As the current transition to clean and sustainable sources of energy continues to progress, the maritime sector, and international shipping in particular, present a unique set of challenges. Current and impending international and regional regulations are urgently driving a transition away from highly polluting heavy fuel oil that has long been utilized for maritime transportation. While immediate industry-wide action is required, it is estimated that a transition to an adequately decarbonized maritime sector able to contribute to objectives such as the 2 degrees Celsius target of agreements such as the Copenhagen Accord is feasible by 2050 depending upon factors such as the scale of technological advancement and future levels of shipping demand (Anderson & Bows 2012; Walsh et al. 2017). In line with the need for prompt action, the shipping industry is increasingly viewing LNG as a viable and practical alternative to heavy fuel oil. LNG offers the shipping industry a presently available, efficient and cost effective fuel alternative that produces fewer emissions than heavy fuel oil, that can comply with current, impending and projected maritime emissions standards (Kumar et al. 2011; Thomson et al. 2015).

Historic energy transitions offer many lessons for the quest towards a sustainable future. Previous energy transitions point to the importance cultivating technology and innovation to find solutions to the challenges of energy demands. Past energy transitions demonstrate the important role that trade has played in the progression of energy transitions. In an age of globalization, the relationship between trade and energy transitions will only be intensified in the future. Earlier energy transitions also reveal the importance of effective and sensible environmental policy. Historic energy transitions have illustrated the importance of effective communication on behalf of governance actors and policy makers in efforts to inform the public about the challenges being faced and the possible outcomes of proposed strategies designed to address problems. Information such as the research presented in this study, particularly the CBA results, can be extremely useful for policy makers engaged in addressing the challenges surrounding the current energy transition.

1.1 Research Structure

The following study was structured in a way that is intended to reflect the setting in which this research was conducted, which was in a school of geography and sustainable development that supports a broad range of interdisciplinary research across numerous disciplines, such as geography, political science, and economics. Likewise, this study adopts a more cross-disciplinary approach than what normally takes place in a CBA. This study will take a critical realist stance and incorporate aspects of empiricism and positivism. This study will objectively address the research questions listed below using quantitative methods and techniques. These research questions will be answered by the results in chapter 5, while the other chapters will provide the necessary context for answering the research questions.

RQ1: What are the benefits of the transition to LNG for shipping in the Arctic region?

RQ2: What are the costs of the transition to LNG for shipping in the Arctic region?

RQ3: Are the benefits of the transition to LNG for shipping in the Arctic region greater than the costs?

The case study for this analysis will be the transition away from the status quo of heavy fuel oil use by ships operating in the Arctic region towards the alternative option of LNG utilization. This study will utilize a collection of existing data and findings from previously conducted research to assist in the answering of the research questions. The method of data analysis utilized by this study will be CBA. This study will use previous works associated with environmental CBA such as Hanley and Barbier (2009) and Boardman et al. (2017) as a guide for the analysis. In the process of conducting the steps of CBA, the study will monetize the cost and benefits related to the transition to LNG in the Arctic region. The objective of the CBA conducted within this study is to determine if society will be better off or worse off as a result of the transition to LNG in the Arctic. While CBA might not tell researchers everything they need to know regarding project and policy decisions, it can and does tell us important things that are needed to be known in order to advance the policy making process (Sunstein 2018). Therefore, research findings such as the CBA results presented in this study will be of great assistance to policy makers evaluating the transition to LNG in the Arctic region.

1.2 Chapter Breakdown

In order to provide a better understanding of the governance context surrounding the transition to LNG in the Arctic, chapter 2 presents a review of the academic literature. The chapter first presents an overview of the broader concept of governance and then progresses to examine aspects of energy governance and maritime governance. The chapter then proceeds to consider Arctic governance and the ways in which the governance arrangement of the region uniquely unites aspects of energy and maritime governance. The chapter reveals several trends that are present the different spheres of governance that were evaluated and discusses the implications of these trends in relation to the transition to LNG in the Arctic.

Chapter 3 presents an investigation of notable energy transitions that have occurred throughout history in order to develop a better understanding of the underlying forces that mold and influence significant energy transitions. By examining the political, geographic, technological, economic, and social dynamics surrounding previous energy transitions, the chapter will provide a better understanding of the challenges associated with the transition from heavy fuel oil to LNG as a maritime fuel in the

Arctic. Lessons of past energy transitions emphasized in chapter 3 help put into context the importance of research such as the CBA results of this study for policy makers considering future energy transitions.

Following the review of historic energy transitions, chapter 4 describes the methodological approach of the study. Chapter 4 begins with an explanation of the ontology and epistemology. The chapter then proceeds with an introduction of the research design and research questions. The case study for the research is then identified, followed by a brief overview of the case background and selection. Following a summary of the data collection process, the tools and methods of data analysis utilized by the study are then presented. The chapter then provides a brief introduction to the steps involved in the CBA process. Chapter 4 briefly considers the timetable and cost associated with the study before concluding with a brief statement on ethical considerations.

Following a brief overview of the process and the steps involved, the CBA is conducted in chapter 5. Following the steps outlined in Hanley and Barbier (2009) and incorporating data collected from selected secondary sources, an initial set of results is obtained. Following the calculation of the initial results, the CBA process is replicated a number of times incorporating various changes in the data in order to reflect different scenarios, as part of the sensitivity analysis stage of the CBA. By conducting the steps of the CBA process and based on the criteria of the net present value test, the results expressed in chapter 5 determine if the LNG option should be accepted or rejected.

Chapter 6 considers the results of the CBA in chapter 5 and discusses the numerous implications for the transition away from heavy fuel oil to LNG being utilized as a maritime fuel in the Arctic region. The discussion parallels the earlier examination of historic energy transitions by analyzing the implications of the CBA results in relation to the technological, social, and cultural dynamics that have framed previous energy transitions. Within this context, the implications of the CBA results for the transition to LNG in the Arctic are analyzed and discussed in detail in chapter 6.

Chapter 7 considers the overall conclusions of the study and summarizes the earlier discussions and results contained in the study. The policy implications of the study are then briefly considered in the chapter. Finally, chapter 7 is drawn to a close with a consideration of plans for future research beyond this study.

1.3. LNG Overview

At this point it is useful to provide a brief overview of LNG. Natural gas is a fossil fuel found in formations beneath the surface of the earth, which can be extracted from reservoirs alone, known as non-associated gas or also along with crude oil as what is known as associated gas (Lawal et al. 2017). Natural gas consists of a mixture of hydrocarbons such as methane, ethane, propane and butane (Kumar et al. 2011). LNG is natural gas that has been cooled to a temperature of -162 degrees Celsius, thus converting it into a cryogenic liquid that has a reduced volume of 600 times less than that of the original gaseous state (Pfoser et al. 2018). As a result of the processing, cooling and conversion procedures, which include the removal of impurities, LNG consists of 98% methane, thus it is considered the cleanest form of natural gas (Kumar et al. 2011, Mazyan et al. 2016). Following conversion LNG can be stored in insulated tanks that are specially designed to maintain the required low temperatures at near atmospheric pressure (Ikealuma & Wu 2014; Khan et al. 2019).

The density of LNG is approximately 0.5 kg/L, which means LNG is lighter than water and will quickly evaporate in the event of a spill on water (Kumar et al. 2011). LNG requires a flammability range of 5% and 10% by volume to ignite when vaporized and will not explode in its liquid state; therefore LNG will only burn when a particular concentration of air is present (Vanem 2008). These properties, along with strict procedures and design codes governing production and distribution, have lead to LNG having a strong safety record in comparison to other portions of the oil and gas industry (Peterson & Weisend 2019). LNG has a particularly noteworthy safety record at sea, considering there have been no major accidents such as a cargo fire, explosion, or related fatality reported onboard LNG ships over a 40-year period (Bubbico et al. 2009). Despite a respectable safety record, LNG is a cryogenic liquid that can damage human tissue as well as certain materials that it comes into contact with (Peterson & Weisend 2019). Notable hazards associated with LNG, as with other cryogenic liquids include health risks such as cold burns, asphyxia, and damage to materials due to a ductile to brittle transition (Spurlock 2016). These hazards highlight the importance of utilizing proper procedures and materials in all LNG related processes.

In the form of LNG, natural gas can be efficiently transported in extremely large quantities over great distances. LNG is often transported in specially designed LNG carrier ships ranging in capacity from 19,000 to 265,000 m^3 (Raj et al. 2016). As a result of the flexibility and advantages that LNG provides in comparison to transporting conventional natural gas via pipelines, LNG has enabled distant markets to be successfully reached. For instance, South Korea and Japan lack substantial domestic natural gas resources and are not connected to gas producing regions via pipelines, therefore both countries depend almost entirely upon imported LNG to meet their respective demands for natural gas (Bernstein et al. 2016).

Japan is the world's largest LNG importer; with year 2016 imports totaling 116.5 bcm, which accounted for nearly a third of global LNG imports for the year (IEA 2019). As Figure 1.1 indicates, Qatar, Australia, Malaysia, and the United States were the top four exporting countries for the year 2018 (IEA 2019).

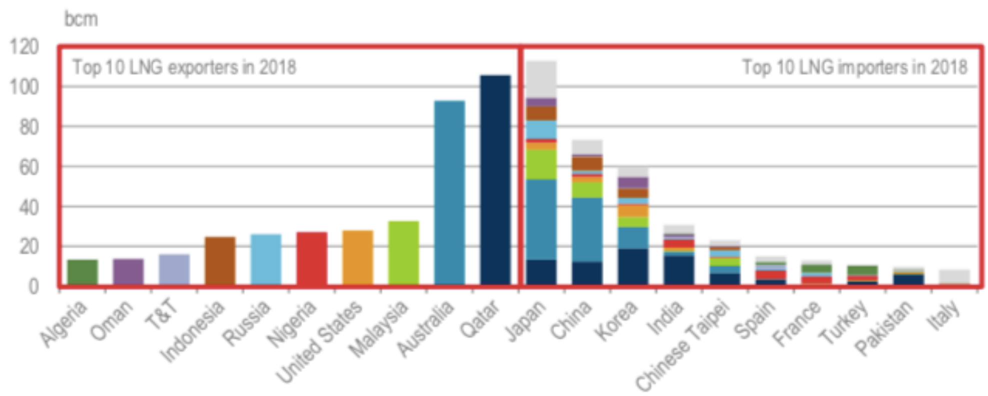

Figure 1.1. Top LNG Exporters & Importers in 2018 (IEA 2019)

For the past several years, the LNG trade has been going through a period of transformation that has led to the emergence of change in traditional aspects of the LNG market (Zhang et al. 2018; Lim & Goh 2019). While LNG has traditionally been traded in local or regional markets, there is currently a progression towards a more globalized marketplace (Bridge & Bradshaw 2017; IEA 2019). Historically, LNG has been traded mostly under rigid, long-term contracts, however a recent trend is developing towards a more integrated marketplace characterized by shorter contracts and increased flexibility (Hartley 2015; Carriere 2018). While factors such as geographic price variations make cost comparisons complicated, natural gas is considered to have an advantage over oil-based fuels from an affordability standpoint (Thomson et al. 2015; Bridge & Bradshaw 2017).

While natural gas and LNG is often touted as a transition fuel in the move to a low carbon energy system, the industry also faces significant challenges related to decarburization that will impact the viability of the industry and act as barriers that impede development and diffusion in the future (Neumann & von Hirchhausen 2015; Stern 2019). As a result of these and other challenges, there is a pronounced sense of uncertainty regarding the future of the LNG trade and the broader natural gas industry (Honore 2016; Rogers 2016). This sense of uncertainty, as well as other relevant aspects of the LNG trade, especially as relates to an energy transition in the Arctic region, will be discussed in further detail in later chapters, particularly in chapter 6.

CHAPTER 2: MARITIME AND ENERGY GOVERNANCE AND THE ARCTIC OPPORTUNITY

2.1. Introduction

The following is a brief review of the literature pertaining to the concept of governance and subsequently maritime governance and energy governance. The two sets of literatures are usually considered separately (Bazilian et al. 2014; Roe 2013). The first contribution of this chapter is that I cover both, as the transition to LNG is not only determined by energy imperatives, but also maritime concerns. As part of an analysis of the transition towards liquefied natural gas as a maritime fuel, I seek to develop a better understanding of how and under what conditions such a transition will take place and who will make decisions that will influence any such transition. Developing a better understanding of how and under what conditions a transition to LNG as a maritime fuel in the Arctic will take place will be a second contribution of this chapter. This thesis argues a key condition for this transition to take place is price and market forces (further outlined in Chapter 6). It also goes on to argue that commercial interests are too often overlooked when understanding what will influence such a transition. When they are considered in governance literature, they are often reduced to fossil fuel companies (Goldthau & Witte 2009), ignoring major industrial players such as shipping companies. Exploring past and current aspects of maritime governance and energy governance is an important step in developing an understanding of how a transition towards liquefied natural gas would develop. The understanding of energy and maritime governance developed in this chapter will assist the CBA conducted in chapter 5 by providing the proper context surrounding the energy transition that is being analyzed.

The review of the literature detailed below indicates several trends regarding the concept of governance in general as well as maritime governance and the governance of energy. My central argument is that commercial interests and organizations are too often overlooked in this literature, which normally focuses on government and not private sector organizations. First, there seems to be a trend towards a progressively expanding role of non-state organizations in governance, often focusing on government and civil society. The review points towards increased globalization leading to opportunities for non-state contingents to become involved in increasing roles and to exhibit greater influence in the process of governance, offering a chance to appreciate the role of private interests. Through increased globalization non-state organizations and nongovernmental organizations (NGOs) as well as corporations have increased opportunities to expand their influence in governance.

In maritime governance the literature seems to indicate a trend towards regional cooperation and coordination between regional organizations such as the European Union (EU) and the Artic Council and the internationally ranging International Maritime Organization (IMO). Not only does it appear that the IMO is able to steer and influence policy decisions made by individual states and regional organizations, but states and regional groups also have the ability through close involvement with the IMO to also steer international policy. Stokke (2013) points to the US Oil Pollution Act of 1990 that was adopted in the aftermath of the *Exxon Valdez* disaster, phasing in double hull requirements for oil tankers and eventually helping to usher in the successive adoption of the requirement by the IMO, as a past example of an individual state influencing international maritime policy. Similarly, as the global influence of the Arctic region continues to increase, the Arctic Council will almost certainly not only encounter opportunities to influence regional policy, but also influence and drive international policy decision making as well. This trend of cooperation and coordination by stakeholders participating in maritime governance will unquestionably play a key role in future of shipping activities conducted in the Arctic region. Propositions aimed at improving the sustainability of Arctic shipping, such as the transition to LNG as a maritime fuel examined by this thesis, will evolve in a milieu characterized by regional cooperation in which a diverse array of state and non-state actors are guiding and influencing convention and policy.

In energy governance there seems to be a trend regarding the involvement of developing nations and emerging markets becoming a greater part of energy governance. While the established states and organizational powers currently prominent in energy governance will undoubtedly continue to wield tremendous influence, Florini & Sovacool (2009) list the International Energy Agency's (IEA) membership excluding several large oil consuming and producing nations such as

India and China as an issue and mentioned efforts at including them in collaborations and the possibility of eventual membership being offered.

2.2. Governance

Governance is a process that moves beyond the traditional model of state controlled organizational units implementing collectively binding decisions through the use of established bureaucracy towards one which also encompasses the influence of private third sector actors within society that participate in the policy process through actions that steer policy decisions (Treib et al. 2007). Therefore, governance can be viewed as including not only the traditional state, but also other parties such as businesses and NGOs into the political decision making process through the use of steering and influence (Jordan 2008). My focus on shipping in the Arctic region demonstrates, above all, the importance of private interests in governance where the traditional state is less present. Farazmand (2013) points to the concept of governance as essentially expanding beyond the traditional state to also include societal organizations and the private sector and therefore empowering these parties to promote their interest and negotiate their differences along with those of the state.

Although the two are certainly closely associated, governance should not be confused with government, as the two terms are different concepts and certainly not simply different terms for the same theory. Florini & Sovacool (2009) attempt to clarify this difference by pointing out that governments can be considered as merely one of many aspects of the overall governance concept in which rules are set and enforced by groups of people in an effort to realize desired conclusions. Hence, while traditional formal governments are a predominantly important and significant part of the governance process, they also share in this process to varying degrees with non-state participants from differing segments of society. As Jordan (2008) indicates, government tends to relate to actions that are based in recognized formal authority, while governance on the other hand relates to actions based on shared goals that also include nongovernmental and informal institutions. Young (2012a) depicts governance as efforts intending to steer sociological systems towards desirable directions through the establishment of rules and decision-making processes.

Another aspect of governance is that it can transcend specifically defined geographic areas across the local, national and international spectrum (Jordan 2008). The Arctic case as expanded upon below in more detail is a case in point where governance is especially apt. This aspect of governance is particularly important in the recent era of increased globalization. Farazmand (2013) lists factors such as technological innovation, the fall of the former Soviet Union, and the expanding role of United Nations (UN) agencies as reasons that globalization has been augmented in recent history, and along with other factors, has led to an increased transformation of governance beyond the traditional state that is characterized by the increasing influence of non-state parties.

Biermann (2010) notes a shift from intergovernmental organizations towards increased public-private cooperation taking place over the past decades, which has been characterized by an increasing number of non-state actors becoming formally involved in norm setting and implementation throughout the world. Biermann (2010) does not however explicitly outline the increasing importance of business, and focuses rather on civil society. Driessen et al. (2012) states that despite recent shifts in modes of governance that modes of governance tend to build upon one another instead of completely replacing one another and that traditional hierarchal structures are often found alongside new modes of governance.

The UN stipulating that recipient countries must first adopt aspects of "good governance" in order to receive certain types of assistance is an example laid out by Farazmand (2013), of donor nations using an illustration of steering mechanisms to influence developing nation recipients to implement numerous policy and structural reforms within their societies and governments.

2.3. Maritime Governance

The governance of the sea is a complex issue due to the vast geographical area that the world oceans cover and the number of affected and concerned stakeholders involved in the use of and dependent upon the oceans' resources (Suárez de Vivero 2007). Maritime governance is managed by a vast assortment of different institutions and organizations at varying levels, from the international level by the IMO, to the supranational level by organizations such as the EU and the national level by individual states and actors. No one government or organization provides unitary leadership. This makes the study of governance especially relevant. Participants such as maritime industries, including shipping, fishing, and offshore oil and gas, as well as non-governmental organizations are also increasingly influential in the governance of the sea process. I outline below the key governance players and legislative framework in international maritime governance, before moving onto focus on energy governance. This is necessary for situating the role of commercial interests, especially shipping companies in maritime and energy governance.

2.3.1 United Nations International Maritime Organization

International shipping governance is managed primarily, though not exclusively, by the IMO through the use of directives and treaties such as the 1982 United Nations Convention on the Law of the Sea and the International Convention for the Prevention of Pollution from Ships, and overlaps and coordinates with regional and individual regimes and organizations (Stokke 2013). As the UN's specialized agency responsible for dealing with international shipping, the IMO is responsible for areas such as shipping safety and the prevention of maritime pollution through the development of a comprehensive regulatory framework (Wieslaw 2012). As Stokke (2013) points out, due to international shipping being a truly global industry, cooperation between principal participants in the shipping sector is facilitated by the desire of stakeholders to prevent fragmented regulation that could potentially prove costly or difficult to comply with. Molenaar (2012), states that in order to not undercut the United Nations Convention on the Law of the Sea's aim of uniformity in minimum global standards and the associated supremacy of the IMO, the Convention does not require or even encourage regional standard setting in the realm of merchant shipping, but does recognize the right of port states to stipulate more stringent standards than the internationally accepted ones.

Wegge (2015) argues that the United Nations Convention on the Law of the Sea tends to naturally benefit coastal states by granting coastal states certain rights to resources, and offers the establishment of 200 nautical mile Exclusive Economic Zones as a primary example. Under the United Nations Convention on the Law of the Sea the jurisdiction of coastal states over territorial waters and seabed resources is established and the criteria that are used to determine the extent of a coastal state's continental shelf is stipulated (Sebastian 2013). The United Nations Convention on the Law of the Sea does provide under certain circumstances, for an extension of coastal state jurisdiction over seabed resources beyond 200 nautical miles in instances where it is proven that the geology of the seabed is a continuation of the coastal state's continental shelf (Peng & Wegge 2014).

The previous passage illustrates the substantial role that the IMO plays in maritime governance. The desire of maritime sector participants to achieve a level conformity of in regulation demonstrates how the IMO is able to facilitate a sense of cooperation among a broad assortment of actors engaged in maritime governance at the international level. While primarily concerned with international maritime governance, as was noted, the IMO does recognize existence occurrences of actors engaging in maritime governance on a narrower scale, such as on a regional or supranational level. An examination of maritime governance on a more narrowly defined scale than at the international level can provide valuable insights on maritime governance at the regional level in a setting such as the Arctic.

2.3.2 The European Union and Maritime Governance

In order to be able to have a better understanding of how maritime governance functions in a regional situation, such as in relation to Arctic shipping, it is useful to examine examples of maritime governance taking place on a more defined scale than the international level directed by the IMO, yet still in a setting that incorporates multiple state and non-state actors. An example of the governance of the sea at the supranational level is the efforts of the EU and the implementation of initiatives such as the Common Fisheries Policy, the Marine Strategy Framework Directive, and the Integrated Maritime Policy (van Hoof et al. 2012). An examination of these initiatives helps illustrate how the European Union manages the governance of the sea. As a prominent actor in maritime governance, particularly one with a keen interest in Arctic issues, an examination of examples of maritime governance on behalf of the EU can provide useful lessons for Arctic region.

2.3.2.1 The Common Fisheries Policy

Created by the EU in 1983 as a policy framework with the objective of sustainable development of the fishing industry and the conservation of fish stocks, the Common

Fisheries Policy now has an expanded ecosystem wide conservation scope as the result of a 2002 reform (van Hoof et al. 2012). Another aspect of the 2002 reform of the Common Fisheries Policy was the creation of Regional Advisory Councils, with the objective of bringing together stakeholders such as fishing industry organizations, consumer groups and environmental organizations to engage in a form of participative governance, and additional 2014 reforms should result in stakeholders being even more involved in the policy making process (Hatchard & Gray 2014). Salomon et al. (2014) point towards further reforms such as a discard ban on unwanted catches, the institution of maximum sustainable yield levels for harvested stocks, and a move towards more regionalism in the governance of fisheries, as valuable steps towards a more sustainable European fisheries policy.

The EU's Common Fisheries Policy is an example of regional stakeholders, representing industry, consumers and environmental advocates, all participating in maritime governance on a regional level towards sustainable development objectives. The success of the Common Fisheries Policy illustrates how encouraging stakeholders to become engaged in maritime governance can prove valuable to the policy making process. The ability of the EU to continually evolve the Common Fisheries Policy over the years, with a series of reforms and new initiatives, highlights the need for policy makers to be prepared to adapt in order to address additional challenges. In terms of the Arctic region, policy makers can look to the success of the EU's Common Fisheries Policy as a guide for Arctic governance and policymaking. The lessons of the Common Fisheries Policy, such as participation, regional cooperation, and continual improvement, are particularly pertinent for the Arctic region, particularly considering the desire of the EU to become increasingly involved in Arctic governance and related affairs.

2.3.2.2 The Integrated Maritime Policy

The European Commission initiated the Integrated Maritime Policy, in 2007 with the objective of developing maritime policies in a joint fashion in order to facilitate the utilization of the sea while also maintaining the marine environment (van Hoof et al. 2012). According to Olsen et al. (2011), the Integrated Maritime Policy is an approach by the EU to develop an integrated approach towards maritime governance as opposed to the mostly fragmented approaches of the past. This is yet another example of an expressed desire for coordination, collaboration, and uniformity in maritime governance for Arctic actors to reflect upon.

The Integrated Maritime Policy foresees the process of marine spatial planning as a method of developing and applying European maritime policy (Suarez de Vivero & Rodriguez Mateos 2012). Marine spatial planning is a policy instrument that allows stakeholders and member states to utilize marine space through the use of coordination in a way that benefits economic development as well as the environment (van Tatenhove 2013). Fritz and Hanus (2015) contend that if the Integrated Maritime Policy is to achieve its objectives, future reform efforts must include the establishment of a committed funding program and efforts to alleviate the tendency of policy formulation processes consulting only certain sectors of stakeholders.

The need to avoid the tendency of excluding certain stakeholders from the policy making process is an important lesson that Arctic governance actors can ascertain from the Integrated Maritime Policy. This lesson is particularly important for the transition to LNG as a maritime fuel in the Arctic region, as it will be crucial to strive that both state and non-state actors such as shipping companies and the broader maritime sector are afforded an opportunity to participate in the governance of the Arctic.

2.3.2.3 The Marine Strategy Framework Directive

Due to the diverse array of state and non-state actors involved in maritime governance, it can be challenging to strike a balance between the need for regulatory consistency while also respecting concerns regarding national and local autonomy. This challenge can be especially difficult when crafting policy undertakings concerning issues that transcend borders such as pollution and environmental protection. The Marine Strategy Framework Directive was adopted by the EU in 2008 to protect Europe's marine environment and has the objective of achieving good environmental status of European Union waters by the year 2020 (van Hoof et al. 2012). Ounanian et al. (2012) note that through the Marine Strategy Framework Directive, together with the Integrated Maritime Policy, the EU attempts to not only manage activities taking place in the oceans, but rather to manage the entire marine environment through an ecosystem based approach. Under the Marine Strategy

Framework Directive, stakeholders such as the fishing industry, the navigation sector, the offshore oil and gas industry, the coastal tourism sector and the offshore renewable energy sector will have to comply with good environmental status guidelines and strategies (Ounanian et al. 2012). This is a reminder that within the EU's jurisdiction, private shipping companies must adhere to common rules and standards. As explored above, the Arctic has a less mature legislative context, which is often a challenge to achieving uniformity in policy and regulatory efforts for the region.

Although the Marine Strategy Framework Directive sets out a framework for member states to follow, each of the member states have a certain amount of freedom and flexibility in the way in which they integrate the adoption and implementation of these framework steps into their national regulations, and therefore, national and local actors have the ability to steer and influence the shape and manner in which the directives are ultimately implemented (van Hoof et al. 2012). Under the Marine Strategy Framework Directive, member states are also required to cooperate and coordinate at the regional level through previously existing Regional Sea Conventions (van Leeuwen et al. 2012). This freedom and flexibility in the implementation process of the European Union Marine Strategy Framework Directive is an example of an opportunity for non-state actors and stakeholders to be involved in the European maritime governance process. The Marine Strategy Framework Directive is a useful example for of maritime governance actors establishing a regional policy framework, while also allowing for national and local flexibility in the implementation process, for Arctic actors to draw upon.

2.4. Energy Governance

Much like the governance of the sea, the governance of energy is a complex issue due to the wide scope of influence and the broad range of effect that energy plays in society. Indeed the governance of the sea and energy are frequently linked and interwoven and often involve the same actors and models. Goldthau et al. (2012) note that energy is an essential aspect of human existence and society and therefore energy affects governments of all levels as well as influences practically every private sector endeavor. Due to the encompassing nature of energy, its governance is exceptionally complex and often uncertain. The role of private interests in governance structures is more pronounced than under its maritime counterparts as explored above, but rarely in relation to shipping interests (often more focused on energy companies).

Energy governance at the international level can be considered disjointed and often consists of a fragmented collection of state and non-state participants such as networks, corporations and civil society organizations. Florini & Sovacool (2009) attempt to illustrate a range of institutions that exemplify global energy governance by presenting and analyzing four types of institutions, intergovernmental organizations, summit processes, multilateral development banks and public-private partnerships. An examination of each type of institution is presented below before then moving on to consider the Arctic context specifically.

2.4.1 Intergovernmental Agencies

Intergovernmental agencies, which are funded by national governments, are the most recognizable form of global governance, and indeed such universally known organizations such as the International Monetary Fund and the World Health Organization are notable examples. The IEA, which was founded by major oil consuming nations as a result of the oil crisis of 1973 and consisting of membership limited to member states of the Organization for Economic Cooperation and Development, has established and administers an emergency oil sharing system, as well as an oil price and supply statistics reporting system (Florini & Sovacool 2009). According to Colgan & Van de Graaf (2014), the IEA's emergency oil reserve allocation system places it among the most powerful international organizations in the world. By gathering oil price and supply data and presenting related information to the public and governments, the IEA is an example of how an intergovernmental organization is able to exhibit influence and steer behavior through the use and distribution of information and knowledge (Florini & Sovacool 2009). While none of the intergovernmental agencies reviewed in this section have an explicitly defined role in the Arctic, but they all remain implicitly part of the overarching international governance structure in energy.

2.4.1.1 Association of Southeast Asian Nations (ASEAN)

A key example of an intergovernmental agency involved in the governance of energy is the Association of Southeast Asian Nations (ASEAN). Established in 1967 in

Bangkok, Thailand by the signing of the Bangkok declaration by the nations of Indonesia, Malaysia, the Philippines, Singapore, and Thailand; ASEAN membership has now expanded to ten countries, currently including Brunei Darussalam, Vietnam, Lao People's Democratic Republic, Burma/Myanmar, and Cambodia (Karki et al. 2005). Through the use of cooperation among its members, ASEAN strives to promote peace and stability throughout the region, as well as fostering economic growth and development for the region (Poocharoen & Sovacool 2012). In recognition of the importance that shipping plays in the economic development of its member states, ASEAN is dynamically engaged in maritime governance through actions such as efforts to establish a single shipping market for the region (Tongzon & Lee 2015). In addition the examples of how ASEAN is active in maritime governance, it is also useful to examine instances in which this intergovernmental agency is involved in energy governance.

According to Poocharoen & Sovacool (2012) ASEAN created the Petroleum Council in 1975 in response to the 1973 OPEC oil embargo, and later established the ASEAN Centre for Energy in 1999 to create a network that would foster and guide energy related investments and policies throughout the region. Located in Jakarta, Indonesia, the ASEAN Centre for Energy is responsible for implementing the ASEAN Plan for Action for Energy Cooperation (Karki et al. 2005). Kanchana & Unesaki (2014) point to ASEAN now using regional cooperation to promote energy security and sustainability through a seven-component action plan concerning issues such as power grids, pipelines, coal, nuclear energy, renewable energy, energy policy, planning, efficiency and conservation. An example of such regional collaboration efforts is the proposed multibillion-dollar Trans-ASEAN Pipeline Network, which would connect gas reserves located in the Gulf of Thailand, Myanmar, and Indonesia with the rest of the region by spanning ten different countries and potentially help to create an eventual regional natural gas market in Southeast Asia (Sovacool 2010).

According to Poocharoen and Sovacool (2012), the ASEAN Centre for Energy is relatively well funded and supported by member states and enjoys close interactions with civil society networks and state owned energy companies such as PETRONAS, however, in spite of these attributes, it could be concluded that due to the lack of any formal ability to implement actual energy projects, the ASEAN Centre for Energy's scope of power is therefore ultimately limited. Since its founding, ASEAN has remained strongly committed to non-intervention into the affairs of member states without inherent consent, and Aalto (2014) contends that this entrenched preoccupation with maintaining a high level of sovereignty among member states has resulted in a lack of formalized legal regulations and delegation of authority, thus hindering ASEAN's ability to achieve optimal levels of coordination between its members and for the region. These challenges and constraints should be addressed by ASEAN member states in order to best address the future economic development needs and to meet the energy supply requirements necessary to sustain growth throughout the region.

The examples of ASEAN participating in energy governance can provide lessons for the Arctic and for the prospect of a transition to LNG as a maritime fuel being implemented within the region. Similar to the maritime governance examples mentioned earlier, ASEAN is an illustration of energy governance being facilitated by regional cooperation. The difficulty ASEAN struggles with in achieving cooperation while also remaining committed to national sovereignty among member states is comparable to the challenge faced by the EU, which mentioned earlier. These lessons point to the importance of a commitment to a high level of inclusion and participation among governance actors, as well as a devotion to constructing policies that are mindful to the respective concerns of stakeholders, being crucial for energy as well as maritime governance.

2.4.1.2 The International Energy Agency (IEA)

Florini & Sovacool (2009) suggest that the IEA is the most prominent intergovernmental organization involved in energy governance. Therefore, despite the IEA not holding an explicitly Arctic focused mission, the intergovernmental agency will certainly be influential in any energy transition, such as LNG becoming utilized as a maritime fuel in the Arctic region. The IEA was established in 1974 by major oil consuming nations, all of whom were members of the Organization for Economic Cooperation and Development (OECD), in response to the governance deficiencies that were made apparent by the oil shocks of the early 1970s which were characterized by oil embargos orchestrated by the Arab members of the Organization of Petroleum Exporting Countries (OPEC) in objection to the Middle East policies of certain countries and later the raising of oil prices by OPEC as a whole in an effort to reflect displeasure with previously earned revenues levels (Florini 2011). According to Van de Graaf (2012) the IEA's membership being limited to OECD member countries can be attributed to the organizations founding at the height of an oil shock predicament and the founders having an urgent desire to establish an agency that could become operational as soon as possible, and thus the OECD provided an existing organizational framework with established mechanisms that allowed the founders to achieve this objective.

While the OECD membership condition certainly served an advantageous and practical purpose for which to deal with the need for rapidly launching an operational organization as an urgent attempt to address the oil shock crisis, it can be contended that the exclusiveness of the IEA's OECD membership prerequisite now stands as a potential hindrance to the IEA being able to optimally carry out its mission and being able to maintain its current position of relevance and prominence in the realm of the governance of energy in the future. Since the founding of the IEA in the 1970s, the economic and geopolitical dynamics pertaining to energy have significantly evolved and as a result countries that do not hold OECD membership now play a much more significant role in global energy affairs. As van der Linde and Luciani (2012) contend, during the era of the IEA's creation, the agency's membership represented the largest oil consuming nations and therefore the largest constituents of global demand, while OPEC represented the largest components of global supply during that time period. The evolution of economic and geopolitical dynamics such as these examples is similar to current issues regarding changes taking place in the Arctic region.

While the IEA with OECD exclusive membership, may have possessed such a commanding role in the dynamics of global energy demand in years past, it cannot be said that the organization maintains the same dominant position in the evolved global energy setting of today or the projected future. According to Van de Graaf (2012), while the IEA membership countries were responsible for 63 percent of global oil consumption in 1974, their share of consumption has now contracted to slightly more that 50 percent and is estimated to further decline to near 38 percent by the year 2030. Indeed, due to factors such as rapid economic growth and increased industrialization, nations that are not members of the OECD are now responsible for an increased share of global oil demand, particularly developing nations such as India and China (Florini 2011). As the fastest growing market for natural gas, Asia will wield significant influence in the global trading of LNG in the future (Shi & Variam 2016).

While the IEA has made efforts to reach out to and cooperate with non-OECD countries, as long as the current OECD membership requirement and the subsequent membership criteria remains in place, these stipulations will remain a substantial obstacle towards being able to fully engage and collaborate with such nations in carrying out the organization's mission. For instance, Van de Graaf (2012) points towards stipulations for OECD membership such as being a democracy, the establishment of a market based economy, and a demonstrated respect for human rights as requirements that would be a major obstruction to certain countries such as China or Russia for example, becoming members of the OECD and consequentially the IEA. As countries that fall into this category continue to play an increased roll in global energy, the validity of these membership requirements will have to be weighed against the necessity of engaging in increasing levels of collaboration with such countries in the future. These exclusive membership requirements also have implications for the ability of the IEA to participate in Arctic governance.

The failure to adequately involve developing nations with emerging economies that are not OECD members not only hampers the IEA's ability to address energy supply and demand issues, but also the organization's ability to address the challenge of climate change and environmental issues such as emissions. Just as the main increases in future energy demand will be attributed to mostly non-IEA member developing countries, so to will the bulk of energy related emissions, and as a result the IEA's ability to effectively provide solutions could be diminished going forward (Van de Graaf 2012). This also hampers the ability of the IEA to be able to play a more influential role in Arctic affairs.

One aspect of the IEA that could be viewed by current members as a reason to be hesitant to alter the existing membership requirements in order to allow the inclusion of new members, particularly members that are substantial oil consuming nations, is the current voting arrangement used by the organization. Under the current voting structure used by the IEA, votes are weighted based on a member nation's oil consumption. Florini (2011) argues that as long as votes continue to be tied to respective levels of oil consumption, that allowing the admission of prospective members that are large consumers of oil such as China, would result in the new members instantly holding a substantial amount of influence, and thus current members would view the admission of such a country as requiring them to cede their own existing influence in order to do so. The current voting arrangement of weighted votes based on oil consumption levels overwhelmingly favors the United States, and as Colgan and Van de Graaf (2014) point out, evidence indicates that the United States currently holds the most powerful position among member states within the IEA organization. If a nation with a significant level of oil consumption potentially rivaling that of the United States in the future were to be granted admission to the IEA, it would be viewed as a threat to the position of power that the United States currently holds within the organization.

Another aspect of the IEA falling under the canopy of the OECD is that the agency's budget is part of the OECD budget, and therefore is subjected to certain constraints that are essentially beyond its control and thus results in some inevitable limitations (Van de Graaf 2012). The IEA is able to carry out a wide range of endeavors with a total staff of only around 250 personnel, yet as Florini (2011) contends, if the IEA wishes to maintain its status in the sphere of global energy, and be able to successfully deal with issues such as climate change and imminent energy transitions, it will certainly have to expand its size and capability in the near future. As the nature and dynamics of global energy continue to rapidly evolve and become more complex, so too must the IEA, in order to sustain its level of relevance.

2.4.2 Summit Processes

An example of a summit process involved in energy governance is the Group of Eight, which was originally organized as meetings between powerful heads of state to deal with economic policies and has now expanded to also include a range of political issues, including energy and climate matters, with membership consisting of Canada, France, Germany, Italy, Japan, Russia, the United Kingdom, and the United States (Karlsson-Vinkhuyzen & McGee 2013). Summit processes have the ability to overcome bureaucratic divisions present between states in an effort to manage the governance of energy and Florini & Sovacool (2009) offered the 2005 Group of Eight summit held in the United Kingdom that resulted in numerous commitments linked to clean energy, climate change and sustainable development as an example. The ability of summit processes such as the Group of Eight to bring together prominent governance actors in order to concentrate on significant challenges, in a manor and setting that is conducive to problem solving, is certainly relevant for the Arctic region as an example of how challenges might be addressed by the region in the future.

2.4.3 Multilateral Development Banks

Unlike with maritime governance, literature pertaining to energy governance tends to more often emphasize the role of markets and commercial interests. Multilateral development banks, for example, provide economic and technical assistance to developing nations in the form of loans for development projects, many of which are related to energy developments (Florini & Sovacool 2009). Multilateral development banks, like most international development organizations, evaluate development projects based on the potential to achieve desired outcomes such as educational and health care improvements, poverty reduction, and environmental sustainability (Buntaine 2011). A notable example of a multilateral development bank that is actively involved in energy related development projects and energy governance is the Asian Development Bank. One form of evaluation criteria that is used by the Asian Development Bank to determine the worthiness of energy related development projects is the requirement that transmission assets be privatized before loans can be approved and granted (Florini & Sovacool 2009).

Simpson and Park (2013) point to the Asian Development Bank's recent interest in development activities in Burma/Myanmar after decades of boycotting the nation due to donor nation sanctions, as having the potential for the organization to entice the government into accepting the required social protections and therefore provide the Asian Development Bank with the opportunity to promote a shift towards further progressive governance reforms. Delina (2011) recommends actions such as increasing the levels of funding and technical assistance provided, as necessary steps for the Asian Development Bank to take in order to address future energy challenges facing region. The lack of a multilateral development bank currently dedicated to providing economic assistance and support to Arctic development projects represents a potential opportunity for actors enthusiastic to participate in Arctic governance.

2.4.4 Small-scale Hybrid Public-private Partnerships

Small-scale hybrid public-private partnerships are increasingly playing a progressively more significant role in energy governance by filling in the gaps of formal mechanisms (Florini & Sovacool 2009). Presented as an example of such a public private partnership, is the Renewable Energy and Energy Efficiency Partnership with a mission of promoting energy efficiency, access to clean energy and reduced greenhouse emissions in developing countries (Florini & Sovacool 2009). Funded mostly through voluntary contributions and having no restricted membership, the Renewable Energy and Energy Efficiency Partnership funds mostly small-scale energy projects that can be replicated in different regulatory situations and also utilizes legal and technical expertise and influence to challenge regulatory barriers to clean energy development projects (Florini & Sovacool 2009). The ability of small-scale hybrid public-private partnerships to overcome barriers in order to cultivate small-scale development projects could prove extremely beneficial to the Arctic region, particularly in the initial stages of a transition to LNG being utilized as a maritime fuel.

2.5. Towards Exploring The Arctic – Uniting Energy and Maritime Governance

The unique physical and political characteristics of the Arctic have led to the region having a rather intriguing arrangement of governance. A diverse assortment of actors and stakeholders such as Arctic and non-Arctic states, indigenous groups, NGOs, and industries, are all participants in Arctic governance. This diverse collection of governance participants in the Arctic, represent a varied series of interest, ranging from, national defense, trade, cultural preservation, conservation, to commercial profit. Considering the sensitive nature of the Arctic, there is an underlying concern regarding environmental protection in future development decisions.

Although no single government or organization has sole responsibility over environmental protection in Arctic, there is still a wide range of actors, such as the ones mentioned above, who can work together in a number of capacities for this purpose. In order for development and commercial activities to continue to take place in the Arctic, stakeholders such as shipping companies will rely on environmental and economic impact valuations in order to make key decisions regarding future actions. The importance of environmental and economic valuations to the future of Arctic development highlights the usefulness of research such as the cost-benefit analysis contained in this study.

2.5.1 Governance in The Arctic

Just as there are physical changes taking place in the Arctic, so too is the governance of the Arctic changing and evolving as both established, as well as recent stakeholders become increasingly interested and involved in the prospect of intensified development activity throughout the region (Koivurova 2010). An understanding of the key stakeholders and their current standing as well as their potential for future influence within the scope of Arctic governance is useful for examining the prospect of future Arctic development.

2.5.1.1 Arctic and Non-Arctic States

The eight states with an actual physical presence in the Arctic are Canada, Finland, Greenland, Iceland, Norway, Russia, Sweden, and the United States. As could be expected, these Arctic states do in principle yield a significant amount of power and influence within the region and the related governance, in comparison to that of non-Arctic states (Ingimundarson 2014). However, this advantage is due to more than merely a physical presence, but also stemming from the authority granted to coastal states under the United Nations Convention of the Law of the Sea. For instance, Berkman and Young (2009) point to aspects of the United Nations Convention of the Law of the Sea such as Article 76 which relates to jurisdictional boundaries beyond Exclusive Economic Zones, and Article 234 concerning areas covered by ice, as provisions used by Arctic coastal states to guide the regulation of activities such as shipping within the region. According to Sebastian (2013), the ability of Arctic coastal states such as Canada to influence and establish rules and policies for the region under the United Nations Convention of the Law of the Sea provides Arctic coastal states with a meaningful political power advantage in comparison to non-arctic states concerning policy issues pertaining to the region.

However, the powerful and influential advantages that Arctic states possess in Arctic governance does not mean that non-Arctic states do not have a considerable opportunity to wield influence and promote their interest throughout the region, particularly in considering the state of transformation that characterizes the Arctic.

Young (2012b) contends that non-Arctic states have the ability to have a significant impact on Arctic governance through such channels as the negotiation process of IMO policies and initiatives such as the Polar Code, as well as through participation in the Arctic Council and the development of discourse with all parties possessing a valid interest in the Arctic.

2.5.1.2 Arctic NGOs

Another important and increasingly influential set of actors in Arctic governance is that of NGOs. This is a different category to private interest organizations, which are also non-governmental. The key distinction is that NGOs are not for profit organizations. The NGOs engaged in undertakings as varied as wildlife conservation and environmental protection among other interest, have long been attentive to developments taking place in the Arctic. Increasingly, NGOs are playing a greater role in the governance of the Arctic and have the potential to exercise a substantial level of influence in future developments in the region, which is in line with observations of the broader governance literature as set out above. Bjola (2013) states that NGOs, which can be granted observer status in the Arctic Council, have influenced the Arctic Council's decision making through actions such as providing research findings and offered the World Wide Fund for Nature's involvement in the proposal for an Arctic Treaty and participation in numerous research projects aimed at Arctic biodiversity preservation as a key example.

2.5.1.3 Arctic Council

In the realm of Arctic governance, the Arctic Council plays an unquestionably significant role. The Arctic Council was established in 1996 by the Ottawa Declaration to manage sustainable development and environmental protection of the Arctic through coordination and cooperation among Arctic states as well as the indigenous peoples living in the Arctic region (Smits et al. 2014).   The membership of the Arctic Council consists of the eight states with territory located within the Arctic: the United States, Canada, Finland, Iceland, Norway, Russia, Sweden, and Denmark (Greenland), as well associations representing the indigenous residents of the Arctic region (Stokke 2013). It should be specified that although the Danish dominion of Greenland was granted self-government under an agreement in 2009, the Danish government retain control over matters of foreign policy and defense;

therefore it is the Kingdom of Denmark that is an actual member state of the Arctic Council (Kluth & Lynggaard 2018).

As noted earlier, an interesting feature of the Arctic Council is the ability of non-Arctic state stakeholders, such as other non-Arctic states and NGOs, to apply for observer status with the Council (Smits et al. 2014). Some examples of organizations that have applied for and been granted observer status by the Arctic Council include the non-Arctic states of China, the Netherlands, and Japan, as well as a number of NGOs such as the World Wildlife Fund for Nature, the International Arctic Science Committee, the International Work Group for Indigenous Affairs, and Oceana, while other organizations such as the European Union have been slow to gain observer statue despite having applied for and desiring it obtain it (Smits et al. 2014; Arctic Council 2019). The increasing collection of organizations eager to obtain observer status with the Arctic Council, particularly powerful non-Arctic states and international organizations, is an indication of the status that the Arctic region has gained in political circles, and also demonstrates the important role the Arctic Council plays in the governance of the region (Smits et al. 2014).

Young (2012b) states that despite facing certain limitations that the Arctic Council has developed into the primary policy shaping organization in the Arctic. Koivurova (2010) lists the promotion of environmental assessments that have been important for discovering pollution and influencing environmental policy, providing a platform for a diverse group of stakeholders to examine the future of the Arctic, and affording the indigenous peoples of the Arctic a means for involvement and participation, as three main areas of success for the Arctic Council.

Despite these successes, Kankaanpaa and Young (2012) point out that the Arctic Council presently lacks the authority to make legally binding decisions on policy matters and that unlike the IMO, who has the authority to develop regulatory codes, the Arctic Council is merely a forum through which issues of concern to Arctic stakeholders are discussed and analyzed. This lack of genuine authority to generate and dictate compulsory policy will pose a substantial limitation to the Arctic Council's ability to exercise definitive influence on the future of the Arctic region.

Another predicament facing the future legitimacy of the Arctic Council is how it will develop a way to better involve non-Arctic stakeholders in a way that addresses their interests and concerns without diminishing those of Arctic stakeholders. Young (2012b) lists offering better opportunities for non-Arctic stakeholder participation as a key step necessary for strengthening the role of the Arctic Council for the future.

2.5.2 Energy in The Arctic: Oil and Gas

Much of the current and prospective development activity present in the Arctic is related to the extraction of natural resources located within the region, particularly oil and gas reserves. Therefore energy governance plays a practically crucial role in the Arctic region. Harsem et al. (2011) point to three major factors that will influence the expansion of oil and gas development in the Arctic region as being climate change, economic and market conditions, and the level of government encouragement by Arctic states. Of all these factors, climate change is perhaps the one most associated with recent issues in the Arctic. Studies of climate models have indicated that global warming will be even more enhanced in high northern latitudes and it is also predicted that the Arctic will be the location of the most dramatic and rapid changes occurring over the next century (Ho 2010). Predictions such as these highlights the need for accurate and comprehensive valuations on the true impacts and contributions of climate change taking place in the Arctic region.

The impacts of climate change are particularly severe in the Arctic region, where temperature increases are taking place at a greater rate than in comparison to the rest of the planet, as a result of polar amplification (Anisimov et al. 2007; Crepin et al. 2017). The dramatic impact of climate change in the region is exhibited in the reduction of Arctic sea ice in terms of extent, thickness, and seasonal duration (Descamps et al. 2017). In addition to the reduction of Arctic sea ice, a reduction of land ice, increased likelihood of wildfires, and the greening of tundra ecosystems are also impacts attributed to climate change in the Arctic (Box et al. 2019).

While global warming and melting ice might facilitate the development of the Arctic's oil and gas resources by making these resources easier to reach and exploit, climate change also presents a series of challenges to the development of Arctic oil and gas. An increase in the frequency and severity of extreme weather conditions resulting from climate change, such as hurricanes would have dire effects on oil and gas developments in the Arctic and present the possibility of devastating events ranging from costly production and transportation disruptions to disasters such as oil spills (Harsem et al. 2011). These potential risks will certainly factor into the rate at which oil and gas development in the Arctic progresses. Nobel et al. (2013) point to the recent purchases of offshore exploration leases in the Beaufort Sea of Canada by gigantic global energy firms such as Chevron, BP and Exxon Mobil as examples of the international attention that potential oil and gas developments in the region are rapidly increasing, but also point to the amplified need for a strategic approach towards impact assessment and planning before developments take place. This helps illustrate why the choice of fuel utilized for maritime propulsion within the Arctic region is so crucial.

While climate change and melting ice are often presented as the main factors influencing increased interest in Arctic oil and gas developments, Bennett (2014) draws attention to arguments contending that it is rather energy prices and a desire to secure resources that has been the actual facilitators of the recent heightening of interest in Arctic oil and gas development. The Fukushima nuclear disaster leading to an increase in oil and gas purchases by Japan is an example presented by Bennett (2014) as one illustration of a recent event that has led to an increased interest in oil and gas development in the Arctic. Harsem et al. (2011) assert that in the future, global economic conditions will be the most important determinant of oil and gas developments in the Arctic, and point towards the worldwide effects that the financial crisis of 2008 had on the price and demand of energy as well as energy related investments as evidence in support of this position.

2.5.3 The Arctic and Maritime Governance

Recent occurrences taking place in the Arctic region provide some intriguing examples of maritime governance. Increasing pressures from forces such as climate change and globalization are driving a transformation in the Arctic and are attracting an increasing amount of interest in the Arctic from parties such as shipping, oil and gas exploration, commercial fishing and tourism that are likely to not only transform but also challenge the governance of the Arctic region (Young 2012a). This investigation of maritime fuel is intimately connected to the broader energy, as well as maritime, governance structures.

Although most of the causes of climate change are almost entirely outside of the Arctic region, the Arctic is nonetheless, certainly on the front line of experiencing the dramatic impacts that are a result of climate change (Young 2012a). While the Arctic once aroused little interest on the world stage, in light of recent development, it now is attracting a rapidly increasing amount of both political and economic attention from the international community (Young 2012a). The emergence of this increased interest and associated activities pose not only numerous economic and geopolitical opportunities for the Arctic region, but also the potential for dire environmental and social consequences if the risks from this mounting interest in the development of the Arctic region is not carefully managed going forward. Therefore, shipping related activities and the manner in which they are conducted are central to the future of the Arctic.

Enticements such as reduced transit times and access to natural recourses is leading to increased interest in commercial shipping activities taking place in the Arctic. The prospect of increased shipping taking place in the Arctic heightens concerns related to environmental issues such as invasive species dispersal by ballast water, wildlife displacement, oil pollution, and air pollution (Ghosh & Rubly 2015).

The use of heavy fuel oil, the extremely viscous, high density residual fuel resulting from the crude oil refining process, poses a number of concerns for the Arctic region such as the threat of spills and the discharging of harmful emissions (Prior & Walsh 2018). The risks associated with heavy fuel oil are intensified in the Arctic due to the environmental conditions in the region. In addition to the disastrous prospect of a spill in icy conditions, the extreme cold temperatures of Arctic waters prevent highly viscous heavy fuel oil from naturally dispersing or degrading (Roy & Comer 2017). In extremely cold Arctic waters, high-density heavy fuel oil can sink and then resurface during warmer periods, thus washing ashore long after surface cleanup efforts have ceased (Roy & Comer 2017).

The combustion of heavy fuel oil produces high levels of air pollution and greenhouse gas (GHG) emissions such as sulphur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM), and the PM constituent black carbon (BC), which pose the risk of accelerating climate change within the Arctic region (Cavazos-Guerra et al. 2017; Sun 2019). Due to the risks associated with the use of heavy fuel oil, particularly in view of the prospect of increased shipping activities in the region, stakeholders such as the Arctic Council and the IMO have proposed a ban on the use and carriage of heavy fuel oil in the Arctic, similar to the ban currently in place for the Antarctic (Bennett et al. 2015; Han 2018).

LNG has gained increasing attention as a potential alternative to heavy fuel oil for the Arctic region (Zhang et al. 2019). In comparison to heavy fuel oil, the utilization of LNG as a maritime fuel offers significant reductions of SO_x, NO_x, and PM emissions and due to LNG being less dense than water and lighter than air, LNG floats and evaporates quickly, thus negating the need for land or water cleanup operations in the event of a spill in Arctic waters (Kumar et al. 2011; Peterson & Weisend 2019). As the prospect of increased shipping activity taking place in the Arctic hastens the call for an alternative to heavy fuel oil and as interest in LNG as a maritime fuel in the region grows, research such as this study will be useful to governance actors of the region.

NGOs have the potential to play an extraordinary part in the governance of the Arctic. Although environmental NGOs such as Greenpeace have struggled with low levels of support in the Arctic, particularly in Greenland, due to past endeavors such as anti-whaling efforts, they now have the ability to organize the population of the region and to also act as monitors of the regional oil and gas resource development, and therefore increase their influence and play an critical role in the governance of the Arctic region (Smits et al. 2014).

Another aspect that makes the governance of the Arctic region unique and interesting is the relationship between Denmark and Greenland. For instance, while Denmark officially holds a membership seat on the Arctic Council, it is Greenland, who established Self-Government in 2009, that is actually the most active participant of the two when it comes to the Arctic Council, with Denmark usually supporting and following Greenland's position on most issues (Smits et al. 2014). However, the increased utilization of their natural resources, particularly those of the oil and gas sector, is seen by many as a means for Greenland to become financially independent and will certainly play a factor in the governance of Greenland and the Arctic region in the future (Smits et al. 2014).

2.5.4 Arctic Shipping

A key aspect of the Arctic that is attracting increased international attention is the potential for increased utilization of Arctic shipping lanes. Future estimates indicate that the reduction of Arctic ice cap will open up new areas and increase the viability of the region to be increasingly used for international shipping (Liu & Kronbak 2010). According to Sakhuja (2014), the two most practical Arctic shipping routes are the Northern Sea Route and the Northwest Passage. Via the Arctic, large bulk carriers can significantly reduce the distance between Asia, Europe, and North America by navigating the Northern Sea Route or the Northwest Passage and the increased melting of Arctic sea ice poses the potential for an expanded navigation season along the routes (Hong 2012a).

Running between the Atlantic and Pacific along the Russian coast, the Northern Sea Route ranges between 2100 and 2900 nautical miles depending on the distribution of sea ice and the Northern Sea Route is part of the shortest connection between Northeast Asia and Northern Europe (Liu & Kronbak 2010). Examples presented by Hong (2012a) of the potential reductions in sailing distances afforded by the Arctic routes include the sailing distance of a voyage between Rotterdam and Yokohama via the Northern Sea Route instead of the Suez Canal being reduced by 40 percent and the sailing distance of a voyage between Rotterdam and Seattle via the Northwest Passage instead of the Panama Canal being reduced by 25 percent.

The prospect of increased shipping activity along Arctic routes also presents a collection of concerns and considerations that must be addressed. Ho (2010) lists increased infrastructure investments and the establishment of expanded maritime services focused on safety and environmental responsibility throughout the region, as steps that are necessary before the Arctic sea routes can be reliably used on a large scale due to the complexities of navigation in hazardous waters of the Arctic region. Cooperative stakeholders such as the IMO and the Arctic Council advocate for strategic and tactical undertakings to mitigate the environmental and safety risks associated with increased maritime activity in the Arctic region (Ho 2010). Current regulations concerning Arctic maritime activity include the legally binding 2013 Cooperation on Marine Pollution Preparedness and Response in the Arctic agreement signed by the Arctic Council, as well as IMO proposals such as the International Code of Safety for Ships Operations in Polar Waters, known as the Polar Code (Mileski et al. 2018; Roach 2018). Liu and Kronbak (2010) discuss various construction and equipment standards such as hull thickness and structural support requirements that are necessary for ships to be qualified as an ice class vessel. Certainly these issues will be taken into consideration among others factors by the maritime community and determine how quickly the utilization of Arctic sea routes increases in the future.

2.5.4.1 Polar Code

As the interest in Arctic development activities increases, particularly the prospect of substantially increased shipping activity taking place in the Arctic, the need for specialized compulsory shipping regulations that address the unique challenges and concerns related to the Arctic becomes ever more essential. In recognition of the complicated challenges the Arctic region faces due to the increased interest in Arctic shipping, the IMO has initiated the development of a mandatory international code of safety for ships that operate in Arctic waters, which would compliment guidelines and regulations that are already in place (Jabour 2014).

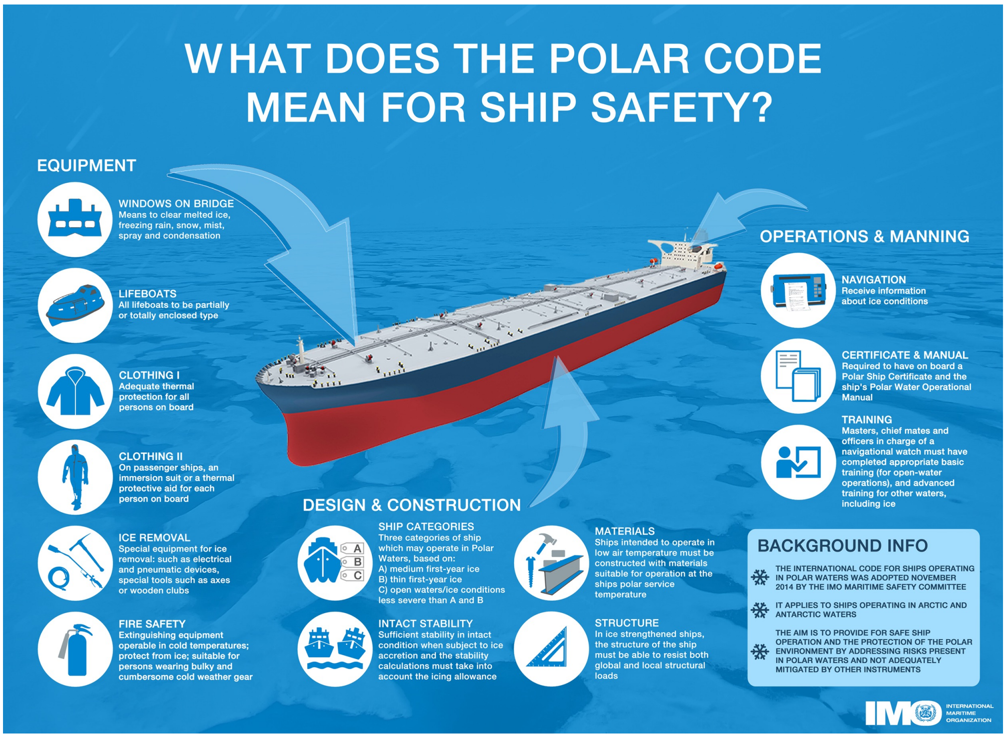

Figure 2.1. Safety Requirements of the Polar Code (IMO 2019)

As Figure 2.1 illustrates, the Polar Code will address such issues as vessel design, construction and equipment, search and rescue procedures, training and environmental protection and will focus on specific risks associated with operating in Arctic waters (Hartsig et al. 2012). The establishment of this code will play a crucial role in the future development of the Arctic region.

2.6. Research Implications

Among the three topics discussed above there exists a common trend of evolution and transition. Both of the intergovernmental agencies reviewed are facing changing dynamics in the landscape of global energy governance, and how well each agency is able to successfully evolve and adapt in response to these changes will determine if their level of relevance is maintained, increased or diminished.

As mentioned, ASEAN must find a way to overcome long existing concerns regarding sovereignty in order to develop a more formalized system of regulations that allows for the delegation of authority. Similarly, the IEA must find a way to better engage non-member countries, particularly developing nations and emerging economies if it wishes to sustain its position of relevance in the governance of energy. In order for the IEA to be able to sufficiently engage and collaborate with current non-member countries, it will have to seriously reconsider OECD membership prerequisites that have been in existence since its founding.

Stakeholders in the Arctic region are facing a tremendous amount of change and uncertainty. How well Arctic stakeholders address and react to these changes in the immediate future will have long lasting outcomes for not only the Arctic region but essentially the greater world as well. Before the level of Arctic development and activity significantly accelerate, it is imperative that stakeholders act with due diligence by carrying out necessary actions such as impact assessments and environmental studies well in advance.

Before stakeholders can engage in a significantly increased level of Arctic development and activity such as shipping and energy projects, further scientific studies related to the effects of climate change taking place in the Arctic, such as changing ice conditions, must be carried out and thoroughly analyzed. Any prudent development plans and related investment decisions concerning the Arctic will depend on reliable and accurate predictions regarding the nature and severity of the impacts of climate change on the region. A more in-depth review of the work of scientific experts related to the impact of climate change in the Arctic is required to gain a more detailed understanding of how these changes will affect the desirability and feasibility of increased development in the region.

An additional analysis of the geopolitical issues facing the Arctic region needs to be conducted to gain a more complete understanding of the issues that current and potential stakeholders engaged in Arctic development activity face. For instance, Liu and Kronbak (2010) list ice-breaking fees charged by Russia to ships navigating the Northern Sea Route as among the factors that most influence the economic viability of using the route. Such ice-breaking services would be relied up regardless of the type of fuel a ship utilized. Recent increased geopolitical tensions involving Russia could slightly factor into the level of fees Russia charges for ice-breaking services, and directly influence the economic viability and attractiveness of the Northern Sea Route. This example of Russian provided ice-breaking services and the influence of contemporary geopolitical frictions demonstrates how political dynamics as well as economic and physical elements influence Arctic development activities (Drewniak et al. 2018; Schneider 2018).

The nature of the Arctic region presents a unique set of challenges that stakeholders much face when engaging in development within the region. How well the different stakeholders cooperate and coordinate their efforts to address these challenges will play a large role in determining the success of efforts to increase development in the Arctic. Kao et al. (2012) point to the 2011 signing of the Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic, as representing an example of Arctic states reacting to these challenges. A lack of infrastructure, extreme weather conditions, ice and remoteness, make petroleum development activities exceptionally challenging and thus the risk of oil spills is of particular concern in the Arctic region (Knol & Arbo 2014). The bilateral oil spill response established by Norway and Russia is an example of an effective system of Arctic states cooperating to address concerns of petroleum development related risks in the region (Sydnes & Sydnes 2013).

Continued cooperation efforts will have to take place not only among Arctic states but also among non-Arctic state stakeholders, such as international shipping organizations, as the level of development taking place in the Arctic increases. An advanced understanding of the concerns and interest of these different stakeholders and how they will influence their willingness and ability to cooperate with other stakeholders in addressing the challenges presented by increased development in the Arctic is needed to be able to explore the potential for large scale growth of development projects to proceed in the region.

CHAPTER 3: BACKGROUND OF ENERGY TRANSITIONS

3.1. Introduction

The following chapter will examine important aspects of previous major energy transitions. The contribution of this examination will be to identify and outline key factors and dynamics of historic energy transitions in preparation for undertaking the CBA in chapter 5 and then discussing its broader implications in chapter 6. An enhanced understanding of significant factors of past energy transitions will assist in the identifications and analysis of dynamics associated with current and future transitions, such as the one from oil-based fuels to LNG for maritime transportation in the Arctic region. It is important to specify that this chapter is not looking at causes and effects of energy transitions but rather context surrounding energy transitions.

In order to better analyze the transition away from traditional oil-based fuels to the utilization of LNG for maritime transport and the consequent implications of the transition for the Artic region, it is prudent to first examine significant historic energy transitions. By investigating past energy transitions, not just for transportation but also for the collective use of energy, we can develop an understanding of the underlying forces that serve to shape and influence energy transitions. Examining aspects such as the social, political, geographic and economic features that have both prompted and resulted from earlier energy transitions, can allow us to begin to develop an enhanced understanding of the current situation that the transition from oil-based maritime fuels to LNG is taking place in at present. Knowledge derived from previous energy transitions can assist us in addressing challenges confronting the transition to LNG as well as being able to identify potential opportunities for the ultimate success of the transition. Examining previous energy transitions also provides an idea of the overall context in which an assessment of costs and benefits is made, which is important in answering the three research questions of this study identified earlier.

This examination of preceding energy transitions seeks to provide a historical background of major energy transitions and explore the societal forces that led to their realization as well as the ramifications and implementations that resulted from these transitions. This background analysis aims to look at not only historic energy transitions that have taken place related to maritime transportation, but to form concentric circles that highlight notable transitions in the overall ways humans have utilized energy throughout history and from there shift the focus of the investigation toward a consideration of issues specifically related to energy transitions in maritime transportation. The study anticipates achieving a clearer understanding of the dynamics facing imminent energy transitions, particularly factors associated with a transition toward LNG becoming a prominent fuel utilized for maritime transportation in the Arctic region.

The broader overview of this background analysis will investigate the energy transitions that took place with the emergence of coal as a dominant source of energy, and then the transition from coal to the utilization of oil as the dominant energy source. Concerning energy transitions specifically associated with maritime transportation, the analysis will focus on the transitions from wind powered sailing vessels, to coal powered steamships, and eventually to the utilization of oil-based fuels prominently utilized for maritime transportation today.

Throughout each notable energy transition there have been unique influential factors that have shaped each transition. Additionally, each transition reveals trends that point to characteristics that offer lessons for experts and policy makers researching future transitions. For instance Grubler (2012) states that the initiation of the next energy transition requires balance in innovation, along with the alignment, persistence and continuity of policies. Solomon and Krishna (2011) contend that the depletion of resource supplies, cost concerns, pollution issues, innovation, and efficiency improvements are among the interrelated factors that may potentially incite a transition from the use of one source of energy to another. Allen (2012) maintains that characteristics from the first transition to coal, such as that the transition was slow to take place, that it was driven by prices, the requirement of new technologies, that it was dependent on human capital, scientific progress and cooperation are still enlightening for those interested in future energy transitions. Furthermore based on lessons of the past, Allen (2012) also contends that as a result of the severity of climate related concerns, planning and coordination are necessary for increasing the speed of future transitions as well as a means of avoiding previously encountered difficulties.

It is important to point out that the structure of the following sections is not a methodological tool or framework, but as mentioned in chapter 1, is intended to reflect the setting in which this research was conducted, which was in a school of geography and sustainable development that supports a broad range of interdisciplinary research across numerous disciplines, such as geography, political science, and economics.

3.2. The Emergence of Coal

The transition to coal from energy sources such as wood, water and wind power is among the most notable energy transitions in history. Driven by factors such as increases in populations and incomes, this transition first accelerated in Britain where it helped facilitate and coincided with the industrial revolution and the advancement of the steam engine (Madureira 2012). This transition eventually progressed to influence maritime transportation. Although steam powered ships had been in use since the early nineteenth century, until the 1880's most steam ships where in fact hybrid ships that featured steam propulsion along with sails (Dijk et al. 2015). Interestingly, the emergence of steamships actually spurred numerous improvements in sailing ship technology such as enhanced masts, sails and mechanized rigging as a result of sailing ships becoming increasingly vulnerable to competition from steamships, thus the phrase "sailing ship effect" today reflects a situation in which incumbent firms are threatened by new technologies (Geels 2005). Major factors according to Geels and Schot (2007) that eventually led to steamships surpassing sailing ships between 1870 and 1890, include the creation by the British government in 1838 of a subsidized market niche for mail carrying steamships, increased demand for trans-Atlantic passenger service starting in the 1840's that was being driven by mass emigration, and the opening of the Suez Canal in 1869 which sailing ships were unable to use.

As with all energy transitions, numerous key factors stimulated the extraordinary transition from predominately organic sources of energy to the widespread utilization of coal. Among these key factors are a collection of technological innovations, as well as social and cultural factors that played a vital role in ushering in the transition of coal becoming the primary source of energy that is unequivocally linked with the industrial revolution.

3.2.1 Technologies and Innovations

As the eighteenth century approached and on the eve of the impending Industrial Revolution, coal began to emerge as a substitute and replacement for the organic energy resources that had been previously utilized by mankind. This transition was characterized by numerous technical advancements and innovations that changed the way energy was used as well as the sources employed. Perhaps the most notable innovation of this era, and certainly one that resulted in widespread and long lasting influences throughout the era of the industrial revolution as well as the future was that of the steam engine. Although humankind had long been aware of the power of steam, several factors combined to see the use and development of steam engines begin to accelerate in eighteenth century Britain. The strategic use of steam engines to pump water from mines, coupled with the availability of abundant amounts of affordable fuel in the form of the coal extracted from the mines of Britain, led to the profitable development of Thomas Newcomen's 1712 steam engine as well as the subsequent improvements by a collection of distinguished engineers and innovators such as James Watt, Richard Trevithick and John Smeaton. This combination of a strong demand for a service that required vast amounts of energy combined with the plentiful availability of an affordable supply of an energy resource was instrumental in initiating the energy transition towards coal that characterized the era surrounding the industrial revolution. Due to these corresponding factors, as the steam engine increased the demand for coal, it also simultaneously made the extraction of the resource more practical. From this nucleus of innovation, steam engine technology would go on to have a tremendous impact on numerous industrial sectors for years to come (Allen 2012).

The development of the steam engine and associated industrial adoption of coal as an energy source was far from the only example of innovative changes that resulted in the increased use of coal. Allen (2012) notes that even prior to the emergence of the steam engine in the eighteenth century that the primary use of coal in the seventeenth century was for domestic heating, which was made possible by innovations in the way houses were designed which required implementations such as newly designed chimneys that were suitable for burning coal, and points to estimates by Flinn (1984, pp252-3) of over half of Britain's net coal consumption in 1700 being devoted to domestic heating. This previous adoption of coal by household consumers was surely further solidified by the subsequent uptake of coal as an energy source by industrial consumers.

As steam engines spurred the increased extraction of coal, other industries began to utilize coal as a result of additional innovations and technical advancements. Madureira (2012) lists iron industry innovations such as coal-fueled blast furnaces and puddling ironworks among the many drivers of British coal extraction. These industrial innovations and advancements, which were fueled by coal, would go on to shape the industrial revolution and initiate remarkable changes, not only in Britain but throughout the rest of the world as well.

Innovations of the era related to coal also played a role in developing lighting to illuminate homes, businesses and streets in many urban areas. Gas consisting of a mixture of gases such as hydrogen, carbon monoxide, and methane was able to be produced from coal and used to generate lighting and offered a substitute for candles and lamps that burned oils such as whale oil (Dodds & McDowall 2013). Notable innovators such as William Murdoch, Philip Lebon and Albrecht Winzer were visionaries who in the late eighteenth century and early nineteenth century helped expand the use of gas produced from coal for the purpose of lighting (Rutter & Keirstead 2012).

Clearly, technology and innovation were extremely important factors of the energy transition associated with the emergence of coal as the predominant energy source. These technical developments and innovations connected with the utilization of coal sparked tremendous changes throughout the world that would see industrial development accelerate to previously unimaginable heights. As these growing industries continued to spread throughout the world, the technical advancements behind it would continue to drive the prominence of coal to fuel the intensifying development taking place. The technical and innovative advancements of the era where also intertwined with numerous social and cultural factors that also played an extremely critical role in prompting the transition to coal. A closer examination of the way these assorted factors combined to influence the emergence of coal as the primary energy source provide interesting insights that are useful in an analysis of subsequent energy transitions.

3.2.2 Social and Cultural

Many social and cultural factors played an important role in cultivating the energy transition to coal as well as the accompanying Industrial Revolution. Pathania and Bose (2014) list legal developments such as the evolution of intellectual property rights during the seventeenth and eighteenth centuries as serving as a major facilitator in the development of technological advancements of the era, thus allowing the development of such technologies to be better able to attract private financing from investors, and points to acts such as the 1710 Copyright Law as examples of such efforts to place an increased importance on intellectual property rights. This emerging emphasis on the recognition and respect for intellectual property helped encourage and incentivize innovators and their investors to develop the numerous technological advancements mentioned above that are associated with the energy transition to coal as well as the Industrial Revolution. In addition to these legal developments, the transition from organic energy sources to coal was also connected to many other social and cultural issues, including economic, political and geographic concerns. Several of these social and cultural topics associated with the energy transition to coal are discussed in the following sections.

3.2.2.1 Economic

The energy transition from organic sources to the emergence of coal as the primary energy resource is surrounded by several economic factors. Some of the economic factors associated with the transition to coal can be considered drivers of the transition, since the presence of these economic factors precedes the transition and served to influence the commencement of the transition. A notable economic issue associated with the transition to coal, and one that helps explain one of the reasons that this transition initially took place primarily in Britain is that of wage rate levels. Allen (2012) notes that preceding the industrial revolution wages in Britain were high in four senses: in comparison to other countries; in relation to the cost of living; relative to capital goods; and relative to the price of energy, and contended that these high wages were able to be sustained in the long run by the cheap energy provided in the form of coal. Allen (2012) also contends that the high British wages created a demand for technologies that could serve as a substitute and that this combination of high wage rates for labor and the presence of cheap, plentiful coal helped to facilitate the industrial revolution being launched in Britain. Furthermore, Allen (2015) argues that in the eighteenth century Britain enjoyed a substantially high standard of living in comparison to the rest of the world, that both prior to the industrial revolution and also as it progressed, that the wage rates paid to British workers were among the highest in the world, and that technical and innovative introductions of the era such as mechanized factories were developed in order to substitute among other things, inexpensive energy for expensive labor.

3.2.2.2 Political

The transition to coal being adopted as a primary energy source also divulges significant political factors. Some interesting political issues related to the energy transition to coal involve matters concerning environmental policy and regulation aimed at addressing pollution linked to the consumption of coal. The transition to coal resulted in severe levels of air pollution in urban Britain during the nineteenth century, which were characterized by thick levels of fog that hung over cities and the resulting high levels of respiratory illness among the population were such a detriment to society that the government was eventually compelled to take regulatory action (Fouquet 2011). Legislative actions such as the Sanitary Act of 1866, the Public Health Act of 1875 and the Public Health (London) Act of 1891 were examples of pollution mitigation policies of the period, although in reality all suffered from weak enforcement and leniency in regards to compliance (Fouquet 2011). Douglas et al. (2002), while discussing air pollution problems present in nineteenth century Manchester note that it was difficult for abatement efforts aimed at combating air pollution from the burning of coal to attract public support and that the prevailing view of a large part of the public was that having to endure the ill effects of air pollution resulting from the consumption of coal was simply a required trade-off that was necessary for the economic progress that industrialization afforded. Many earnest abatement efforts aimed at combating the problem of smoke pollution stemming from the use of coal, such as the passing of local legislation, the appointment of inspectors and the implementation of fines for violators in nineteenth century Manchester were hampered not only by views and perceptions that were decidedly concerned with maintaining industrial growth but also by an absence of adequate abatement technologies at the time (Bowler & Brimblecombe 2000).

As this analysis shows, although concerns over environmental issues such as air pollution during this era did not halt the utilization of coal, these concerns certainly shaped the way in which coal was utilized. As the harmful effects of pollution associated with the large-scale use of coal became progressively understood, the need for adequate policies to address the issue increased. Despite these regulatory efforts often being met with considerable resistance, over time, the political pressure of the need to address environmental issues associated with the use of coal would eventually prove to be an important driver of the subsequent energy transition. It evident that even in the early stages of this transition, the environmental problems related to coal utilization could be considered as an indicator that coal would have long-term limitations. Likewise, these early efforts at addressing pollution resulting from the use of coal are an indication of how the challenge of addressing environmental concerns while at the same time supporting industrial development and economic growth would continue to serve as a driver of energy transitions. The long reliance on coal during this era, in large part due to a focus on economic growth, despite the severe manifestation of negative impacts offers lessons for the future, as we become increasingly more aware of the impacts of energy use.

3.2.2.3 Geographic

The energy transition to coal and the corresponding industrial revolution were marked by several geographic characteristics in Britain where the transition to coal and the industrial revolution first took place and also throughout the world as well. The economic geography of England during the industrial revolution saw changes to employment that mainly resulted from migration to condensed centers of industrial activity located in the North from agricultural areas (Trew 2014). Approaches to industrial pollution in the nineteenth century often were more concerned with containment and as a result, heavily polluting industrial activities were concentrated in specific localities in what tended to be working-class areas, therefore the presence of industrial pollution in the countryside and more expensive middle class suburbs was drastically less (Fouquet 2012a). Due to the industrial revolution and the corresponding growth in population, by the middle of the nineteenth century Britain was increasingly dependent on trade and therefore was required to sustain an international trading system (Clark et al. 2014). This dependence on international trade saw Britain’s influence throughout the world expand tremendously.

The transition to coal during the industrial revolution also had implications on the landscape such as forestlands, which had previously been a crucial source of fuel. As coke began to replace charcoal in the iron industry the reliance on timber acreage as a source of energy was significantly reduced. Not only did the use of coke by the iron industry in Britain release the industry from its previous dependence on timber, it also allowed the industry to reach new levels of growth previously unlikely. Steinmueller (2013) estimates that the British iron industry would not have been able to maintain the growing demand for iron and steel during the nineteenth century through the exclusive use of timber as an energy resource.

3.2.3 Transport

As with other applications of energy, the transition from organic sources of energy to the prominence of coal had a profound impact on the transportation sector. Among the most revolutionary developments related to the transition to coal and the associated advancements in steam technology is that of rail travel. Much like other notable milestones of the emergence of coal becoming a predominately utilized energy source, this development first materialized in Britain. Aydin & Dzhaleva-Chonkova (2013) point to the Liverpool and Manchester Railway, which opened in 1830 and is considered the first inter-city passenger service using steam locomotives in the world, and mentioned the contributions of early railway innovators such as George Stephenson as playing a crucial role in the development of early railway advancements. George Stephenson's locomotive named Rocket served as a prototype for all steam locomotives to follow, and his design was instrumental in the establishment of the first inter-city steam powered railway for passenger use (Smith & Zhou 2014). In addition to the contributions to early steam rail travel delivered by George Stephenson, his son Robert also played a fundamental role in the initial development of early railway in Britain during the nineteenth century (Smith & Zhou 2014). Innovations in railways began to spread from their British birthplace to cover most of Western and Central Europe by the 1850's and by the middle of the 1870's even most of Eastern Europe saw the presence of a railway system (Grubler 1996).

3.2.3.1 Maritime Specific

During the late eighteenth and early nineteenth century the steam engine began to revolutionize maritime transportation as coal fueled steam technology began to replace traditional sailing ships. This transformation in maritime transport was spurred by the work of innovators such as John Fitch, Robert Fulton, and Henry Bell.

Emerging innovations in steamship technology offered several advantages over sailing ships, which as Geels (2002) notes had long been inundated with problems such as uncertainty and a lack of planning ability in regards to journey completion times, which had a particular impact on overseas commerce. The emergence of steamship technology enabled overseas shipping to be less beholden to such natural phenomenon as wind and currents, thus allowing for more flexible and predictable voyage options than could be previously utilized merely with the existing sailing ship technology. The British naval officer and Arctic explorer Sir John Ross laid out the revolutionary advantages that the emergent steam technology offered from a naval perspective and also expounded on the ways in which embracing steamship technology could revolutionize naval warfare strategy, as well as warning of the prospect of Britain's naval superiority ceding to rivals that more effectively employ steamship innovations, in his 1828 work entitled *A Treatise on Navigation by Steam* (Hore 2000).

3.3. The Emergence of Oil

As developments in the exploration, extraction, and utilization of petroleum began to emerge in the late nineteenth and early twentieth centuries, products derived from oil began to be employed for an increasing number of uses. These uses included not only acting as an energy resource utilized by emerging technologies and advancements of the era, but also as a substitute for existing energy resources such as coal. From kerosene utilized for lighting, to gasoline and diesel consumed as motor fuel used for transportation and industrial purposes, petroleum and its derived products began to emerge as increasingly relied upon sources of energy in the late nineteenth and early twentieth centuries.

Just as with the earlier transition from organic sources of energy to coal was incited by notable key factors, so too did the transition from coal to petroleum involve significant innovative technological advancements as well as social and cultural issues that served as factors that facilitated the transition. An examination of these key factors helps provide a better understanding of the energy transition that saw petroleum become the most predominantly utilized source of energy.

3.3.1 Technologies & Innovations

In the late nineteenth century several technical innovations and engineering advancements led to petroleum beginning to be ushered in as a replacement for coal. Solomon and Krishna (2011) point to technical advancements developed by innovators such as Nicolaus Otto the developer of what is considered the first practical four-stroke internal combustion engine, Karl Benz the developer and builder of what is credited with being the first practical internal combustion powered automobile and Rudolf Diesel who in 1892 patented the diesel engine, as well as numerous others, as developments that helped revolutionize the ways in which energy was utilized and consumed. Although other inventors such as Emil Capitaine and Akroyd Stuart had previous internal combustion engine designs, Diesel's design which used compression ignition proved to be the most impactful (Griffiths 1995). These technical innovations triggered transformations that would see the importance of petroleum increase throughout the twentieth century and eclipse or replace coal in many sectors.

As mentioned previously, one of the earliest uses of petroleum as an energy source was for illumination in the form of kerosene being utilized for lighting. Prior to the utilization of kerosene as a fuel for illumination, lighting was provided by a variety of other sources, including whale oil. A whale oil shortage crisis in the Unites States during the 1850's, which was brought about by the depletion of the whale population as a result of overly intense whaling, coincided with early developments in kerosene refining which provided fuel for illumination purposes, thus allowing kerosene to serve as a substitute for increasingly scarce whale oil (Pathania & Bose 2014). The increased use of kerosene as a fuel employed for illumination led to the increased importance of oil as an energy source and was among the earliest emphases of the evolving petroleum industry. During the first 40 years of the development of the petroleum industry, kerosene production for the purposes of illumination was the primary focus of the industry, rather than motor fuels such as gasoline (Hall & Ramírez-Pascuall 2013).

3.3.2 Social and Cultural

Just as the previous energy transition to coal was characterized by numerous social and cultural issues, so too was the energy transition that commenced during the early twentieth century surrounded by notable social and cultural issues that not only helped foster and shape the energy transition to petroleum, but also many social and cultural changes that were a result of the transition taking place. Over the course of the twentieth century and beyond, the social and cultural issues associated with the energy transition towards petroleum becoming the predominately relied upon source of energy would see the importance of oil proliferate to play an enormous role in everyday life of the modern world.

3.3.2.1 Economic

As the energy transition to petroleum becoming the most vital energy source began to unfold during the twentieth century, oil began to play an increasingly important role in global economics. In addition to the crucial role that oil played during World War II, following the war, developed nations became increasingly dependent upon petroleum products for the facilitation of such vital needs as transportation, power generation and manufacturing (Cherp & Jewell 2011). The heightened importance of oil led to a situation in which the economies of developed nations were increasingly reliant upon a mostly imported supply of oil, while the economies of petroleum exporting countries were increasingly dependent upon revenues derived from oil exports (Cherp & Jewell 2011).

3.3.2.2 Political

The emergence of petroleum as a vitally strategic energy source has profoundly effected global politics, the results of which very much influence current worldwide political conditions. Among the most notable events in the history of how petroleum has shaped global politics, is the conversion of the British naval fleet from a coal utilizing steam powered fleet to an oil-powered fleet. Shortly before World War I, then First Lord of the Admiralty Winston Churchill strategically decided to transform the British Royal Navy to utilize oil instead of coal in an effort to reap improvements such as speed (Below 2013). Churchill was also extremely aware that as a consequence of this strategic decision, that the capabilities of the British military would thus be dependent on a resource unlike coal which was available domestically, but instead on one that was located in other countries, and in this case the British turned primarily to Persia to secure a supply of the vital resource (Below 2013). British involvement in the petroleum reserves located in Persia, later known as Iran, dates back to the dawn of the twentieth century. The obtainment by William Knox D'Arcy in 1901 of an exclusive sixty year concession for the exploration of oil in Iran, led to the subsequent establishment of the Anglo Persian Oil company of which in 1914 the British government obtained a 51% interest in, which would later be renamed the Anglo Iranian Oil Company in 1935, which was a predecessor of what would eventually become known as British Petroleum in 1954 (Abdelrehim et al. 2012). Although through the Middle Eastern oil reserves, Britain had found a source of petroleum to supply its energy needs, the long-term ramifications of doing so would be felt for decades to come.

During the period of time between the two World Wars, the reliance on oil and access to supplies of the resource would play a major role in shaping the balance of power throughout the world. The Unites States started to convert its naval fleet to utilize oil in an effort to increase the speed and range of the fleet, but unlike Britain, which was compelled to look beyond its own shores to secure a petroleum supply, the United States was fortunate to be in possession of an adequate domestic supply of oil to rely on in order to meet its growing energy needs (Painter 2012). Despite the existence of a domestic supply of petroleum, Venn (2012) points out that as a means to address concerns at the time regarding predictions of shortages in the future, the United States Government began to promote a policy that endorsed exploration abroad, which was characterized by American oil companies being encouraged to pursue petroleum resources located in foreign countries. The United States and Britain's pursuit of foreign petroleum resources led to the nations engaging in both competition and cooperation that continued from before, during and after World War II and through policies such as the Lend-Lease agreement the two countries worked together through a series of intense negotiations that ultimately helped achieve victory in the war but also saw the United States significantly increase its influence in the oil abundant region of the Middle East (Venn 2012).

3.3.2.3 Geographic

As mentioned above, the emergence of petroleum as a strategically vital energy resource resulted in widespread global political ramifications, and this emergence also manifests itself in numerous important geographic consequences as well. Among the most notable of the geographic transformations occurred in the vast oil resource rich Middle East. Following the collapse of the Ottoman Empire after World War I, social and political disruption befell the inhabitants of Arabia and the Levant as previously existing political and social entities were transformed or overthrown as foreign actors attracted to the resources of the region such as Britain and France competed alongside local actors for influence (Toth 2012). In the case of Saudi Arabia, the subsequent exploitation and development of the country's petroleum resources provided the eventual ruling entity that emerged from the chaos that followed the collapse of the Ottoman Empire, with a source of income that allowed it to maintain and expand its level of distinct influence and power (Toth 2012).

As the use of automobiles powered by petroleum derived fuels became more practical and increased in prevalence, this form of transportation began to have a significant impact on the landscape in the form of infrastructure development and urban sprawl resulting in noticeable impacts on the lives of the population. Over the years, the automobile and associated infrastructure have grown to dominate substantial portions of urban space and have had a significant impact on issues ranging from deaths and injuries to livelihoods (Lutz 2014). Acts such as the Federal Aid Highway Act of 1956 which created the Highway Trust Fund to finance construction through gasoline taxes, were milestones that drastically led to reshaping the landscape of the United States by expanding and cultivating the system of roadways throughout America (Weber 2012). As a result of the dramatic increase in automobile use, urban areas started to increasingly become designed and adapted for accessibility of the automobile, and thus everyday social and cultural activities also started to be increasingly influenced by automobile use (Fouquet (2012b).

3.3.3 Transport

In the early twentieth century, innovations and technical advancements such as those mentioned above led to the emergence of the automobile. The rise of the automobile would not only have tremendous implications for transport, but would also have tremendous cultural and social implications as well. The Ford Model T, which was produced in the United States, and the Volkswagen Beetle, which was produced in Germany starting in 1938 were examples of affordable automobiles that helped make the prospect of car ownership more accessible to the public in the years following World War I (Acharya et al. 2013). Although automobiles had previously been affordable only to the wealthy, by utilizing the concepts of assembly lines and interchangeable parts, Ford was able to produce an affordable automobile that could be obtained by members of the middle class, and with over 15 millions units of the model produced between the years of 1908 and 1927, the Model T played an important role in the increase of automobile ownership in the United States (Foellmi et al. 2014). The revolution in transportation brought about by the rise of the automobile would serve to see the importance of petroleum as an energy source increase substantially.

The early twentieth century also saw another revolution in a form of transportation that depended on petroleum for fuel, in the development of the airplane. Beginning with the first successful flight by the Wright brothers in 1903, the airplane would continue to be developed over the century. Schmitt and Gollnick (2016) list Charles Lindbergh's direct transatlantic solo flight in 1927 between New York and Paris, engineering advancements during World War II, and the dawning of the jet age as notable milestones in the development of aviation during the twentieth century.

By the middle of the twentieth century, petroleum would begin to usher out coal as the dominant fuel source for railway transport, for which the coal fueled steam engine first made possible. After the 1950's developments in technology facilitated the rapid replacement of steam-powered locomotives with diesel powered train engines, eventually leading to the diesel-electric designs predominately in use today (Dincer et al. 2016).

3.3.3.1 Maritime Specific

At the dawning of the twentieth century, the potential of petroleum powered maritime transportation began to attract growing attention. A century after inventor Rudolf Diesel patented his revolutionary compression ignition engine in 1892; his design would be the predominant engine type powering the world's merchant vessels

(Griffiths 1995). As mentioned earlier, petroleum offered several advantages over coal as a fuel for maritime transportation. Although engineers and innovators had been experimenting with the potential of petroleum as a maritime transportation fuel since around the turn of the twentieth century, significant advancements began to take place in the quest for naval improvements in the years prior to World War I. Naval strategists of the era began to view the utilization of petroleum as a fuel that could offer naval fleets advantages such as improvements in speed, a more practical refueling procedure, and a considerable reduction in weight that would thus allow for the installation of increased protective armor as well as additional armaments (Hugill 2014). The transition to oil assisted the United States in being able to enhance its naval power in the Pacific as a result of being able to utilize oil reserves located in California as opposed to coal which was required to be shipped from supply sources located in distant regions due to the type of coal found in the western United States being regarded as unsuitable for use in steamship engines (Painter 2012).

Another noteworthy advantage that transitioning to oil from coal offered naval fleets was a significant reduction in the number of crewmembers required to perform the fueling and related maintenance duties associated with the operation of ship engines. For instance, Goldrick (2014) notes that the reduction in manpower that petroleum fueled ships offered in comparison to coal-fueled vessels was a substantial advantage, considering that ships which relied on coal required crewmembers to perform critical functions such as feeding coal into the furnaces, removing ash and residue, and transferring coal between different bunkers, and that as a consequence around half of the onboard crew of a coal dependent vessel consisted of engineering related personnel. Obviously, such a significant reduction in required manpower combined with the other advantages made the transition from coal to oil an attractive strategy not only for planners concerned with naval applications but also for commercial maritime functions as well.

The transition to oil also allowed for noteworthy changes and advancements in ship design to take place. As Goldrick (2014) mentions advantages of oil over coal such as the storage of oil requiring less space inside of a ship, oil being more practical to transfer among storage areas by being easily pumped between tanks, the ability of oil tanks to utilize more of their capacity than coal bunkers could, and a reduction of maintenance concerns as details that allowed for changes and improvements in the way ships were designed as a result of the utilization of petroleum as opposed to coal.

3.4 Beyond Oil (Toward A Sustainable Future)

Throughout the twentieth century, as the world's demand for energy increased and as new technologies were developed and implemented, additional sources of energy began to play an increasingly important role in meeting global energy needs. Even as energy derived from fossil fuels such as petroleum and coal remained crucial for supplying global energy demand, technical advancements and innovation led to non fossil fuel derived forms of energy supplying an increasingly significant role in fulfilling the world's energy demands. Among the more noteworthy alternatives to fossil fuel derived energy sources currently playing an impactful role in global energy supply are nuclear, wind, and solar energy.

A principle role of nuclear and renewable energy is that of electrical power generation. According to Nuclear Energy Institute (2016), as of July 2015 there were a total of 438 nuclear reactors throughout the world generating electrical power. The Nuclear Energy Institute (2016) also states that in 2012 the proportion of world electricity production provided by nuclear power plants was equal to 10.9 percent. According to BP's Statistical Review of World Energy (2018), in the year 2017, renewable power generation provided over 8 percent of global electricity. Figures such as these are indicative of the increasingly important role that nuclear and renewable energy sources serve in the modern world.

Although alternatives to fossil fuels such as nuclear and renewable energy have been utilized for electricity generation purposes, other sectors, such as domestic heating and transportation have remained dominated by fossil fuels. In the United Kingdom for example, gas continues to be the dominant fuel source for domestic heating, accounting for over 80% of energy consumption for the sector (Connor et al. 2015). Kranzl et al. (2013) note that the promotion of renewable technologies for the heating sector has been hindered in the past by energy polices that have been overly focused on energy efficiency. Despite this comparatively slow uptake, renewable sources such as solar thermal, heat pumps, and biomass systems have shown increasing potential as alternative solutions for the domestic heating sector in recent years (Connor et al. 2015).

Similar to the example of domestic heating, the transportation sector has also remained dominated by a reliance on fossil fuels. Aside from a few exceptions such as nuclear icebreakers and naval vessels, fossil fuels, primarily in the form of petroleum products, have traditionally been the dominant energy source for roadway, aviation and maritime transportation (Statoil 2015). Thus, finding long-term sustainable solutions for supplying the energy needs of the transportation sector remains a crucial challenge for researchers, innovators and policy makers.

3.4.1 Technologies and Innovations

Among the numerous technologies and innovations that developed over the twentieth century related to nuclear and renewable energy, several designs would eventually become the most prevalent and widely used technologies in practice. Nuclear reactor design has evolved since the mid twentieth century and can be divided into four generations, with first generation reactors consisting of early prototype designs, second generation designs being mostly light water commercial reactors, third generation reactors being the contemporary evolution of light water reactors, and fourth generation designs being those that are currently under development and hoped to be utilized by the year 2030 and beyond (Locatelli et al. 2013). Generation four nuclear systems are intended to provide substantial environmental, economic and safety advantages over the generation three nuclear systems that are currently in use (Abram & Ion 2008). In 2001 the Generation IV International Forum was founded as an international organization for the purpose of directing the technological development of generation four nuclear systems (Locatelli et al. 2013).

Although individual nuclear power plants can differ in terms of design characteristics and features, most reactor types share an assortment of common components such as fuel, moderator, control rods, coolant, reactor vessel, steam generator, and containment structure (Kessides 2012). Nuclear reactors can also be differentiated as being heavy water reactors that use water that contains deuterium as a coolant and moderator, as opposed to light water reactors, which instead use pure water (Hultman 2011). The two light water third generation reactor designs, which account for the two most prominent reactor designs currently in operation in the United States, are General Electric's boiling water reactor and Westinghouse's pressurized water reactor (Hultman 2011). Although in both boiling water reactors and pressurized water reactors, heat is generated from an internal core and steam is used to turn a turbine generator to produce electricity, according to the United States Nuclear Regulatory Commission (2016), the two types of reactor designs differ in that a boiling water reactor actually boils the water that is heated, while a pressurized water reactor heats water under high pressure but does not actually boil the water.

Implementing the utilization of renewable energy technologies is viewed as a means of reducing the environmental impacts of energy systems as well as reducing national and regional dependency on conventional fossil fuel based forms of energy (Negro et al. 2012). Sources of renewable energy such as wind, solar, and hydropower are among the prominent types of renewable energy currently utilized for electrical power generation that are predicted to play an increasingly important role in supplying the energy needs of consumers in the future (Ellabban et al. 2014). Renewable energy technology, particularly solar is especially promising for communities who do not have access to conventional electricity grids, and off-grid renewable technologies have been promoted as a means for providing electricity in rural communities and developing nations (Kebede & Mitsufuji 2017).

3.4.2 Social and Cultural

As nuclear energy technology developed and began to be adopted over the second half of the twentieth century, numerous social and cultural ramifications were associated with the utilization of nuclear energy. From 1965 to 2014, world energy consumption increased from 3,728.04 to 12,928.40 million tonnes of oil equivalent (BP 2015). As the demand for energy throughout the world increased, nuclear energy would prove to be a much debated and controversial technology. Particular social and cultural factors would lead to the extent to which nuclear energy was embraced and utilized varying greatly throughout different areas of the world.

Despite advancements in meeting the energy needs of the world, there remains a substantial amount of individuals, particularly in in developing nations and remote locations that do not have adequate access to dependable and reliable sources of modern energy. Urmee and Md (2016) point to over one billion people not having access to electricity and over three billion people having to rely on highly polluting sources of fuel such as charcoal, dung or kerosene for cooking as examples of situations in which renewable energy can serve to improve the quality of life, alleviate poverty and provide increased living standards. By providing developing nations and remote communities with increased access to reliable modern energy services, renewable energy can play a significant role in the advancement of both economic and social development in the future (Kaygusuz 2012).

3.4.2.1 Economic

Among the important factors associated with ongoing debates regarding the adoption of nuclear energy are economic factors, particularly issues related to cost and financing of nuclear plant construction projects. According to Kessides (2012), capital requirements connected to the planning and construction of a new nuclear facility, operational costs related to running and maintaining a nuclear plant, the cost of fuel required for a nuclear plant, back end costs connected to such activities as waste disposal and decommissioning, are the four principal nuclear power cost components. Nuclear energy projects such as the Watts Bar-2 site in the United States and the Olkiluoto site in Finland are examples of nuclear power projects that have been fraught with costly problems such as construction delays and costs drastically exceeding estimates (Mez 2012). Hultman (2011) lists reducing costs in comparison to other alternatives as a key challenge facing nuclear energy technical innovation. How successful future innovations and advancements in nuclear energy are at alleviating previously encountered difficulties related to costs will play an imperative factor in determining the role that nuclear power plays in supplying global energy in years to come.

Energy security, job growth, reduced environmental damages, and poverty reduction are among the economic policy objectives related to renewable energy technology development according to Edenhofer et al. (2013). Contemporary renewable energy projects tend to suffer from high investment costs and as a result are often supported by substantial state subsidies (Khatib & Difiglio 2016). Energy researchers such as Kaygusuz (2012) contend that perceptions surrounding cost barriers to renewable energy technologies in comparison to conventional fossil fuels can be overcome by examining the true cost of emissions and related externalities associated with status quo technologies. By taking into account the costs of externalities, decision makers can make a more informed economic comparison of different energy solution options.

Externalities are impacts that are borne by third parties who are not directly involved in the production or consumption of a good or service (Boardman et al. 2017). Examples of externalities associated with different forms of energy include air pollution from the combustion of fossil fuels, noise and the disruption of scenery from wind turbines, and risks related to long-term storage of radioactive waste from nuclear energy (Sheldon et al. 2015; Droes & Koster 2016; Rentschler & Morgan 2017). Since these externalities are often not reflected in the price of the good or product, in this case the energy source, they are often borne by society in the form of a reduced quality of life, medical expenses, damages to nature, or increased insurance premiums among other costs (Corona et al. 2016). In order to quantify these non-market environmental impacts, environmental economists utilize stated preference valuation methods such as contingent valuation and choice experiments, as well as revealed preference valuation methods such as travel costs and hedonic values (Tietenberg & Lewis 2018).

Notable examples in which environmental valuation methods were utilized by economists include in the aftermaths of both the historic *Exxon Valdez* oil spill in 1989 and the BP *Deepwater Horizon* oil rig disaster of 2010 (Kling et al. 2012). Environmental valuation methods enable a monetary value to be placed on environmental impacts thus allowing CBA to be utilized as a tool in decision-making processes such as project or policy appraisal (Annema & Koopmans 2015). Research tools such as CBA can serve as useful instruments for policy makers responsible for decisions related to energy transitions, such as making comparisons between renewable energy technologies and conventional fossil fuel based systems.

3.4.2.2 Political

Since it's earliest days of pioneering advancements and throughout its development during the later half of the twentieth century and beyond, nuclear energy has been a particularly contentious political subject. Certainly, previous notable events related to nuclear energy have had tremendous influence on not only public perception regarding nuclear energy, but have also shaped policy associated with nuclear energy in differing regions throughout the world as well. Attitudes, perceptions and reactions to notable events concerning nuclear energy have combined with factors such as specific energy needs and capabilities of respective regions to determine the level to which nuclear energy systems have been adopted and implemented throughout the world.

Among the infamous historic events associated with nuclear are the disasters that occurred at Chernobyl in Ukraine, Three Mile Island in the United States, and Fukushima in Japan. These disasters, and their influence on public perception regarding nuclear energy have played a significant role in shaping modern energy policy throughout the world. Wittneben (2012) states that issues such as the differences in media coverage, election cycle timing, and previous attitudes and perceptions led to very different responses and reactions from Germany and the United Kingdom in the aftermath of the Japanese Fukushima disaster in 2011, with the United Kingdom remaining committed to future increases of nuclear power, while Germany demonstrated a much more reactionary response, characterized by temporarily shutting down older nuclear reactors, reassessing the safety of the nations nuclear facilities and with concerns as well as negative sentiments towards nuclear energy markedly increasing with the German public.

The way in which nuclear energy is perceived to provide certain benefits in comparison to other energy alternatives is influential in how nuclear energy is accepted and adopted. For instance, Teravainen et al. (2011) state that in Finland, France and the United Kingdom nuclear energy is depicted as an energy security strategy and as an option for addressing problems related to climate change, while concerns regarding negative issues such as accidents and nuclear waste have managed to be overshadowed to an extent, and as such, each country is currently committed to increasing their already significant utilization of nuclear energy. Conversely, Huenteler et al. (2012) mention that Germany has recently strengthened its national commitment to renewables and in conjunction with policies such as the German Renewable Energy Act, has significantly increased the percentage of electricity produced from renewables as opposed to nuclear energy, and argue that Germany can actually serve as an example for Japan to emulate as a means to increase electricity production derived from renewables thus reducing their reliance on nuclear energy, post Fukushima.

Despite the recent German commitment to renewables, policies such a the German Renewable Energy Act have still encountered political opposition, demonstrating that much like nuclear energy, renewable energy developments also face challenges of a political nature. For example, the German Renewable Energy Act and subsequent amendments faced opposition from factions such as large utilities, industries, the Ministry of Economic Affairs and political parties (Lauber & Jacobsson 2016). Stokes (2013) contends that policy makers must carefully consider the politics surrounding not only the enactment stage, but also the implementation stage of renewable energy projects in order for strategies to be able to remain viable over the extended period of time required for a successful transition.

3.4.2.3 Geographic

As alluded to earlier, different regions and countries are engaged in varying levels of nuclear energy utilization. According to the Nuclear Energy Institute (2016) with 798.6 billion kilowatt-hours produced in 2014, accounting for 19.5 percent of total national electricity generation, the United States is the nation with the most nuclear generation. While the United States generated the most electrical power from nuclear energy in terms of total kilowatt-hours, France generated 418 billion kilowatt-hours of electricity from nuclear in 2014, which accounted for 76.9 percent of the nation's total electricity production, making France the nation with the largest percentage of total electricity production provided by nuclear energy and the nation with the second highest level of nuclear electrical generation in terms of total kilowatt-hours produced (Nuclear Energy Institute 2016). In addition to the United States and France, the other countries in the top ten of nuclear electricity production in terms of kilowatt-hours generated in 2014 were, Russia, South Korea, China, Canada, Germany, Ukraine, Sweden, and the United Kingdom respectively (Nuclear Energy Institute 2016).

Renewable energy is not as geographically constrained as fossil fuel energy sources, and although the extent to which different countries are endowed with sources of renewable energy varies, every country has access at least some variety of renewable energy (Scholten & Bosman 2016). How different countries are able to utilize various forms of renewable energy is illustrated by observing the rankings of top countries in terms of renewable energy power capacity for different renewable energy technologies. For example, according to the International Renewable Energy Agency (IRENA), in 2017 the top three countries in terms of solar energy capacity were China, Japan, and the United States, while the top three countries in terms of wind energy capacity were China, the United States, and Germany (IRENA 2018).

3.4.3 Transport

Problems related to the transportation sector such as congestion and environmental issues such as emissions have driven efforts towards sustainable transport. In regards to land based transportation, there are many contemporary strategies and approaches towards sustainability. For instance, Shiau (2012) mentions the three approaches utilized by Taipei City that involve the promotion of clean energy such as biofuels, natural gas, and electric powered vehicles, mode shifting from private to public transportation, and improved land use planning. Strategies such as these represent a few examples of recent approaches aimed at improving the sustainability of the land based transportation sector.

Hybrid and electric vehicles have shown the ability to increase fuel economy and reduce environmental impacts related to personal transportation and are forecast to make up a growing part of future automobile fleets in countries such as the United States (Al-Alawi & Bradley 2013). Electric powered buses have been successfully utilized in locations such as London in efforts to reduce the environmental impact of land based public transportation (Miles & Potter 2014). In addition to electric powered vehicles, natural gas based alternative fuels such as compressed natural gas (CNG) and liquefied petroleum gas (LPG) have been successfully utilized in public transport and commercial vehicle fleets (Windecker & Ruder 2013). These examples illustrate how efforts to reduce harmful environmental impacts, combined with innovation and technology are transforming the transportation sector.

3.4.3.1 Maritime Specific

Beginning in the very early stages of nuclear technological development, the prospect of using nuclear energy for the purpose of maritime transportation was examined. For example, the United States Navy directed much of the early research related to nuclear technology (Hultman 2011). Pressurized water reactors where initially designed in connection with the Unites States Navy, for the purpose of powering submarine propulsion in an effort to increase the amount of time it was possible for a submarine to remain submerged without refueling, and in 1955 the world's first nuclear powered submarine, the USS *Nautilus* was launched (Oka et al. 2014).

Following the pioneering developments of nuclear powered submarine applications, the use of nuclear powered maritime propulsion expanded to also be utilized by surface vessels and has since been adopted in such a capacity not only by major naval fleets throughout the world, but also for such applications as icebreaker vessels, the first of which was put into service by the USSR in 1959 (Hirdaris et al. 2014). Russian nuclear icebreakers operating along the Northern Sea Route serve a crucial role in the economic development of the Arctic, and nuclear icebreakers have the important advantage over diesel petroleum powered icebreakers by being able to operate over significantly longer periods of time without the need for refueling (Bukharin 2006).

Applying renewable and other alternative energy technologies for use in maritime transportation is more challenging than doing so with land based transportation scenarios. Despite the challenges of developing alternative energy sources suitable for maritime transportation, emerging innovations are being utilized for maritime applications. The suitability of existing alternative technologies for maritime transportation applications varies depending on characteristics such as vessel size, area of operation and purpose of use. Small Norwegian automobile and passenger ferries that operate on electrical power are an example presented by Vogler and Sattler (2016) of a successful application of alternative energy for maritime transport applications. The use of hydrogen based technology as a source of alternative energy for the maritime sector has generated a substantial amount of interest recently, but faces challenges to large scale implementation such as infrastructure, production and distribution difficulties, among other impediments (Bicer & Dincer 2018). The concept of hydrogen technology being utilized by the maritime sector will be discussed in more detail in a subsequent section of this study.

3.5. Role of CBA in Facilitating Energy Transition

This examination of historic energy transitions reveals the potential role for CBA in facilitating future energy transitions. As noted early in this chapter, according to Grubler (2012) the initiation of future energy transitions will require not only innovation and persistence but also a continuity of policy. Contemporary problems such as the risks of climate change necessitate that future energy transitions are accelerated, which will require careful planning and coordination in order to avoid obstacles and difficulties encountered by previous transitions (Allen 2012). These requirements point to the usefulness of decision-making tools such as CBA in making decisions on projects and policies related to future energy transitions. The quest for a sustainable future and the development of contemporary renewable energy projects highlights the role that CBA can play in facilitating energy transitions. Through the use of CBA and the examination of externalities associated with different choices, policy makers can make better decisions based on a clearer understanding of the true cost of energy options. The CBA process described and demonstrated in the following chapters is an illustration of how this decision making tool can be used to facilitate energy transitions.

3.6. Conclusions

Historic energy transitions provide many lessons that can serve as useful examples for policy makers facing the challenges of future energy transitions such as the transition towards LNG. Lessons from the transition from organic sources of energy to coal demonstrate the importance of sound environmental policy and regulation with effective enforcement and compliance mechanisms that are administered in a fair and just manner. Likewise, it is important to gain and maintain public support for environmental regulations and policies and it is critical that the public is made aware of not only the reasons why such policies are needed but also helped to understand the negative ramifications that will result from a failure to act. A challenge for policy makers is to find a way to communicate with and inform the public that economic growth and prosperity can coincide with effective policies and regulations in order to combat the mindset that undesirable environmental outcomes are a necessary trade off for economic success. By working to successfully communicate and demonstrate to the public how sound policies can provide positive benefits and assist strategies designed to avoid or minimize detrimental outcomes, while simultaneously allowing for economic growth and prosperity, policy makers can combat the often-encountered mindset that negative environmental outcomes must simply be endured in order to advance economic development. Research findings such as the results of the CBA conducted by this study can help policy makers effectively communicate issues related to future energy transitions to the public.

Past energy transitions also point to the important role that technology plays in facilitating future energy transitions. The development and refinement of adequate and effective innovations, such as abetment technologies are crucial for the success of future energy transitions. Just as innovations and design improvements allowed for the increase in the intensity and scope of different sources of energy to be utilized in the past, so too can new and developing technologies enable alternative ways in which energy needs are provided for and thus expedite future energy transitions. As the utilization of certain sources of energy become more practical and useful as the result of innovations and technical advancements, future energy transitions can be accelerated. Research tools such as CBA can help to demonstrate the potential benefits of emerging technological innovations and serve to greatly facilitate their implementation.

Due to the unique challenges facing the world today, technology and innovation are even more important now than in the past. In order for energy transitions that will adequately address issues such as increased energy demand, climate change and environmental protection to take place, novel advancements in technology and innovation will be required. Due to the urgency of the need to address current problems associated with climate change and the effects of pollution, the speed at which technical advancements to address these issues develop is also a much more crucial issue today than in past eras. Policies and strategies that encourage and facilitate the development of such technical innovations will be a key component for timely and successful energy transactions.

An analysis of previous energy transitions points to the ability of energy transitions to act as an instrument of economic development and growth. Future energy transitions, offer the possibility, just as past transitions have, to remove barriers and limits to economic growth. By offering the potential to free energy users form existing constraints related to energy use and dependence on particular sources, future energy transitions can provide new alternatives and prospects to society that can have meaningful global impacts for the future, not only in economic terms but also in political and social outcomes as well.

Historically, trade has played an integral role in past energy transitions, as it surely will in future energy transitions (Pascali 2017; Sharmina et al. 2017). Similarly, international trade is a fundamental aspect of the transition towards LNG as a maritime propulsion fuel, particularly within the Arctic region, where the prospect of potential increases in trade and related development activity taking place within the region present the potential for significant impacts not only for the Arctic region but also well beyond. Specific trade agreements between nations will have considerable influence on how future energy transitions unfold. Trade agreements and the needs and objectives of their respective signatory nations will significantly influence the level to which different sources of energy are embraced and utilized for specific purposes by different countries, as well as the degree to which different countries are willing to collaborate and coordinate in the implementation and enforcement of future environmental policies.

Just as effective communication with the public has long been vital to the success of environmental policies and regulations connected to energy transitions, so too is public perception critical to how energy transitions evolve (van der Schoor & Scholtens 2015). The message related to an energy transition, and how the public processes such information, has a significant influence on the development and success of an energy transition. Sovacool and Brossmann (2014) point to the importance of an effective rhetoric campaign, in determining the success of an energy transition and point to past instances such as the way in which the early nuclear industry was able to successfully appeal to the public's preconceived notions of modern progress as examples. This illustrates some of the numerous challenges faced by policy makers tasked with ensuring that future energy transitions are successful. Once again, this highlights the importance of research such as the results of the CBA of this study in in being able to provide the public with worthwhile information regarding issues surrounding the prospect of future energy transitions.

In the following chapter the study will introduce CBA and illustrate the steps involved in conducting such an analysis. The prospect of a transition to LNG taking place within the Arctic region will then be analyzed following the CBA process along with data from selected secondary sources. Through the use of CBA, the study will attempt to determine if society will be better or worse off as a result of adopting LNG as a maritime transportation fuel in the Arctic region. Based on the criteria of the CBA process, the study will endeavor to determine if the transition to LNG as a maritime fuel in the Arctic should be accepted or rejected.

CHAPTER 4: RESEARCH METHODOLOGY

4.1. Ontology and epistemology

The study has elected to take a critical realist stance. A critical realism perspective offers an interesting opportunity to think about the positivist aspects of the study. As Zachariadis et al. (2010) asserted critical realism could be viewed as a middle ground between positivism and interpretivism. Thus critical realism affords a position that is concerned with knowledge that can be derived from that which is observed and experienced as well as beyond that which is easily observable. A critical realist stance also lends itself to the use and rationale of interdisciplinary research. Of the numerous approaches to quantitative methods in interdisciplinary research, several are particularly pertinent for this study. Perhaps the most relevant of these is what Bryman (2008) states as diversity of views, in which a researcher seeks to gather qualitative data that will provide them the perspectives of those that they are studying, as well as investigating a specific set of issues through the use of quantitative data. Therefore through a critical realist stance the study can address the research questions from both the perspectives of the researcher as well as those that are being studied.

The study will incorporate aspects of empiricism and positivism by focusing on that which can be experienced and determined objectively. Through the use of quantitative methods and techniques the study will objectively address the research questions. Through a positivist position, the study will be concerned with knowledge that is derived from that which can be easily observed or experienced by the researcher as opposed to that which is derived from gaining an understanding of the personal feeling of research respondents and subjects. From an empiricism and positivism position, the study will address the research questions and gain knowledge from the perspective of the researcher. Thus from this position the results will solely be expressed from the point of view of the researcher as opposed to those of subjects or research participants. It should be noted, that initially mixed methods were considered for this study but in consideration of limited resources, principally time and money, it was ultimately decided to utilize only CBA for this investigation. However, the utilization of mixed methods would be a desirable approach for future research.

4.2. Research Design

4.2.1 Research Questions

RQ1) What are the benefits of the transition to LNG for shipping in the Arctic region?

The transition toward liquefied natural gas (LNG) becoming the prominent fuel used for maritime shipping will have a number of benefits. These benefits will be manifest in the form of environmental impacts that will be experienced by a wide selection of stakeholders. From an environmental standpoint, the transition to LNG has the potential to result in some positive environmental outcomes, such as diminished pollution levels, decreased risks of environmental disasters and mitigated climate changes consequences.

For the purpose of this study, the benefits will be the abatement of NO_x, SO_x, and PM achieved by electing to utilize LNG as a fuel source as opposed to the status quo option of heavy fuel oil utilization, by a vessel operating in the Arctic region. The motivation for selecting the abatement of NO_x, SO_x, and PM is based on these three pollutants being the focus of IMO emissions regulations that driving a transition away from heavy fuel oil use in the maritime sector (IMO 2015). Likewise, based on this motivation other impacts that could potentially be considered benefits of a transition to LNG such as reduced risk of oil spills, or savings on fuel expenditures are not included in this analysis. An investigation including these potential impacts would warrant a complex and complicated separate study that is beyond the scope and means of this analysis. While these potential impacts are worthy of future research projects, the three pollutants targeted by recent IMO regulations will be the focus of the benefits analyzed in this study.

RQ2) What are the costs of the transition to LNG for shipping in the Arctic region?

The maritime industry will be confronted with substantial economic costs due to the transition as investments in technology and equipment will be required to conform and adapt, particularly in the early stages of the transition. For the purposes of this study, the costs of the transition to LNG will be additional cost of construction for a new vessel that must be incurred as a result of electing to utilize LNG as a fuel source instead of maintaining the status quo option of heavy fuel oil utilization. This being the most immediate and inescapable cost involved with a transition to LNG was the motivation for the focus on this cost and the exclusion of other potential costs. While shipping companies will pay this additional cost of construction, it is likely that companies will react by shifting these costs to customers, as has been the case with increased costs associated with compliant low-sulphur oil based fuels (EIA 2019) in the past.

RQ3) Are the benefits of the transition to LNG for shipping in the Arctic region greater than the costs?

If the benefits of the transition to LNG for shipping in the Arctic region are greater than the costs, then it can be deemed that the transition should be adopted. If the benefits of the transition to LNG for shipping in the Arctic region are determined to be greater than the costs, it would therefore be concluded that society will be better off as a result of adopting the transition, than it would be should the transition not be adopted and the heavy fuel oil status quo maintained.

4.2.2 Why select a case study approach?

By selecting a case study approach, the study will be able to focus on one specific situation and to concentrate on gaining an enhanced understanding of the particular case from numerous perspectives. By selecting and contemplating a particular case, the study will be able to analyze a realistic situation as opposed to immaterial or theoretical issues. By incorporating a case study approach, the study will be able to determine tangible understandings of genuine conditions related to an actual problem. Thus, utilizing a case study approach will result in the study generating practical and tangible findings that will be of realistic use to an actual case. Although selecting a case study approach will prevent the use of generalization, this is not particularly of concern for the study due to its primary concern with the specific and unique situation of interest.

4.2.3 Case Study

The case study for this research is the transition away from heavy oil based fuels used for maritime transportation towards the utilization of LNG as a replacement. Current and forthcoming International Maritime Organization (IMO) environmental regulations such as fuel sulphur content limits, nitrogen oxide emissions limits, and the creation of Emissions Control Areas in which stricter emissions regulations will be implemented are prompting a transition away from the highly polluting heavy oil based fuels traditionally used for maritime transport towards a cleaner burning and more environmentally responsible alternative. Among the practical available alternatives such as scrubber systems, which are discussed in more detail in chapter 6, LNG is emerging as a preferred option due to several characteristics that give the fuel certain advantages in comparison to that of other alternatives (Cullinane & Cullinane 2013; Panasiuk & Turkina 2015; Lindstad & Eskeland 2016). A timeframe for the case study will be the lifespan of a vessel, which will be assumed to span a 25-year period of time.

4.3. Case Background and Selection

This study will focus on the Arctic region due to the unique opportunity the Arctic region presents as an environmentally important yet sensitive area that has experienced relatively low levels of previous development but has recently attracted a tremendous amount of attention for possible future development activity, particularly related to maritime activity. As was noted in chapter 2, due to occurrences such as polar amplification, the impacts of climate change are exceptionally severe and already exhibited in the Arctic region (Anisimov et al 2007; Crepin et al. 2017). As an extremely environmentally sensitive area that is experiencing tremendous amounts of change, the environmental related implications of a transition toward LNG as a replacement for heavy-fuel oil are of critical importance for the Arctic region (Sun 2019). While the impacts of maritime pollution and efforts to mitigate its damaging effects are of supreme concern for the global community as a whole, the Arctic region is particularly susceptible to the damaging effects of maritime pollution (Zhang et al. 2019). The effects of pollution and climate change are already having a profound impact on the Arctic and additional development and industrial activity will surely further strain and impact the region (Ho 2010).

Due to the unique characteristics of the Arctic region, alternative strategies and options that might be feasible in other areas may not be practical or desirable in the Arctic region (Lack & Corbett 2012; Panasiuk & Turkina 2015). The sensitive nature of the Arctic requires that special attention be given to any strategic development planning taking place in the region and presents a unique set of challenges for those involved in the process (Solvang et al. 2018). The Arctic region also presents an opportunity to develop best practice strategies and benchmarks (Ghosh & Rubly 2015; Fedi et al. 2018). By carefully planning development strategies suitable for the complex and sensitive Arctic region, other regions throughout the world stand to benefit from the potential adoption of practices and strategies similar to those utilized in Arctic development (Bennett et al. 2015).

Of particular interest to the study are the Arctic sea routes and related coastal areas that are gaining increasing levels of interest, as they become a more attractive alternative for maritime transport (Buixade Farre et al. 2014). As these Arctic sea routes attract more maritime traffic and become a more utilized option for shipping companies, coastal developments and infrastructure enhancements along the routes will be required to support the increased shipping traffic (Solvang et al. 2018). This demand for new infrastructure and development in areas where there has previously been little or none, presents a unique situation to analyze. The increased interest and demand for new development along Arctic sea routes through an environmentally sensitive region make the Arctic an ideal area of which to study the transition toward LNG replacing heavy-fuel oil as a maritime fuel.

Another aspect of the Arctic region that makes it an ideal area to study the transition toward LNG as maritime transportation fuel is the unique and complex governance character of the Arctic region. The Arctic as a region has long been the site of disagreement among the regions' states over territorial boundaries and ownership (Lajeunesse 2016). Although these territorial confusions and disagreements have long been an issue of debate, a comparatively low level of interest in the region has prevented the disagreements from becoming a highly contested matter among the concerned states in the past (Geddert 2019). However, the increased interest in development activity within the Arctic region has caused the territorial disagreements to become an issue of amplified concerned for the involved states (Guy & Lasserre 2016). This complex backdrop, coupled with the already prominent function that maritime law performs in Arctic governance, make the Arctic an ideal region to analyze the transition toward LNG as a maritime fuel (Xu et al 2015; Bartenstein 2019).

4.3.1 Shipping Stakeholders

Of the numerous stakeholders involved in the transition to LNG becoming the prominent maritime fuel, among the most involved and impacted would certainly be vessel owning and operating companies. Within the focus area of the Arctic region, there are a diverse collection of shipping companies that vary in characteristics ranging from their function, the type of vessels employed, to certain specialties and niche services provided.

An approximated 6,000 individual vessels conducted operations in the Arctic region during 2004, representing a varied range of vessel types including, container ships, fishing vessels, tankers, and cruise ships among others (Arctic Council 2009). As Figure 4.1 illustrates, Arctic sea routes utilized by vessels include the Northern Sea Route running along the northern coastline of Russia, the Northwest Passage along the northern coastlines of Alaska and Canada, and the Transpolar Route bisecting the Arctic via the North Pole (Buixade Farre et al. 2014; De Silva et al. 2015). Projections such as the number of ice-free days per year along the Northern Sea Route increasing from a current 120 to 100 days per year by 2080, point to an increase in Arctic navigational traffic in the future (Ghosh & Rubly 2015; Stevenson et al. 2019).

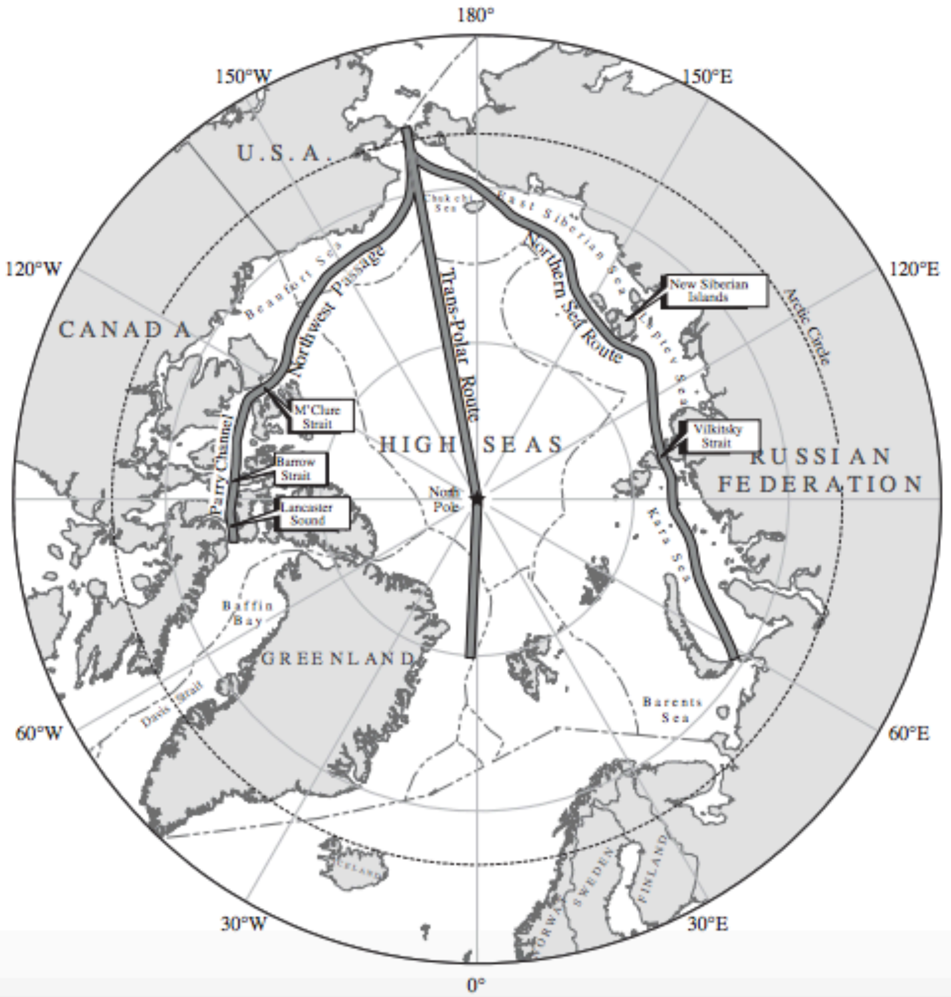

Figure 4.1. Arctic Sea Routes (Buixade Farre et al. 2014)

The extreme physical characteristics of the Arctic lead to shipping activities within the region being rather unique in comparison to maritime activity elsewhere in the world. An overview of a collection of some prominent types of shipping companies and their respective endeavors in the Arctic region is an important step in gaining an understanding of the ramifications of the transition towards LNG from the perspectives of a major stakeholder group. The variety of companies engaged in Arctic shipping range from large conglomerates such as Maersk to private owned regional operators such as Coastal Shipping Limited headquartered in Goose Bay Canada (Lasserre 2014; Pelletier & Guy 2015). The following overview of a selection of firms is provided as a paradigmatic sample of shipping companies currently active in the Arctic region.

Of the shipping firms active in the Arctic, some companies' principal area of operation is primarily within the Arctic and the surrounding far northern regions. One such company is Nunavut Eastern Arctic Shipping Inc. According the company's website, Nunavut Eastern Arctic Shipping Inc. provides cargo and supply services to the Arctic with a fleet of multi-purpose container vessels and supporting equipment (NEAS 2015). Headquartered in Iqaluit, Canada and a majority Inuit owned company, Nunavut Eastern Arctic Shipping not only offers a unique insight into Arctic maritime activities, but also a view into the development and cultural landscape of the Arctic region.

An example of companies operating specialty vessels designed for a specific purpose in Arctic waters are seismic data acquisition vessels such as those operated by London based WesternGeco which is a segment of the global oil field services company Schlumberger. According to the company's website, their new Amazon-class seismic data acquisition vessel was designed to Polar-Class 7 specifications with the aim of enhanced capabilities of conducting seismic research operations in the Arctic region (WesternGeco 2015). An investigation of this type of vessel owning firm can offer an interesting insight into not only maritime operations taking place in the Arctic, but also the future of development interest throughout the region, particularly related to the exploration of Arctic natural resources.

An example of a large international shipping firm operating heavily within the Arctic region is the Canadian shipping company Fednav. Headquartered in Montreal, with European offices based in London, Fednav has a significant presence in Arctic maritime operations. According to the company's website, Fednav has the words largest fleet of ice-class bulk carriers with which they connect the Great Lakes and Canadian Arctic with markets throughout the world (Fednav 2015). As a large international company with a history of expertise concerning Arctic maritime operations, Fednav can provide useful insight into maritime and development activities in the Arctic, from not only that of an individual firm, but from a regional and global perspective as well.

Another example of an international shipping company active in the Arctic region is Eimskipafélag Íslands, which is headquartered in Reykjavík, Iceland. According to the firm's website, Eimskipafélag Íslands, commonly referred to as Eimskip, is

Iceland's oldest shipping company and has offices in eighteen locations throughout the world, including the United Kingdom (Eimskip 2015). With such a long history of operating in and around Arctic waters, and with such an extensive international presence Eimskip can provide a unique perspective into maritime operations in the Arctic region.

Another interesting example of shipping stakeholders active in the Arctic region is the Greenlandic company Royal Arctic Line which is headquartered in the capital city of Nuuk. According to the company's website, Royal Arctic Line is owned by the government of Greenland and provides shipping services to and from Greenland with a fleet of 10 vessels specially designed for Arctic operations (Royal Arctic Line 2015). As a wholly government owned firm, Royal Arctic Line can not only provide the study with the perspective of a shipping firm, but a also the opportunity to examine a governmental perspective related to LNG being utilized as a maritime fuel.

By examining organizations involved in Arctic maritime operations such as the vessel owning firms mentioned above, an understanding of the perceptions and attitudes from the firm level regarding a transition towards LNG replacing heavy fuel oils as the primary fuel used for maritime transportation can begin to be developed. These examples of shipping companies also illustrate the relevance of such firms in terms of Arctic governance, as well as their importance to a transition to LNG as a maritime fuel within the region.

4.3.2 Non-shipping Stakeholders

In addition to shipping companies operating within Arctic waters such as the ones mentioned above that are able to provide perspectives from firm level organizations, the study will also analyze non-shipping stakeholder organizations at other levels in order to consider their perspectives on the transition towards LNG as a maritime fuel for the Arctic. For the purposes of this study, organizations at the country/regional level as well as the regulatory level will be examined in order to address the research questions.

By examining stakeholders at the country/regional level the study will be able to analyze the perspectives and attitudes of Arctic stakeholders that are actually located with the Arctic region regarding the transition towards LNG becoming the prominent maritime fuel. Investigating the perspectives of stakeholders whose organizations are engaged in Arctic governance at the country/regional level will help provide an insight into the perspectives and attitudes of the numerous Arctic actors that they represent.

An example of an organization engaged in Arctic governance at the country/regional level of which an examination could provide insight into the perspectives and attitudes of stakeholders located within the Arctic region concerning the transition to LNG, as a maritime fuel would be the Arctic Council. As an important actor in Arctic governance that represents both the citizens of Arctic states and indigenous peoples of the region, the Arctic Council can provide keen insight into the perspectives and attitudes that the residents of the Arctic have regarding the transition towards LNG being utilized as a maritime fuel. Therefore, a consideration of the Arctic Council as a means of gaining an understanding of the perspectives of the transition toward LNG at the country/regional level will greatly facilitate the study in addressing the research questions.

In addition to the non-ship owing actors at the country/regional level, it is also of interest to examine stakeholders at the regulatory level as well. Stakeholders and organizations that can be considered to be at the regulatory level can provide the chance to offer the perspectives and attitudes from yet another level, but to also provide insight form a more encompassing and far-reaching scope of influence than merely the firm or country/regional level. An analysis of a stakeholder at the regulatory level can provide a broader view of the perspectives regarding the transition towards LNG as a maritime fuel than that of the firm level or country/regional level, which will add to the degree of understanding concerning the wider implementations of the transition for collective stakeholders.

Perhaps the most prominent actor at the regulatory level involved in the transition is the IMO. Therefore, analyzing the IMO can provide an excellent opportunity to gain the perspective of a wide reaching stakeholder organization at the regulatory level in order to assist the study in addressing the research questions.

Developing an understanding of the perspectives and attitudes of Arctic stakeholders through a review of existing research prior to conducting the CBA, enables the study to better approach the energy transition from a societal view and context. Analyzing the prospect of a transition to LNG taking place in the Arctic region in this manner aligns with the principal objective of environmental CBA, which is to determine if society will be better or worse off as a result of a project or policy being selected.

4.4. Sources of data collection

4.4.1 Documents

The study will utilize a variety of documentation for the purposes of carrying out the necessary analysis to address the research questions. For the purposes of analyzing environmental impacts, previous environmental assessment reports and studies from sources such as governments and corporations will be reviewed and utilized. Secondary data is often utilized in CBA when time or budgetary constraints deem an original valuation study impractical (Atkinson et al. 2018). Existing data and related documents pertaining to the environmental impact of previous maritime and Arctic related development activities will be gathered and analyzed. Scientific data related to current impacts of shipping emissions as well as future projections derived from sources such as government and industry studies will be assembled and examined. Copies of certain documentation concerning relevant regulatory and legal matters will need to be obtained and evaluated for analysis.

For the purposes of the CBA, data and information from previous studies concerning the costs to shipping companies of building new vessels that are capable of utilizing LNG will be evaluated. In addition to previous studies, information related to Arctic shipping activities such as fleet sizes, vessel types, and emissions generation will be sought out and utilized when available. Various types of shipping and maritime industry related data such as construction costs estimates and emissions inventories will also be highly useful in addressing the research questions.

Documentation concerning IMO regulations will be of particular importance for the study. Not only will documentation on existing IMO regulations need to be reviewed but also documentation pertaining to the development of future regulations related to the research questions will also need to be reviewed and analyzed. Documentation concerning the implementation and compliance of IMO regulations will also be examined. The IMO's Maritime Knowledge Center located in London can serve as a valuable source of regulatory documentation that can be assessed by the study.

Although large volumes of the types of documents referred to above will reviewed over the course of this analysis, certain pieces of research will be found to be ideally useful for the purposes of this investigation. Examples of the types of documents mentioned above that will ultimately prove to be useful to the study include the Arctic Emissions Inventory offered by Corbett et al. (2010) which present emissions estimates for different categories of vessels operating in the Arctic region for the year 2004. A study by Burel et al. (2013) will prove useful by providing estimates on the levels of emissions abatement that can be realized as a result of utilizing LNG as a maritime fuel. The cost of emissions estimates contained within in a report for the European Commission by Holland and Watkiss (2002) will prove extremely valuable to the CBA process of this study. The Arctic Marine Shipping Assessment produced by the Arctic Council (2009) will prove useful by identifying the number vessels of each category type that were active in the Arctic region over the course of a year. Estimates regarding the construction and conversion costs related to LNG utilization from research conducted by DNV GL (2014) prove useful for the CBA conducted within this study.

4.5. Methods of data analysis

4.5.1 Cost-benefit analysis

In order to address the research questions, the study will utilize cost benefit analysis (CBA). The study will use CBA to identify and quantify the relevant internal and external costs as well as benefits of electing to utilize LNG as a maritime fuel in the Arctic. Through the use of cost benefit analysis, the study will monetize the associated benefits and costs of choosing to utilize LNG as a fuel, in order to compare and assess the decision against opting to maintain the status quo heavy fuel option instead. Through the use of cost benefit analysis, the study will evaluate if society will become better off or worse off, as a result of the transition to LNG in the Arctic region.

The study will refer to previous cost benefit analysis literature as a guide for conducting the evaluation. For example, the study will follow the six stages of CBA stated by Hanley and Barbier (2009) as a guideline. While the six stages of CBA stated by Hanley and Barbier are utilized by this study as a guideline, other studies such as Kuosmanen et al. (2009) and Boardman et al. (2017) offer similar sets of basic steps for conducting a CBA. According to Hanley and Barbier (2009) the six stages of CBA are: 1) project/policy definition, 2) identification of physical impacts of the policy/project, 3) valuing impacts, 4) discounting of cost and benefit flows, 5) applying the net present value test, and 6) sensitivity analysis. A particularly unique aspect of the CBA conducted for the study will involve the sixth and final stage of sensitivity analysis. In order to acknowledge and address the issue of uncertainty the sensitivity analysis stage of the CBA will incorporate changes to various elements of the data such as the discount rate and cost of emissions estimates to reflect different scenarios.

By following these six stages as a guideline and utilizing established valuation methods and techniques conducted in prior research, the study will analyze the socio-economic costs of a transition towards LNG as a maritime fuel. The study will build on related previous research such as that of Helle et al. (2015), which used CBA to evaluate oil spill management in the Gulf of Finland, and that of Bertram et al. (2014), which focused on German waters in an examination of the EU Marine Strategy Framework Directive and the use of CBA. The study will seek to utilize and build upon the evaluation techniques and practices utilized in previous CBA research in order to more thoroughly address the research questions. The study will also review the procedures, results and outcomes of previous CBA research such as Annema and Koopmans (2015) and Hickman and Dean (2018), in order to identify issues that can be considered weaknesses or shortcomings involved in previous works, so that they might be properly addressed and either alleviated or minimized during the process of carrying out this study.

Environmental CBA can be described as a helpful tool that can be used to evaluate alternative environmental projects and policies (Kuosmanen et al. 2009; Boardman 2017). Environmental CBA can also be described as a tool for the appraisal of projects or policies that have environmental impacts (Atkinson & Mourato 2008).

Fundamentally, CBA is an approach to evaluating policy choices based on the simple framework of supporting actions in which gains exceed losses (Tietenberg & Lewis 2018). An important aspect of environmental CBA is considering actions from the viewpoint of society as a whole in an attempt to determine if society as a whole will be better or worse off as a result of a project or policy (Hanley & Barbier 2009).

Having been applied to projects throughout the world, CBA offers policy makers a widely used and established decision making tool for the assessment of projects and policies (Atkinson & Mourato 2015). From early examples of CBA utilization, such as the evaluation of flood prevention projects in the United States in the 1930s, to contemporary examples such as the appraisal of a port expansion project in Rotterdam, the use of CBA has grown and is now frequently applied to an extensive range of projects and policies (Annema & Kiipmans 2015; Hickman & Dean 2018).

CBA is now considered a prevalent economic approach to project appraisal (Hwang 2016). Traditionally, CBA has been applied in the appraisal of clearly defined projects, often funded with public money, such as large-scale infrastructure projects (Vickerman 2007). The use of CBA to evaluate an energy transition, such as is conducted in this study, is a fairly novel application of CBA. Although the application of CBA in this study is novel, it offers a useful approach to the evaluation of energy transitions that is particularly relevant considering the challenges currently facing the global energy system.

Many of the challenges and indeed criticisms faced by CBA involve the issue of uncertainty, particularly as related to the quantification of impacts (Hickman & Dean 2018). Likewise, the novel application of CBA in this study is also faced with uncertainty. Despite the challenge of uncertainty, CBA as a decision making tool, and the CBA application in this study still provide useful information for stakeholders and policy makers. For example, Kling et al. (2012) contend that even in instances of limited information, CBA remains useful to policy makers. Hockley (2014) states that CBA can serve to identify areas where further research should be directed and additional resources allocated in order to improve decision making and benefit of society. Likewise, increasing awareness of the issues surrounding this energy transition and facilitating additional research related to this topic would certainly be commendable outcomes of this study.

Again, it should be noted that initially a mixed methods approach incorporating both CBA and discourse analysis was contemplated for this study. This approach envisioned a scenario in which results from a CBA would subsequently be used in conjunction with interviews in order to combine quantitative and qualitative methods. However, in the early stages of this study, it became apparent that a mixed methods approach such as this was not practical given the time and resource limitations associated with this study. Therefore it was decided that the study would rely on the application of CBA to address the research question.

4.6. Ethical considerations

Although the research conducted for the purpose of this study will not involve children or any vulnerable groups or any anticipated exposure to unusual risks or danger, there are still, as with all research, certain ethical considerations that that must be contemplated beforehand.

Issues regarding confidential or sensitive information could potentially arise as a result of the research of and interactions with governance actors. For instance, some information obtained from the Arctic Council or the International Maritime Organization regarding future policy planning and strategies could likely be considered of a sensitive and confidential nature and therefore have special rules and regulations regarding the release of such information to the public. As such instances are encountered, all restrictions and regulations concerning classified or sensitive information will be strictly observed and complied with at all times.

Whenever instances concerning confidentiality or anonymity are encountered, the wishes of the relevant individuals or organizations will be respected and appropriate actions will be taken to comply with these wishes in a manner that will be agreed to beforehand. In instances where parties wish for any data or information to remain anonymous, their wishes will be respected and appropriate actions taken to accommodate them.

Should situations be encountered in which an individual or organization requests that a copy of the of the finalized thesis text be delivered to them as stipulation of their involvement in the study, efforts will be taken to accommodate such request in a manner that is in compliance with the rules and regulations of the University of St

Andrews. All research conducted for the purposes of this study will follow the University of St Andrews University Teaching and Research Ethics Committee policies and guidelines and all related ethics forms and documentation will be attached and included as part of the final thesis report.

CHAPTER 5: CBA RESULTS

5.1. Project/Policy Definition

(Step 1: *Project/Policy Definition*)

This section will address the first of the six steps for conducting the cost-benefit analysis (CBA) process covered by Hanley and Barbier (2009), the initial step of *Project/Policy Definition*. The purpose of this step is to clearly define and state what it is that the study is analyzing, as well as outlining whose welfare the analysis will be taking into consideration and with what time period the analysis will be concerned. The details of the specific project/policy definition explained in this step are an important stage in the analysis that will guide the subsequent steps of the CBA process.

Although conducting this opening step of the CBA process, which is defining the project or policy to be analyzed, might appear to be an easy and simple task; in reality it can be quite a difficult undertaking and must be addressed with care. All proposed projects or policies are complex in nature and involve a collection of different scenarios, possibilities and uncertainties. These possibilities and scenarios can range from the specific aspects of a propositioned project or policy, the goals or objectives that are meant to be achieved as a result of implementation, the details of how the project or policy is to be implemented, the timeframe to consider, and the different perspectives from which the project or policy is to be analyzed in terms of welfare, in addition to other aspects. How well these details are addressed in the project/policy definition stage will significantly affect the ability of the concluded analysis to serve as a useful tool for policy decision makers.

Studies employing CBA involve a perspective project or policy under the scope of certain scenarios and assumptions, and this is certainly the case with this study. This study is examining the prospect of a switch from the status quo of heavy fuel oil to the option of LNG being utilized as a fuel for maritime transportation within the Arctic region, but the CBA process requires that the policy be more specifically defined. For the purposes of this individual study, a collection of hypothetical scenarios and situations will be presented and a series of assumptions will be made.

It is recognized that the hypothetical scenarios and assumptions assigned to the proposed project in this study would almost certainly vary from an actual project carried out in reality. The parameters laid out for the project under examination in this study are intended to be a diligent effort to produce an analysis that is of use for policy makers and decision makers. In this outlook, some of the assumptions of the project definition will certainly be issues for debate that will in some instances be discussed in later sections of this study, while some will be more appropriately addressed in follow up studies to be embarked on after the completion of this analysis (as outlined further in the overall conclusions). As is the case with each section throughout this study, matters of practicality, time, availability of resources, and intended purpose are all factors that guide the criteria employed for this section.

At this point, it is useful to outline the scope of the examination. Although a transition to LNG as a maritime fuel in the Arctic region will involve actors from different industries such as shipping and energy, for the purposes of this study one segment of the shipping industry will be analyzed to serve as a sample of the broader shipping industry. The CBA in this study will focus on the 200 *tanker category vessels active in the Arctic* listed in the Arctic Council (2009) Arctic Marine Shipping Assessment 2009 Report and also incorporated in the Corbett et al. (2010) study, both of which are utilized as data sources by this study. In regards to timeframe, this study will examine the 200-vessel sample over a 25-year period of time representing the typical vessel lifespan used for maritime finance and accounting purposes (Patterson 2016).

Although the sample of 200 vessels would be from a diverse assortment of flag states, the prospective heavy fuel oil ban or a similar policy such as the establishment of an Arctic ECA, would require primary action to be taken on the part of the eight Arctic states, followed by cooperation with the broader international community within the context of the IMO (Zhang et al. 2019). As mentioned in chapter 3, the prospect of a heavy fuel oil ban for the Arctic, similar to what is in place in the Antarctic is often debated (Bennett 2015; Prior & Walsh 2018). Recent efforts by the Arctic Council and the IMO, such as the Polar Code environmental requirements illustrated in Figure 5.1, aimed at addressing issues related to shipping emissions and heavy fuel oil use in the Arctic point towards the potential implementation by the IMO of a heavy fuel oil ban in the Arctic, with some estimating that a ban could be implemented as early as the year 2021 (Han 2018; Sun 2019). It is under the prospect of such as policy being implemented by the IMO that this examination of a transition to LNG as a replacement for heavy fuel oil in the Arctic region is conducted.

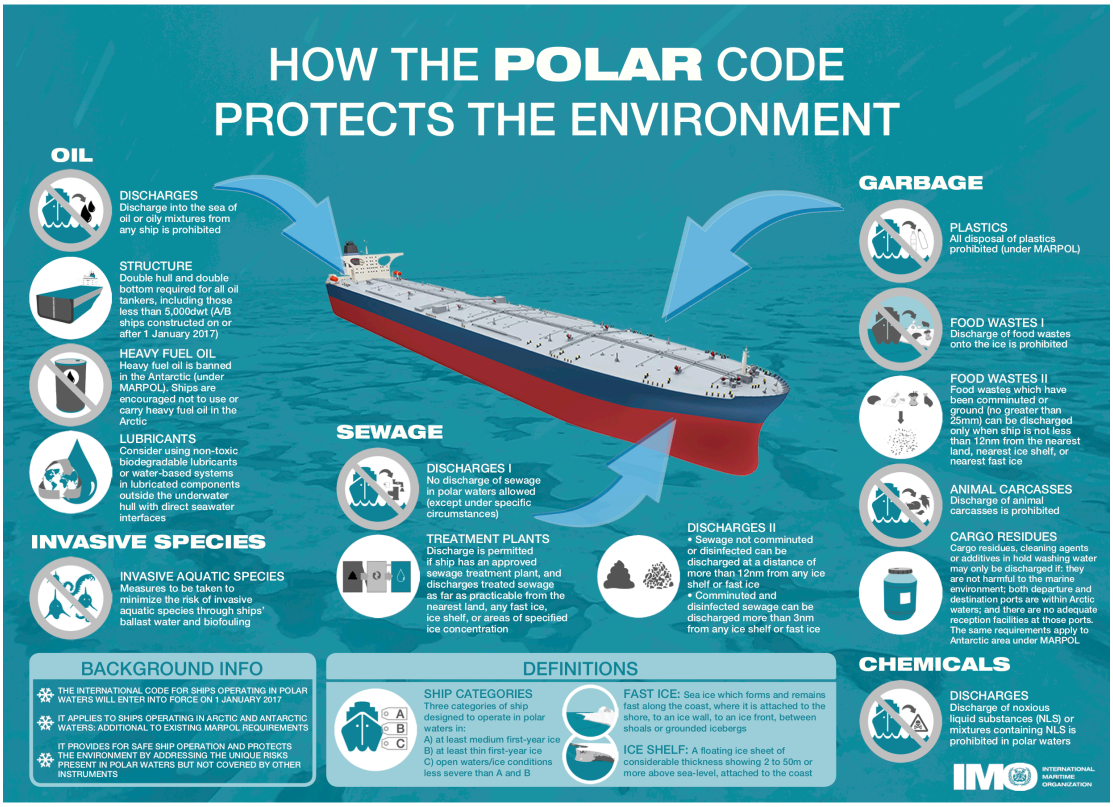

Figure 5.1. Environmental Requirements of the Polar Code (IMO 2019)

5.2. Policy/Project Benefits

This analysis will investigate the cost and benefits of adopting the strategy of utilizing LNG as a fuel for maritime transport, instead of the current status quo strategy of using heavy fuel oil, for ships operating within waters of the Arctic region over the typical lifespan of a vessel. The benefits taken into consideration for this study will be defined as the abatement of NO_x, SO_x, and PM as a result of adopting the use of LNG as a strategy instead of the status quo scenario of continuing to utilize the more highly polluting heavy fuel oil for maritime transportation. These abatement achievements can then be monetized using existing estimates for damage costs per tonne for each of the three pollutants being examined. The level of emissions abatement achieved as a result of adopting the LNG utilization strategy can be derived by referring to widely respected previously published studies such as Burel et al. (2013) that express typical abatement achievements resulting from the LNG strategy in terms of percentages of emissions abatement for individual pollutants, including the three pollutants focused on by this study.

Although the use of these widely referred to estimates of the level of abatement achieved through the use of the LNG utilization strategy offer a simple and convenient means of being able to determine the potential reduction in emissions the LNG strategy option can present, deriving the baseline level of emissions for the status quo of heavy fuel oil utilization to be used for the analysis can be a more difficult task. Determining the baseline level of emissions associated with the status quo heavy fuel oil scenario presents challenges and can be approached in two different ways.

The first approach to establishing an emissions baseline for this study is to incorporate the use of estimates of fuel consumption for a particular ship of a particular type and size, along with an example of annual distance traveled by said ship based on typical route history of a similar vessel, and then through the use of emissions factors, an example of which is presented in Table 5.1, to derive an estimate of each of the three pollutants being examined. One issue of this approach would be that both the estimates of fuel consumption and annual distance traveled would be based on examples sourced from studies of actual ships, the incorporation of two such estimates in this manner would result in the case of a hypothetical ship and associated annual emissions production. Similarly, as all ships are unique and vary in characteristics, comparisons of different vessels are often a challenge, and indeed is an issue that is discussed in other sections of this study. Although this issue related to this approach is something to be mindful of, it is one that would result in a relevant analysis that would be of use for guiding policy-making decisions.

	Ship Type	2004 EFs	2020 EFs	2030 EFs	2050 EFs
CO	All	7.4	7.4	7.4	7.4
NO_x	Transport	78	67	56	56
	Fishing vessels[2]	56	56	56	56
PM	Transport	5.3	1.4	1.4	1.4
	Fishing vessels[2]	1.1	1.1	1.1	1.1
So_x	Transport	54	10	10	10
	Fishing vessels[2]	10	10	10	10
CO_2	Transport	3206	3206	3206	3206
	Fishing vessels[2]	3114	3114	3114	3114
BC	All	0.35	0.35	0.35	0.35
OC	All	1.07	0.39	0.39	0.39

[1]Based on IMO Study (Bauhaus et al., 2009) and Lack et al. (2008, 2009); future Eves reflect current legislation implementation schedules.

[2]Fishing emissions rates provided for comparison; estimates include totals even though spatial processing of fishing emissions is not included here.

Table 5.1. Gas and PM emissions factors applied to current and future Arctic shipping (g/kg fuel) (Corbett et al. 2010)

A second approach would be to refer to emissions inventories, presented in previous research. A good example of such an emissions inventory is found in the study by Corbett et al. (2010), examining Arctic shipping and future scenarios, in which Arctic region emissions estimates are expressed in terms of metric ton per year, with estimates listed for different pollutants and vessel types for the year 2004. For example, Corbett et al. (2010) list total Arctic emissions estimates of SO_x, NO_x, and PM for the year 2014 in terms of mt/y as 146000; 254000; and 145000 respectively, ranging across all categories of vessel types, as illustrated in Table 5.2 below.

Vessel Category	CO_2 (000 mt/y)	BC (mt/y)	OC (mt/y)	SO_x (mt/y)	NO_x (mt/y)	PM (mt/y)	CO (mt/y)
Container Ship[2]	2400	260	790	40000	58000	3900	5500
General Cargo Ship	2000	220	670	34000	49000	3300	4600
Bulk Ships	1200	130	410	21000	30000	2000	2800
Passenger Vessels	1100	120	380	19000	27000	1900	2600
Tanker	900	100	300	15000	22000	1500	2100
Government Vessels	380	40	130	6000	9000	630	880
Tug and Barge	40	4	12	600	863	59	82
Offshore Service Vessel	10	1	4	183	263	18	25
Transit Total	8000	880	2700	136000	196000	13300	18600
Fishing[3]	3200	350	1080	10000	58000	1100	7500
In-Arctic Total (mt/y)[4]	11200	1230	3780	146000	254000	14500	26100

[1]Values are rounded to nearest 10 mt/y, except for CO_2 (rounded to 10000 mt/y) and for values that would round to zero (rounded to integer); data sets reported in grams and not rounded.
[2]Containership activity includes a portion of transpacific route within the AMSA domain.
[3]Fishing vessel estimates reported in this table for comparison, but not provided within the Transport Vessel inventory reported here. Estimates for fishing vessels should be considered very uncertain.
[4]Total CO_2 emissions (for example comparison) in the Arctic represent less than one percent of global CO_2 from shipping as reported in Sect. 2.

Table 5.2. In-Arctic shipping emissions by vessel type 2004 (mt/y) (Corbett et al. 2010)

This approach provides realistic estimates of emissions generated from shipping in the Arctic region during the time period under review and therefore has what can be considered the desirable characteristic of offering a real world representation of the amount of shipping emissions in the Arctic. However, a challenge with this approach is being able to use the data provided in the emissions inventory to derive the emissions produced by an individual vessel during the time period. Once again, the unique characteristics of individual vessels present a challenge for conducting this type of research. Emissions inventories such as presented in Corbett et al. (2010) listing emissions estimates for different categories of vessel type does, however offer an option for addressing this challenge. By incorporating shipping data such as historical vessel activity and route information collected by various organizations, a representation of what could be considered the typical annual operating activity for a ship of a certain category type can be shaped for use in conjunction with the emissions inventory to establish a useful emissions baseline. As will be discussed later in more detail, being able to narrow the focus of the analysis to a specific category of vessel type is helpful in establishing other estimates required for the study, such as costs associated with construction or conversion requirements associated with uptake of the LNG utilization strategy option.

5.3. Policy/Project Costs

The costs considered for the CBA of this study will consist of the cost of the necessary construction or conversion requirements that must be performed As has been discussed, the issue of most vessels, even vessels of the same category type, can often be quite different often presents a challenge for studies concerning shipping. This variety among vessels can be a challenge when considering estimates of the cost of vessel construction or conversion projects. Fortunately, previous studies such as that conducted by DNV GL (2014) related to the strategic uptake of LNG as a fuel for maritime transportation, provide estimates for both the additional costs incurred in the construction of a new vessel, as well as the conversion costs of retrofitting an existing vessel in order to utilize LNG as a fuel source. Examples of such LNG construction/conversion assessments vary from general estimates for any ship type, such as in Wang & Notteboom (2014), to more specific estimates for an individual category of vessel type as in the case of the DNV GL (2014) study. The use of construction/conversion costs estimates from previous studies offers a convenient and reasonably straightforward approach to addressing the costs associated with the option of LNG as a shipping fuel.

5.4. Identification Of Impacts

(Step 2: *Identification of Impacts of Policy*)

For the second step in the CBA process, it is necessary to identify the relevant impacts of the policy or project under consideration. Since any outcome from a policy or project can be considered an impact, it is a challenge to identify the relevant impacts appropriate to be evaluated in a CBA study. In the following sections the relevant impacts related to the utilization of LNG as a maritime fuel option that will be examined in this study will be identified and discussed.

5.5. Emissions Introduction

The following section will address the three principal pollutants that are abated by utilizing LNG as an alternative to heavy fuel oil for maritime propulsion. The three primary pollutants that are abated by the utilization of LNG as a maritime fuel are sulphur oxides (SO_x), nitrogen oxides (NO_x), and particulate matter (PM). The damage costs of these three pollutants will be examined from human health and natural environment perspectives. The numerous ways that the emission of each of these pollutants negatively affects human health and the natural environment will be analyzed and discussed in order to develop an understanding of the cost that the emission of these pollutants has on society and conversely, the benefits that can be realized by successful abatement efforts. Since this research is concerned with the effects that a transition to LNG as a maritime fuel will have on the Arctic region, the study will also examine the issue of black carbon emissions and the particularly adverse consequences of this pollutant for the Arctic. This section will culminate in the analysis of a sample of damage cost estimates of each of the concerned emission pollutants for the purposes of conducting a cost benefit analysis on the transition to LNG as a maritime fuel in the Arctic region.

By analyzing and drawing attention to the potential benefits to society that might be derived as a result of a transition to LNG being utilized as a maritime fuel in the Arctic region, this study will strive to address the void that exists in previous research, which as Jiang et al. (2014) point out, has tended to focus more on the costs of abatement strategies to shipping companies and associated payback times, and as a result potentially diminishing the benefits of certain strategies. Indeed, analyzing the transition towards LNG as a maritime fuel for the Arctic region from a perspective that appreciates the benefits to society as a whole, is one of the primary aims of this research study and a feature that will hopefully serve to augment not only the distinctiveness but also the usefulness of the study as a contribution to the present body of knowledge.

5.6. Air Pollution

Before examining emissions specifically resulting from maritime transport, it is useful to first explore the wider subject of air pollution to gain a clearer understanding of the issue and the effect it has on the environment. Air pollution and the detrimental consequences resulting from it are by no means a recent concern. Although the dilemma of air pollution has long been an issue facing the world, particularly as industrialization has proliferated, the characteristics of the problem and the ways in which humans have addressed it have changed throughout the years.

Over time our understanding of the causes and effects of air pollution has increased dramatically. Just as the industrialized world has continued to change, so too has the types and sources of air pollution, thus altering the ways in which the issue has needed to be contended with. Fenger (2009) states that prior to World War II, the principal compounds in urban air pollution were sulphur dioxide and soot resulting primarily from the utilization of fossil fuels for heat and power production, but around the particular timeframe that coincided with these contaminants becoming somewhat successfully combated by strategies such as the adaptation of cleaner fuels, higher stacks and other abatement techniques, the phenomenon of an increase in urban traffic levels occasioned the onset of a predicament of air pollution characterized by nitrogen oxides and volatile organic compounds.

In the past, air pollution was viewed more as a localized urban problem but over time it came to be understood as a global problem spanning across continents and oceans, with emissions produced in one region possibly being transported over great distances to other regions elsewhere in the world (Ramanathan & Feng 2009). As attitudes regarding air pollution began to take more of a global perspective, the need to alter policies and approaches aimed at addressing the issues began to be adapted accordingly. Fenger (2009) points out that towards the end of the 1960s the mindset of air pollution from heating and power generation as a local problem that could be appropriately dealt with by dispersion via high stacks, began to give way to the understanding that air pollution is not actually dispersed but in reality, is simply transferred elsewhere, and offers the environmental conference held in Stockholm in 1972 by the United Nations as a seminal moment for air pollution being viewed as a global concern.

The reality of air pollution being produced in one locality being transported beyond the source region to impact another area of the world is particularly experienced in the Arctic. It is estimated that a significant amount of air pollutants present in the Arctic originates from mid-latitude Northern Hemisphere sources located in Asia, Europe, and North America (Arnold 2016; Law 2017). Environmental changes taking place in the Arctic also have an impact on air quality elsewhere in the world. For instance, decreasing Arctic sea ice has been found to significantly contribute to increased haze pollution in eastern China (Wang et al. 2015; Zou et al. 2017). Occurrences, such as this illustrate how the successful abatement of harmful environmental impacts in the Arctic will benefit not only the population of over four million people who reside within the Arctic, but also populations well beyond the region (Bastos 2018).

Currently air pollution is a concern for many of the global community's developing nations. Fenger (2009) notes a pattern that is often observed, characterized by air pollution levels within a developing nation initially increasing as material welfare also increases, but with air pollution levels subsequently decreasing as a society is more able to afford practices that serve to combat the pollution. As a result, some of the worst cases of air pollution are presently seen in developing countries with emerging economies. Today, many cities with the worst air pollution in the world can be found in developing countries in areas such as central Asia and the Indian subcontinent where rapid development and industrialization has led to tremendous levels of air pollution, from which studies have shown has resulted in significant increases in mortality and morbidity within these areas (Langrish & Mills 2014). For instance, in China where levels of air pollution have reached alarmingly high quantities, particularly in the northern part of the country, which is home to several of the nation's most populated cities, poor air quality has become associated with social unrest (Chen et al. 2013).

One of the most important ways in which researchers and policy makers analyze air pollution is as an important issue related to human health. As researchers have over time developed an enhanced and more sophisticated awareness of the aspects of air pollution, so too, have the detrimental consequences that air pollution has on the health of human beings come to be more fully recognized. Air pollution is considered to be a significant risk to human health and quality of life, with studies showing links between increased levels of substances such as ozone (O_3) and particulate matter (PM) stemming from air pollution and an increase in long-term mortality as well as cardio-pulmonary diseases and lung cancer (Pascal 2013). Laumbach & Kipen (2012) note studies that indicate air pollution being a significant contributor to respiratory diseases such as asthma, pneumonia and chronic obstructive pulmonary disease.

The World Health Organization (WHO) estimates that over 4.2 million premature worldwide deaths were caused by ambient air pollution in 2016, which places air pollution among the top global risk factors for death and disease (WHO 2018). Air pollution has been identified as an exceptionally leading risk factor for disease in low-income and middle-income countries (Kelly et al. 2015; Cohen et al. 2017). The World Bank (2016) has estimated that the costs of air pollution to worldwide health and well-being exceed $5000 billion. Globally, it is estimated that air pollution accounts for 40% of deaths from lung cancer, 25% of deaths from stroke, and 22% of deaths from cardiovascular disease (Reddy & Roberts 2019). Considering alarming findings such as these, it is understandable why developing strategies for effectively protecting air quality are of the upmost importance for policy makers .

5.7. Overview Of Shipping Emissions

The discharge of air pollution resulting from international shipping has serious negative effects that are harmful to both health and the environment. To help place the impact of shipping on global air pollution consider a study by Corbett and Winebrake (2010) that states that the GHG emissions generated from the global shipping industry exceed that of Germany, which would place it as the sixth largest GHG emitter if the industry were to be thought of as a nation. As the impact of these detrimental effects become more clearly understood, efforts aimed at the abatement of these emissions have received increased attention, particularly in the form of recent regulatory actions. Until recent regulatory efforts began inciting the need for a viable alternative, most large vessels engaged in international shipping burned heavy fuel oil which is a residual by-product of the refining process (Bloor et al. 2014).

The emissions generated from the use of heavy fuel oil by the shipping sector discharge into the air large volumes of SO_x and NO_x, which have been shown to be extremely harmful to crops, forests and the ocean as a result of acidification, and also fine particulate matter which has been shown to be a cause of serious health issues such as lung disease and coronary illness (Bloor et al. 2014). The emission of these harmful substances by ships therefore has a serious impact on world health; with one study by Corbett et al. (2007) estimating that emissions from shipping were attributed to 64,000 premature deaths worldwide in 2002 (Bloor et al. 2014).

Although there are other negative impacts resulting from shipping emissions in the Arctic, such as the damages related to climate change, this study accounts only for air pollution and SO_x, NO_x, and PM emissions specifically, because these are the three pollutants targeted by recent IMO regulations that are motivating a transition to LNG as a replacement for heavy fuel oil in the maritime industry (IMO 2016). Likewise, there will be other benefits of a transition to LNG as a replacement for heavy fuel oil, such as a reduction of the risk of oil spills, that are not included in this study for the same reason (Kumar et al. 2011). While not analyzed in this study, these additional benefits, along with issues such as the environmental impact of LNG production and transportation are excellent topics for future research, potentially involving a life cycle assessment (LCA) as cited in studies such as Brynolf et al. (2014), Gilbert et al. (2018), and Jeong et al. (2019).

5.8. Sulphur

Of the main pollutants addressed by recent abatement efforts, sulphur oxide (SO_x) emissions are perhaps the most targeted. Heavy fuel oil conventionally utilized for maritime propulsion is characterized by high sulphur content and the exhaust emissions resulting from the consumption and combustion of such fuels escalates the potential acidification of the atmosphere (Gilbert 2014). SO_x, along with NO_x emissions are contributors to ocean and soil acidification, as well as climate change (Blasco et al. 2014). Ocean acidification has the potential to result in detrimental impacts on marine organisms and marine ecosystems. Ocean acidification can negatively impact the survival and development of marine organisms and a reduction in coral abundance, as well as other harmful ramifications (Kroeker et al. 2013). Sulphur emissions exposure has also been linked to negative public health outcomes such as increased mortality rates and cardiopulmonary disease (Smith et al. 2009; Ling-Yun & Jia-Jia 2016).

Indeed, many contemporary policy and regulatory efforts are focused on reducing the sulphur content of fuels utilized for maritime propulsion, such as the designation of sulphur emissions control areas (SECA's) and the European Union sulphur directive are aimed at reducing the levels of SO_x emissions generated by shipping (Jonson et al. 2015). The implementation of the International Maritime Organization's MARPOL Annex VI and North Sea and Baltic Sea emissions control areas, are recent, specific examples of regulatory efforts aimed at addressing the reduction of SO_x emissions from shipping, which operators and industry stakeholders must be mindful of (Holmgren et al. 2014). In an analysis of the impacts of the reduction of maximum sulphur content from 1.0% to 0.1% for fuels within the European SECA's, that was implemented on 1 January 2015, CE Delft (2016) pointed to initial studies indicating reductions in sulphur concentrations of 50% or more, and associated health benefits resulting from the improvement in air quality ranging between €4.4 and 8.0 billion. Preliminary results such as these demonstrate the significant impact that sulphur oxide emissions have in terms of socio-economic costs, as well as the benefits of successful abatement efforts.

Ongoing discussions of the creation of additional emissions control areas, in locations such as the Mediterranean Sea for example, indicate that addressing SO_x emissions from shipping, will continue to be a concern for policy makers for the foreseeable future (Panagakos et al. 2014). Compliance with SO_x emissions regulations such as MARPOL Annex VI can be a complex strategy dilemma for shipping industry decision makers, choosing from compliance options such as exhaust gas cleaning systems and alternative low sulphur fuels among other possibilities, and as Schinas & Stefanakos (2014) note, is a decision process in which ship operators often utilize a financial model to compare different viable compliance options.

5.9. Nitrogen

As with sulphur oxide emission, ongoing efforts are aimed to reduce the amount of nitrogen oxide (NO_x) emissions resulting from maritime transportation. Bodies such as the European Union and the IMO have developed policies and regulations ranging from regional to the global, which are designed to reduce NO_x emissions from maritime vessels. IMO MARPOL Annex VI regulates NO_x through a three-tier system of controls based on ship construction date, and NO_x limits being determined by rated engine speed, with Tier II pertaining to ships constructed on or after 1 January 2011 operating outside of designated ECA waters, and Tier III pertaining to ships constructed on or after 1 January 2016 for ships operating within designated

ECA zones (IMO 2016a). Exposure to NO_x emissions leads to adverse public health outcomes such as increased morbidity, heart disease, and respiratory diseases such bronchitis and emphysema (Boningari & Smirniotis 2016; Pfeffer et al. 2019).

5.10. Particulate Matter

Another extremely harmful pollutant that is emitted in significant quantities by the utilization of conventional heavy oil based fuels for maritime transportation that has been addressed by contemporary regulatory actions is that of particulate matter (PM). Consisting of a heterogeneous mixture of solid and liquid particles that vary in size and are suspended in air, PM can include metals, organic compounds, biological compounds, and other chemical components (Kim 2015). Fine particulate matter is also known as $PM_{2.5}$ due to consisting of particles with a diameter of less than 2.5 micrometres (Defra 2016). Emissions of $PM_{2.5}$ are usually the result of the combustion of fossil fuels (Martinelli et al. 2013).

PM has been linked in numerous studies to serious harmful health impacts such as heart attacks, asthma, and hospital admissions (Pope et al. 2002; Cohen et al. 2005; Maji et al. 2018). It has been estimated that PM emissions from shipping are responsible for approximately 60,000 annual cardiopulmonary and lung cancer deaths (Corbett et al. 2007). Previous research has indicated that PM leads all pollutants in the cause of morality and morbidity (Tian et al. 2013; US EPA 2004). Nickel (Ni) and vanadium (V) concentration in PM have been found to increase the risks of cardiovascular disease hospitalization in port cities as a result of the use of heavy fuel oil use by the shipping industry (Tian et al. 2013). Such findings as these highlight the particular importance of ongoing abatement efforts aimed at addressing PM emissions from the shipping sector.

5.11. Arctic Emissions

While the negative effects of air pollution emissions are indeed an issue of global concern, emissions can have particularly detrimental effects at the regional level, and none perhaps more so that in the Arctic region. Due to the sensitive and unique climate of the Arctic, the region is exceptionally susceptible to the adverse impacts of air pollution generated from shipping emissions. When compared to other regions throughout the world, the Arctic is uniquely vulnerable to the threat of damaging effects of shipping emissions.

Black Carbon (BC) emissions have been shown to absorb light and as a result reduce surface albedo (Aliabadi et al. 2015). In comparison to other localities throughout the world, the polar regions of the Antarctic and the Arctic are exceptionally vulnerable to the effects of light absorbing compounds such as BC due to the potential of increasing the acceleration of melting ice (Corbett et al. 2010b). Unlike the Antarctic, the Arctic is facing the possibility of significantly growing levels of development activity in the near future, including substantial increases in shipping activity. Therefore, it can be argued that the Arctic is the most susceptible region in the world to these types of emissions pollutants.

This unique vulnerability highlights the importance of efforts designed to address and minimize emissions from shipping within the Arctic region. As the effects of shipping emissions have garnered increasing attention from policy makers in recent years, particular focus has been placed on addressing the impact of emissions on the Arctic region. Considering that significant increases in the level of shipping activity taking place within the Arctic are likely to occur in the near future, it is important that policy endeavors aimed at addressing shipping emissions within the region take place sooner rather than later. For example, an analysis by Marelle et al. (2016) indicated that shipping emissions along the northern Norwegian coast have had a substantial impact on regional air quality, therefore the predicted increases in the level of shipping activity and related emissions within the region are of particular concern for Arctic stakeholders.

5.12. Damage Costs Of Pollution

For the purposes of conducting the third step of the cost benefit analysis, *Valuation of Impacts*, it is necessary to monetize the impacts identified in the impacts of policy identified in the second step. A monetized example of emissions of the three types of air pollution discussed above can be found in the marginal external costs from emissions from shipping at sea stated by Holland and Watkiss (2002) in a report created for the European Commission DG Environment. In their report for the European Commission DG Environment, Holland and Watkiss (2002) provide a series of lists of estimates of the marginal external cost of air pollution emissions for the three scenarios of *rural*, *urban*, and *shipping at sea*, in € per tonne of emissions, in year 2000 prices, that can be used to analyze policies and projects concerning SO_2, NO_x, and $PM_{2.5}$ emissions, as well as volatile organic compounds (VOCs). It should be noted that researchers such as the United States EPA (2018) consider SO_2 as the indicator for the broader SO_x category; therefore the following examples will utilize the Holland and Watkiss (2002) estimates for SO_2 to analysis SO_x. It should also be noted that the Holland and Watkiss (2002) estimates for $PM_{2.5}$ represent particles measuring 2.5 micrometers or smaller in diameter.

For the *shipping at sea* scenario, Holland and Watkiss (2002) provided marginal external costs estimates for five sea areas: the Eastern Atlantic, the Baltic Sea, the English Channel, the Northern Mediterranean, and the North Sea. For the purposes of this analysis, the Eastern Atlantic estimates will be utilized initially. The respective values for each of the five sea areas are presented in Table 5.3 below. For NO_x, the Eastern Atlantic value is €4,800. For $PM_{2.5}$, the Eastern Atlantic value is €9,100. For SO_2, the value is €4,500. The use of cost estimates such as these can be an extremely useful and simple way to value emissions impacts and analyze policy scenarios.

	SO_2	NO_x	$PM_{2.5}$
Eastern Atlantic	4,500	4,800	9,100
Baltic Sea	1,600	2,100	2,500
English Chanel	5,900	5,400	12,000
Northern Mediterranean	4,700	6,200	10,000
North Sea	4,300	3,100	9,600

Table 5.3. Emissions at sea costs € per tonne in year 2000 prices (Holland & Watkiss 2002)

The report by Holland and Watkiss (2002), which is often referred to as BeTa has been referenced by numerous studies such as Miola et al. (2009), Tzannatos (2010), Castells et al. (2014) and (Tichavska & Tovar 2015) among others. For their report, Holland and Watkiss (2002) utilized an impact pathway approach following the ExternE methodology (ExternE 2012; Tichavska & Tovar 2017). Impacts included in the Holland and Watkiss (2002) analysis involved short-term and long-term effects on mortality and morbidity, effects on materials used in buildings and other structures, and effects on arable crop yield.

While it is recognized that there are some issues and challenges related to the use of the Holland and Watkis (2002) estimates, there use in this study can be justified. Finding secondary data sources for per tonne costs of emissions for the three pollutants was one of the most challenging aspects of this study. During the course of this research, a limited number of sources of per tonne cost of emissions for the three pollutants were located. Likewise, of the sources of per tonne costs estimates that were found, none were specific to Arctic shipping emissions. Ideally, it would have been preferred to identify a set of estimates that were specifically tailored to an Arctic-shipping scenario, but unfortunately no such data was revealed during the course of this study. The void of Arctic specific secondary data of this type and the related uncertainty associated with it, as well as the opportunity this void presents for future collaborative research are discussed in further detail in chapter 6.

As a report prepared for the European Commission, the Holland and Watkiss (2002) study contains estimates for the three EU Arctic states of Denmark, Finland, and Sweden, but none for the remaining non-EU Arctic states. Combining the Holland and Watkiss (2002) estimates for the three EU Arctic states with estimates for the remaining non-EU Arctic states, would prove extremely complex and challenging since each additional study would derive estimates using a unique methodology and set of data. Of the limited additional examples of per tonne cost estimates found in the course of conducting this research, the values varied widely. For example, estimates cited by the UK Department for Environment, Food and Rural Affairs (Defra), which are presented in Table 5.4 list central values of £25,252 for NO_x, £58,125 for PM, and £1,956 for SO_x (Defra 2015). Conversely, Liu et al. (2018) cite per tonne values of \$12,329 for SO_2 and \$76,867 for PM.

Emissions		Central	Central sensitivities	
			Low	High
NO_x	Transport average	£25,252	£10,101	£40,404
PM	Transport average	£58,125	£45,510	£66,052
SO_x		£1,956	£1,581	£2,224

Table 5.4. Air quality damage costs £ per tonne 2015 prices (Defra 2015)

Ultimately, it was decided to utilize the Holland and Watkiss (2002) Eastern Atlantic values to conduct the CBA in this study. As estimates based on a shipping scenario, the Holland and Watkiss (2002) Eastern Atlantic values can be considered more appropriate for this study which is concerned with shipping emissions in the Arctic. Since the study is concerned with emissions from ships that are operating within the Arctic region, as opposed to a stationary source of emissions located in a specific country, estimates from a sea area, such as the Eastern Atlantic values from Holland and Watkiss (2002) are more fitting in this instance than nation specific land based estimates. Studies such as Ding et al. (2007) noting the spatial distribution and atmospheric transportation of air pollution in the Arctic, also motivated the use of estimates based on a sea area shipping, rather than land based national estimates for the purposes of this study, particularly in the absence of comprehensive Arctic specific figures. Tichavsk and Tovar (2015) note the appropriateness the Holland and Watkiss (2002) BeTa estimates for examining shipping emissions due to the accounting of pollutants from the high stacks of ships and point to the frequent citation of these estimates in other studies. As mentioned above, the opportunity presented by the void of Arctic specific estimates for similar analyses is discussed in further detail in chapter 6.

5.13. Abatement Benefits

As mentioned earlier, the ultimate benefits being considered in the CBA are the emissions abatement achievements associated with the option of utilizing LNG as a maritime fuel instead of the status quo option of consuming heavy fuel oil as a fuel source. As was discussed earlier in section 2, once an emissions baseline for the status quo option of consuming heavy fuel oil has been established, estimates of emissions reductions associated with the LNG option stated in previous studies can be referred to in order to derive the value of benefits as a result of the abatement of each of the three pollutants being considered in the study.

Existing research indicates significant levels of emissions abatement for each of the three pollutants that are the focus of this study, as a result of the LNG option in comparison to the status quo heavy fuel oil option. A study by Burel et al. (2013) point to abatement levels 80-85% for NO_x, 90-100% for SO_x, and 90-100% for PM, as is illustrated in Table 5.5 below. In a report on the use of LNG by ships, DNV GL (2014) list emissions reductions of 85% for NO_x, 100% for SO_x, and 95-100% for PM. A study for the IMO (2016b) examining the utilization of LNG as a fuel for ships noted potential abatement achievements of 85% for NO_x, while SO_x and PM were reduced to amounts deemed practically insignificant.

Emissions	Abatement levels
NO_x	80 - 85%
SO_x	90 - 100%
PM	90 - 100%

Table 5.5. Levels of abatement achievements under LNG option (Burel et al. 2013)

5.14. Construction Costs

As mentioned earlier, the costs taken into consideration by the CBA of this study will consist of the construction costs incurred in enabling a vessel to be able to utilize LNG as a source of propulsion fuel. For a project involving the construction of a completely new vessel, the cost under consideration for the CBA of this study would involve the additional expenses incurred as a result of a vessel being capable of utilizing LNG, that are in excess of the cost of building a similar vessel that would exclusively utilize conventional heavy fuel oil. Previous research provides estimates for new build construction scenarios. For a study considering the new build construction of a medium range tanker designed to utilize LNG, DNV GL (2014) provided an estimate of total additional cost of $5.8 million.

5.15. Valuation Of Impacts

(Step 3: *Valuing Impacts*)

The third step in the CBA process according to Hanley and Barbier (2009) is *valuing impacts*. In this step the impacts identified in the second step will be expressed in monetary values to reflect their cost or benefit to society. Using secondary data from previous studies, the relevant impacts associated with the LNG option identified in the second step will be valuated in the following sections.

5.16. Valuation Of Costs

As mentioned earlier, the principal costs analyzed by this study will be the additional cost incurred by the necessary new build construction required to enable a vessel to be capable of employing LNG as a source of operating fuel. Therefore, for the purposes of conducting the third step in the CBA process, *valuation of impacts*, this study will focus on the impact of additional costs associated with the construction of a new vessel designed to utilize LNG as a propulsion fuel. In order to value the impact of additional costs related to the construction of a new vessel opting to utilize LNG, this study will refer to the previous DNV GL (2014) study mentioned in an earlier section, which gave an estimate of $5.8 million as the additional cost to a new build vessel construction project for a medium range tanker electing to adopt the option of LNG utilization.

Although in reality, various and indeed numerous other costs would be taken into consideration during the evaluation and planning process of a real world vessel project, for the purposes of the evaluation carried out in this analysis, these additional costs associated to the construction of a vessel in order to utilize the option of LNG as opposed to the status quo option of solely utilizing heavy fuel oil, will be the only cost impact concentrated on in this study. According to Patterson (2016) the economic lifetime of a ship can vary depending on maintenance and other factors, but that for a new vessel, it is typically 25-30 years. For the purposes of this study a vessel lifespan of 25 years will be assumed. Therefore the additional cost to new build construction, represented by the $5.8 million estimate stated in the DNV GL (2014) report, will be the sole cost over the 25-year vessel lifespan that will be analyzed by the CBA in this study.

Since the $5.8 million figure listed in the DNV GL (2014) report was an estimate of the additional costs of construction associated with utilization of LNG for a medium range tanker, this study will use the estimates for the *tanker* vessel category in the In-Arctic shipping emissions estimates expressed by Corbett et al. (2010) for the valuation of emissions abatement benefits. The emissions inventories referred in the study by Corbett et al. (2010) incorporated data from the Arctic Council (2009) Arctic Marine Shipping Assessment 2009 Report, which lists the number of vessels in the tanker vessel type category that were reported in the Arctic for 2004 as 200. Applying the $5.8 million costs to additional construction associated with the LNG option to the 200 tanker category type vessels reported in the Arctic would result in a total figure of $1.16 billion. Incorporating these figures into a scenario in which the 200 tanker category vessels reported in the Arctic for 2004 by the Arctic Council (2009) Arctic Marine Shipping Assessment 2009 Report, were to be replaced with newly constructed vessels, the total additional construction costs of all the vessels choosing the option of utilizing LNG as a fuel source would total $1.16 billion as illustrated in Table 5.6 below.

Additional cost to new-build vessel project	Tanker category vessels active in the Arctic	Total additional cost to vessel category
$5,800,000	200	$1,160,000,000
	Total cost	**$1.16 billion**

Table 5.6. Summary of LNG option cost valuation

Since these costs are expressed in U.S. dollars and the benefits will be expressed in euros, the values will need to be converted into a common currency. If the costs value of $1,160,000,000 were to be converted into euros at a EUR/USD exchange rate of 1.180 [the EURUSD=X on 24 August 2017], the value of costs expressed in euros would be €982,934,228.14.

As the estimates used for the costs and benefits in this study are from different years, 2014 for the cost estimates from the DNV GL (2014) study and 2000 for the benefits from Holland and Watkiss (2002), the values will have to be adjusted for inflation to a common year, which for the purposes of this study will be the year 2019. For example, adjusting the cost value of €982,934,228.14 for inflation incorporating the 0.7% change in the consumer price index from January 2014 to January 2019 stated by the Central Statistics Office of Ireland (2019), will result in an adjusted value of €989,753,395.23.

5.17. Valuation Of Benefits

In order to perform the valuation of the benefits associated with the LNG option, this study will utilize data derived from previous studies conducted by Corbett et al. (2010); Holland and Watkiss (2002); and Burel et al. (2013). Data from these studies will be used in the valuation of benefits examined in this study, which as mentioned previously, will be in the form of the abatement of SO_x, NO_x, and PM achieved as a result of selecting the option of utilizing LNG as a fuel source as opposed to the status quo of consuming heavy fuel oil.

The first step in this process involves taking the figures listed by Corbett et al (2010) as the 2004 mt/y in-Arctic shipping emissions estimates for the *tanker* vessel category. Corbett et al. (2010) estimate that the in-Arctic emissions in 2004 in terms of (mt/y) by vessels in the tanker category were 15,000 for SO_x; 22,000 for NO_x; and 1,500 for PM. The mt/y emissions estimate for each of the three respective pollutants can then be multiplied by a corresponding marginal external cost of emissions at sea € per tonne estimate provided by Holland and Watkiss (2002), in order to calculate the damage cost per year of each emission under the status quo option of utilizing heavy fuel oil. The € per tonne marginal cost from emissions cited in Holland and Watkiss (2002) that will be used are the Eastern Atlantic values of €4,500 for SO_2, €4,800 for NO_x, and €9,100 for $PM_{2.5}$. As estimates of offshore emissions, the Eastern Atlantic values offer a noteworthy scenario for analyzing shipping emissions in the Arctic. These calculations results in damage costs of €67,500,000 for SO_x, €105,600,000 for NO_x, and €13,650,000 for PM. The damage costs for each of the three pollutants can then be summed to calculate the total costs for the status quo heavy fuel oil scenario. This will result in an amount of €186,750,000 as the total damage costs under the heavy fuel oil status quo option, as illustrated in Table 5.7 below.

Once the damage costs associated with the status quo heavy fuel oil scenario have been derived, estimates of the levels of abatement achievements possible as a result of selecting the LNG utilization option can be used to calculate the benefits associated with the LNG scenario. For this purpose the study will refer to the abatement level estimates stated by Burel et al. (2013) of 80-85% for NO_x, and 90-100% for both SO_x and PM. For the analysis, the study will use the lower level estimates of 80% for NO_x, and 90% for SO_x and PM, of these ranges.

Multiplying the status quo damage costs for each respective pollutant by the associated percentage of abatement achievable under the LNG option will provide the annual amount of abatement benefit for each pollutant as a result of electing the LNG scenario. This task results in figures of €60,750,000 for SO_x, €84,480,000 for NO_x, and €12,285,000 for PM, which represents the amount of abatement benefit for each emission as a result of choosing the LNG option. The sum of these benefit figures shows an amount of €157,515,000 as the total monetized benefit annually of selecting the option of utilizing LNG as a fuel source instead of the status quo option of heavy fuel oil, based on the above-mentioned data, as is illustrated in Table 5.7 below.

Emissions	SO_x	NO_x	PM	TOTAL
2004 (mt/y) Emissions	15,000	22,000	1,500	
Damage Cost Price (€'s)	4,500	4,800	9,100	
Status Quo Cost of Emissions (€'s)	67,500,000	105,600,000	13,650,000	186,750,000
LNG Abatement Levels	90%	80%	90%	
LNG Option Cost of Emissions (€'s)	6,750,000	21,120,000	1,365,000	29,235,000
LNG Option Abatement Benefits (€'s)	60,750,000	84,480,000	12,285,000	157,515,000
			Total LNG Option Abatement Benefits in €'s	**157,515,000**

Table 5.7. Summary of LNG option abatement benefits valuation using Holland and Watkiss (2002) Eastern Atlantic estimates

5.18. Discounting Of Cost And Benefit Flows

(Step 4: *Discounting of Cost and Benefit Flows*)

Now that all the cost and benefit flows being examined by the study have been expressed in monetary values, it is now necessary to convert all of them into terms of *present value* (PV), which is the objective of the fourth step in the CBA process identified by Hanley and Barbier (2009), *Discounting of Cost and Benefit Flows*. According to Hanley and Barbier (2009), it is necessary to convert all of the cost and benefit flows into *present value* (PV) terms in order to take into account the time value of money or time preference. Hanley and Barbier (2009) explain that the rationale behind time preference is that most benefits, which in this case are expressed in monetary terms are more highly valued the sooner that they are received, while conversely most costs to be paid, again in this case expressed monetarily as a sum of money to be paid out, are considered to be less of a burdensome obligation the further away in time that they are required to be paid. In order to take into account time preference and to be able to compare cost or benefit flows that occur at different times, all cost or benefit flows are discounted using a discount rate, which as Hanley and Barbier (2009) suggest, can be assumed to be the rate of, *i*. Hanley and Barbier (2009) present the equation for calculating the present value of a cost or benefit represented by *X* received in time *t* at a discount rate of *i* as follows:

$$PV(X_t) = X_t[(1+i)^{-t}] \qquad \text{Equation 1. Present Value}$$

Hanley and Barbier (2009) identify the part of the above equation located inside the square brackets as a *discount factor*, which will always have the property of lying between 0 and +1, meaning that since it will always be less than 1, the discount factor reduces the present value of the future costs or benefits. As Hanley and Barbier (2009) point out, the further into the future costs or benefits occur, the discount factor moves more towards zero, hence the higher the value of *t* is the lower the discount factor, which indicates a greater effect of discounting. Hanley and Barbier (2009) also point out that since a higher discount rate reflects a higher preference for things sooner as opposed to later in time, the greater the value of discount rate *i* for a given time *t*, the lower the discount factor will be. Again, a key characteristic to remember is that the higher the value of *i* the lower the discount factor, also the higher the value of *t* the lower the discount factor, and the lower the discount factor, the greater the effect of discounting. These properties of how the discount factor is influenced by changes in the values of *t* and *i* are important for understanding the concepts of discounting and present value. Once the discounted value for each period of time has been calculated, the discounted values can be summed to derive the sum present value over time of the cost or benefit being examined.

The choice of discount rate in environmental CBA is an often debated and sometimes highly contested subject. Prominent economists such as Nordhaus (2007) and Stern (2007) often disagree on what discount rate is appropriate for analyzing environmental policies and projects. For the purposes of this study a discount rate of 3.5% will be used. The motivation for using a discount rate of 3.5% in this analysis is based on the recommendation presented by HM Treasury (2003) for analyzing proposed projects or policies with a timeframe of 30 years or less, which is applicable for the 25 year vessel lifespan under consideration in this study. In the sensitivity analysis stage, an example of a scenario using a larger 5% discount rate will be presented for the purposes of illustrating the effects utilizing of a higher discount in the CBA process.

Now that the cost and benefits associated with the LNG option scenario for this study have been calculated, discounting can be used to determine the present value of these cost and benefit flows over time. As mentioned earlier, the $1.16 billion additional cost to new-build construction associated with electing the LNG option rather than the status quo heavy fuel oil scenario will be the only cost related to the LNG option considered for the purposes of this study. In the new-build ship market all construction cost are paid in full prior to an owner taking delivery of a vessel (Stopford 2009). Since the $1.16 billion additional cost to new-build construction associated with the LNG option would be have to be paid before the beginning of the project or in year zero and at no other point thereafter, this cost will not be discounted. Although costs are not discounted in this example, in any instances in which the costs of a project are to be incurred over multiple period in the future, it is important to remember the characteristics mentioned earlier that the higher the value of t the lower the discount factor, and the lower the discount factor, the greater the effect of discounting.

However, unlike the cost to new-build construction, the abatement benefits associated with the LNG option will appear in each year of the 25-year vessel lifespan of the 200 tanker category vessels active in the Arctic being examined by this study. The study will assume that the same €157,515,000 of abatement benefits will be achieved each year throughout the 25-year lifespan of the 200 tanker vessels. Assuming a discount rate of 3.5%, the discounted value for each year of the 25-year lifespan as well as the sum present value can be calculated using Equation 1 shown above.

For example, a calculation of the present value of the €157,515,000 benefit for year 1 with a 3.5% discount rate using Equation 1 from above would be exhibited as:

$$PV\ (157{,}515{,}000_1) = 157{,}515{,}000_1[(1+0.035)^{-1}]$$

$$PV\ (157{,}515{,}000_1) = 157{,}515{,}000_1[(1.035)^{-1}]$$

$$PV\ (157{,}515{,}000_1) = 157{,}515{,}000_1[0.966183574879227]$$

$$\mathbf{PV\ (157{,}515{,}000_1) = 152{,}188{,}405.80}$$

Conducting a similar calculation for each of the 25 time periods representing the 25 years making up the vessel lifespan and then summing the 25 corresponding discounted values for each year would result in a sum present value of €2,596,085,771.00 for the abatement benefits over time for the LNG option using a 3.5% discount rate, as is illustrated in Table 5.8 below.

Year (*t*)	Benefits in year *t*, €	Discount rate	Discount factor	Discounted value
1	157,515,000	3.5%	0.9662	152188405.80
2	157,515,000		0.9335	147041937.97
3	157,515,000		0.9019	142069505.28
4	157,515,000		0.8714	137265222.50
5	157,515,000		0.8420	132623403.38
6	157,515,000		0.8135	128138553.99
7	157,515,000		0.7860	123805366.17
8	157,515,000		0.7594	119618711.28
9	157,515,000		0.7337	115573634.08
10	157,515,000		0.7089	111665346.94
11	157,515,000		0.6849	107889224.10
12	157,515,000		0.6618	104240796.23
13	157,515,000		0.6394	100715745.15
14	157,515,000		0.6178	97309898.70
15	157,515,000		0.5969	94019225.79
16	157,515,000		0.5767	90839831.68
17	157,515,000		0.5572	87767953.32
18	157,515,000		0.5384	84799954.90
19	157,515,000		0.5202	81932323.57
20	157,515,000		0.5026	79161665.29
21	157,515,000		0.4856	76484700.76
22	157,515,000		0.4692	73898261.60
23	157,515,000		0.4533	71399286.57
24	157,515,000		0.4380	68984817.95
25	157,515,000		0.4231	66651998.01
			Sum PV	2,596,085,771.00
Total present value of benefits				**€ 2,596,085,771.00**

Table 5.8. Discounted values and total present value of benefits from LNG option using Eastern Atlantic estimates (Holland & Watkiss 2002) with a 3.5% discount rate

Notice that the in the above calculation the sum present value of the benefit flow of €2,596,085,771.00 is less than the amount of €3,937,875,000 that would be derived by simply summing the €157,515,000 annual benefit for each of the 25 time periods. The calculations exhibited in Table 5.8 demonstrate the principle mentioned above, that the further forward in time that discounting takes place, the greater the impact of discounting is. This can be seen in how over the 25-year timespan, both the discount factor as well as the discounted value for each time period becomes smaller with each progressing year as a result of the increasing impact of discounting over time. The impact of higher discount rates on the present value of benefit flows associated with the LNG option will be examined later in the sensitivity analysis section.

As mentioned earlier, since the cost and benefit estimates originate from different years, they must be adjusted to a common year to account for inflation, which for this study will be the year 2019. Therefore, the €2,596,085,771.00 total present value of benefits from the Eastern Atlantic scenario, based on estimates from Holland and Watkiss (2002) expressed in prices for the year 2000, adjusted for inflation incorporating the 38.5% change in the consumer price index from January 2000 to January 2019 stated by the Central Statistics Office of Ireland (2019), results in an adjusted value of €3,596,635,198.18.

5.19. Applying The Net Present Value Test

(Step 5: *Applying the NPV Test*)

Now that the relevant cost and benefit flows have been discounted, the fifth step in the CBA process as identified by Hanley and Barbier (2009), which is *Applying the Net Present Value Test*, can be performed. As Hanley and Barbier (2009) note, net present value is the gauge which is used in CBA to determine if the benefits generated by a policy or project are greater that the costs incurred. As Hanley and Barbier (2009) declare, net present value (*NPV*) simply assesses whether the sum of discounted benefits exceeds the sum of discounted costs, expressed by the following equation:

$$NPV = \Sigma B_t(1+i)^{-t} - \Sigma C_t(1+i)^{-t}$$ Equation 2. Net Present Value

Once calculated, the net present value is used to assess if a project or policy should be accepted. If a project has a net present value that is greater than zero, meaning that the benefits are greater than the costs, then according to the benchmark of the net present value test, the project should be accepted. Likewise, if a project has a net present value that is less than zero, or in other words negative, meaning that the costs are greater than the benefits, then the project would be deemed unacceptable.

So for the proposition of the LNG option under examination in this study, applying the net present value test using the values derived earlier simply involve taking the sum present value of abatement benefits of €3,596,635,198.18 and subtracting the €989,753,395.23 of additional cost to new-build construction. This would be demonstrated as follows:

$$NPV = €3{,}596{,}635{,}198.18 - €989{,}753{,}395.23$$

$$NPV = €2{,}606{,}881{,}802.95$$

Based on the criteria of the net present value test of a project being accepted if it has a *NPV* that is greater than zero, then with a *NPV* of €2,606,881,802.95 the LNG option would therefore be accepted.

5.20. Sensitivity Analysis

(Step 6: *Sensitivity Analysis*)

The sixth and final step of the CBA process identified by Hanley and Barbier (2009) is to conduct a *Sensitivity Analysis*. Performing a sensitivity analysis involves investigating how changes to different elements of the data will result in a change to the net present value of the project. Analyzing how changes to elements of data will impact the net present value is done to account for issues of uncertainty. As Hanley and Barbier (2009) point out, CBA often involves predictions and estimates regarding the future, and these predictions can never be made with complete foresight and perfect accuracy. By incorporating changes in the data based on various scenarios and recalculating the net present value, the sensitivity analysis step of CBA can help address the issue of uncertainty. Therefore the study will examine scenarios that involve changes to key elements of the data in order to see how these changes will result in changes to the net present value for the LNG option.

5.21. The Discount Rate And Sensitivity Analysis

As mentioned earlier in the discussion on discounting an increase or decrease in the value of the discount rate results in changes to the discount factor which indicates changes in the effect of discounting. Increasing the discount rate will lower the discount factor and reflect a greater effect of discounting. This effect can be seen below in Table 5.9.

By replacing the 3.5% discount rate used in the previous example to calculate the sum present value of benefits from the LNG option as demonstrated in Table 5.8 with a discount rate of discount rate of 5% would result in a sum present value of €2,220,007,678.32. Notice that in comparison to the calculations in Table 5.8 with a 3.5% discount rate, the discount factors shown in Table 5.9 with a 5% discount rate are lower for each of the 25 time periods, thus indicating a greater effect of discounting reflected in a lower sum present value.

Year (*t*)	Benefits in year *t,* €	Discount rate	Discount factor	Discounted value
1	157,515,000	5%	0.9524	150014285.71
2	157,515,000		0.9070	142870748.30
3	157,515,000		0.8638	136067379.33
4	157,515,000		0.8227	129587980.32
5	157,515,000		0.7835	123417124.11
6	157,515,000		0.7462	117540118.20
7	157,515,000		0.7107	111942969.72
8	157,515,000		0.6768	106612352.11
9	157,515,000		0.6446	101535573.44
10	157,515,000		0.6139	96700546.13
11	157,515,000		0.5847	92095758.22
12	157,515,000		0.5568	87710245.92
13	157,515,000		0.5303	83533567.55
14	157,515,000		0.5051	79555778.62
15	157,515,000		0.4810	75767408.21
16	157,515,000		0.4581	72159436.39
17	157,515,000		0.4363	68723272.75
18	157,515,000		0.4155	65450735.95
19	157,515,000		0.3957	62334034.24
20	157,515,000		0.3769	59365746.89
21	157,515,000		0.3589	56538806.57
22	157,515,000		0.3418	53846482.44
23	157,515,000		0.3256	51282364.23
24	157,515,000		0.3101	48840346.89
25	157,515,000		0.2953	46514616.08
			Sum PV	2,220,007,678.32
Total present value of benefits				**€2,220,007,678.32**

Table 5.9. Discounted values and total present value of benefits from LNG option using Eastern Atlantic estimates (Holland & Watkiss 2002) with a 5% discount rate

Adjusting the €2,220,007,678.32 total present value of benefits from the Eastern Atlantic 5% discount rate scenario for inflation incorporating the 38.5% change in the consumer price index from January 2000 to January 2019 stated by the Central Statistics Office of Ireland (2019), results in an adjusted value of €3,075,614,005.23. Therefore, this scenario has a *NPV* of €2,085,860,610.00. Based on the criteria of the net present value test of a project or policy being accepted if it has a *NPV* that is greater than zero, with a *NPV* of €2,085,860,610.00 the LNG option would therefore be accepted in this example. The above example illustrates how changes to the discount rate can result in changes to the net present value of a project.

5.22. Changes In Damage Cost Of Emissions Estimates And Sensitivity Analysis

As mentioned above, the purpose of sensitivity analysis is to recognize and address the issue of uncertainty. This underlying uncertainty is often related to the magnitude of predicted impacts and the values that are assigned to them (Boardman et al. 2017). As noted elsewhere, much of the uncertainty encountered by this study is associated with the marginal external costs of emissions estimates from Holland and Watkiss (2002) that are utilized in the CBA process. To acknowledge and address this uncertainty, a scenario involving a change in the value of the Holland and Watkiss (2002) estimates can be examined as part of the sensitivity analysis. Reducing the value of the estimates can address concerns that the Eastern Atlantic prices presented by Holland and Watkiss (2002) might overestimate the real costs of emissions. For this purpose, the Holland and Watkiss (2002) Eastern Atlantic values from the previous example can be reduced by 50% to derive a different total LNG option abatement benefits value as illustrated in Table 5.10 below.

Emissions	SO_x	NO_x	PM	TOTAL
2004 (mt/y) Emissions	15,000	22,000	1,500	
Damage Cost Price (£'s)	2,250	2,400	4,550	
Status Quo Cost of Emissions (£'s)	33,750,000	52,800,000	6,825,000	93,375,000
LNG Abatement Levels	90%	80%	90%	
LNG Option Cost of Emissions (£'s)	3,375,000	10,560,000	682,500	14,617,500
LNG Option Abatement Benefits (£'s)	30,375,000	42,240,000	6,142,500	78,757,500
Total LNG Option Abatement Benefits in €'s				**78,757,500**

Table 5.10. Summary of LNG option abatement benefits valuation using 50% reduced Holland and Watkiss (2002) Eastern Atlantic estimates

As Table 5.10 illustrates, reducing the values of the Holland and Watkiss (2002) estimates by 50% results in a total LNG option abatement benefits value of

€78,757,500. As in the previous examples this value can then be discounted over a 25-year timespan using a 3.5% discount rate as demonstrated in Table 5.11 below.

Year (*t*)	Benefits in year *t*, €	Discount rate	Discount factor	Discounted value
1	78,757,500	3.5%	0.9662	76094202.90
2	78,757,500		0.9335	73520968.98
3	78,757,500		0.9019	71034752.64
4	78,757,500		0.8714	68632611.25
5	78,757,500		0.8420	66311701.69
6	78,757,500		0.8135	64069276.99
7	78,757,500		0.7860	61902683.09
8	78,757,500		0.7594	59809355.64
9	78,757,500		0.7337	57786817.04
10	78,757,500		0.7089	55832673.47
11	78,757,500		0.6849	53944612.05
12	78,757,500		0.6618	52120398.12
13	78,757,500		0.6394	50357872.57
14	78,757,500		0.6178	48654949.35
15	78,757,500		0.5969	47009612.90
16	78,757,500		0.5767	45419915.84
17	78,757,500		0.5572	43883976.66
18	78,757,500		0.5384	42399977.45
19	78,757,500		0.5202	40966161.79
20	78,757,500		0.5026	39580832.64
21	78,757,500		0.4856	38242350.38
22	78,757,500		0.4692	36949130.80
23	78,757,500		0.4533	35699643.29
24	78,757,500		0.4380	34492408.97
25	78,757,500		0.4231	33325999.01
			Sum PV	1,298,042,885.50
Total present value of benefits				**€ 1,298,042,885.50**

Table 5.11. Discounted values and total present value of benefits from LNG option using 50% reduced Eastern Atlantic estimates Holland and Watkiss (2002) with a 3.5% discount rate

As illustrated in Table 5.11, the resulting sum total present value of benefits is €1,298,042,885.50 in this example. Adjusting the €1,298,042,885.50 total present value of benefits for inflation incorporating the 38.5% change in the consumer price index from January 2000 to January 2019 stated by the Central Statistics Office of Ireland (2019), results in an adjusted value of €1,798,317,599.09. Therefore, the *NPV* is €808,564,203.86 in this example. Based on the criteria of the net present value test of a project or policy being accepted if it has a *NPV* greater than zero, the LNG option would be accepted in this example.

Table 5.12 displays the different scenarios examined in this analysis and the resulting outcomes based on the criteria of the net present value test.

Scenario	Result
Base case with 3.5% discount rate	Accept
5% discount rate example	Accept
50% reduced estimates example	Accept

Table 5.12. Results based on the criteria of *NPV* test

CHAPTER 6: DISCUSSION

6.1. Introduction

The results of the cost-benefit analysis (CBA) conducted in this study offer numerous issues for discussion in relation to the transition towards LNG being utilized as a maritime fuel in the Arctic region. As with the examination of historical energy transitions in the previous section, a discussion of the results from the CBA can be analyzed in relation to technological innovations and various social and cultural factors that have played crucial roles in facilitating preceding energy transitions. Just as these technological, social and cultural dynamics have served as key factors surrounding historic energy transitions, they will also undoubtedly shape current and future energy transitions as well.

6.2. Technology & Innovation

As noted in the assessment of historical energy transitions, technology and innovation play an essential role as factors of energy transitions and have tremendous influence not only in initiating transitions, but also in determining the manner in which transitions take place and progress over time. As the results from the CBA indicate, electing to utilize LNG as a maritime fuel can be considered a viable strategy for achieving desired emissions reduction objectives, such as meeting IMO regulatory compliance. Indeed, conducting the steps of the CBA process demonstrated that in each of the scenarios carried out the LNG option would deem to be accepted based on the criteria of the net present value test.

Although the results of the CBA are encouraging for the LNG option and certainly speak positively toward the adoption of LNG as a strategy, a thorough analysis of the utilization of LNG as a maritime fuel should include at least a brief discussion of other prominent options for maritime emissions reduction strategies. Some of the additional options for reducing the emissions from shipping examined in this study could be considered alternatives or even competitors to the LNG option, while certain other options could be viewed as complements that could potentially be utilized in conjunction with the LNG option. While some emission reduction strategies are non-technical or non-operational options, such as market-based measures mentioned by Smith (2012) such as emissions trading and fuel levies, other abatement strategies rely on the implementation of innovation and technical advances being implemented by active vessels. While emissions reduction options that consist of market based strategies or policy and regulatory endeavors will be discussed in subsequent sections of this study, the following section will focus on alternative emissions reduction strategies that primarily involve the employment of technological or innovative approaches to achieving emissions reductions.

The contemporary literature mentions numerous emission abatement options that utilize a variety of innovations and technologies. Smith (2012) discusses available abatement options such as reductions in ship speed, the utilization of wind power, renewable fuel sources, and exhaust scrubbers as options for consideration. Many alternative abatement strategies focus on the adaptation and utilization of alternative fuel sources. In addition to LNG, other existing fuel sources mentioned by Cullinane and Cullinane (2013) as possible emissions abatement strategies include the utilization of hydrogen, nuclear power, biofuels, wind and solar power. While many abatement strategies rely on the employment of alternative fuels, others strategies involve the implementation of abatement technologies. Cullinane and Cullinane (2013) list humid air motor systems, selective catalytic reduction systems, and seawater scrubbers as examples of key abatement technologies currently available.

Several emissions abatement strategies focus on various approaches aimed at improving energy efficiency. Approaches to achieving improved energy efficiency according to Cullinane and Cullinane (2013) include, improved hull design, improved propellers and rudders, and reduced vessel speeds, among other strategies. By traveling at reduced vessel speeds, a practice known as slow steaming, ships can significantly improve fuel efficiency (Lee 2015). Improved fuel efficiency resulting from reductions in vessel speed has the potential to significantly reduce emissions as well as fuel costs (Cullinane & Cullinane 2013). As noted by Lack and Corbett (2012) due to the varying speed requirements demanded of ships operating in Arctic waters due to challenges such as ice conditions, achieving energy efficiency improvements through reductions in vessel speed can be problematic for vessels operating in the Arctic region. Other problematic issues with the practice of slow steaming include increased transit related costs due to longer journey times, and the potential to entice shippers to utilize alternative forms of cargo delivery such as land based transport options, which could actually lead to an increase in the level of emissions emitted (Psaraftis 2016).

Aside from the utilization of an alternative fuel source, perhaps the most viable emissions abatement option is the implementation of scrubber system technology. The addition of exhaust scrubber systems to existing maritime engines reduces the exhaust emissions and allows the vessel to operate on fuels with higher sulphur content while maintaining compliance with regulations (Lack & Corbett 2012). A seawater scrubber system involves utilizing seawater to clean the engine exhaust gas emitted by a vessel via an onboard scrubber system. There are two types of seawater scrubber systems, an open loop system and a closed loop system. After treating the exhaust gas in a closed loop scrubber system, the water is stored in tanks, while in an open loop scrubber system the water is discharged into the sea after treatment (Cullinane & Cullinane 2013). The release of seawater used to clean the exhaust gases in an open loop scrubber system after the exhaust treatment process is an issue of environmental concern and a problem related to the utilization of scrubber systems.

Scrubber systems have the potential to realize significant abatement achievements. For example, Nikopoulou et al. (2013) point to SO_2 reductions of 90-95%, NO_x reductions of 10-20%, and PM reductions of 80% as the result of incorporating a seawater scrubber system. However, despite the desirable emissions reductions scrubber technology presents, the option also has unique points of contention. Seawater being discharged back into the sea after being used to treat exhaust gases in open loop scrubber systems is of particular concern. As a result of these concerns, open loop scrubber systems that discharge seawater back into the sea after treating exhaust gases are not allowed to be employed in the Baltic Sea (Panasiuk & Turkina 2015).

In addition to concerns related to the discharge of post-treatment seawater back into the sea, several other concerns related to the utilization of scrubber systems have appeared in the literature. Lindstad and Eskeland (2016) note concerns that the embracing of exhaust treatment options such as scrubber systems poses a potential risk to the development of clean fuel options.

As mentioned earlier, many emissions abatement strategies focus on the adoption and utilization of alternative fuel sources. In addition to LNG, an alternative fuel source that is often proposed as a future option for the maritime industry is hydrogen. The potential utilization of hydrogen as an alternative fuel source for the maritime sector has gained a great deal of interest from researchers. The prospect of hydrogen becoming adopted as a transportation fuel has been examined for decades. El-Gohary (2013) notes the upsurge in research related to the use of hydrogen as a fuel for the transportation sector following the oil crisis and highlights efforts by automobile manufacturers to develop vehicles that could utilize hydrogen fuel. As a high quality energy carrier that is very efficient, low polluting and versatile, hydrogen is considered an extremely promising fuel for the future (Najjar 2013).

Hydrogen is currently commonly utilized for a variety of purposes such as refining, chemical processing, food processing, rocket fuel, and fertilizer production among numerous other industrial and commercial uses (Balat 2008). Despite hydrogen having a history of different uses and promising sustainability potential, the prevalent utilization of hydrogen as transportation fuel faces many challenges. As the assessment of historic energy transitions in the earlier section observed, the widespread adoption of a previously underutilized fuel type seemingly always faces challenges and obstacles that must be addressed before achieving pervasive acceptance and application.

In relation to the prospect of achieving environmental and sustainability goals through the utilization of hydrogen as a transportation fuel, a major challenge is the method in which hydrogen is produced. Despite hydrogen being able to be produced from a range of renewable and non-renewable methods, currently most of the hydrogen produced for industrial use is derived from fossil fuels, due to factors such as low costs and accessibility (Mazloomi & Gomes 2012). In order for hydrogen to realize its full potential as a clean and sustainable fuel choice for the long-term future, hydrogen needs to be produced principally from renewable sources and only a small number of such methods are currently commercially practical (Sharma & Ghoshal 2015).

In addition to the challenge of sustainable hydrogen production processes, there are also many obstacles related to the increased consumption and utilization of hydrogen as a transportation fuel. One of the foremost challenges facing an increased adoption of hydrogen as a transportation fuel is that of storage. Balat (2008) notes that in comparison to gasoline, hydrogen stores approximately 2.6 times more energy per unit of mass, however, due to the extremely low density of hydrogen, it requires approximately 4 as much volume to store. This storage dilemma presents an obstacle to the hydrogen being widely adopted as a transportation fuel. According to Sharma and Ghoshal (2015) the storage of hydrogen for use as a prominent transportation fuel poses a materials research challenge that necessitates major technological innovation.

In addition to the storage issue, the transportation and distribution of hydrogen also presents a challenge to hydrogen being prominently utilized as a transportation fuel. While discussing the challenge that transportation and distribution present to a potential transition to hydrogen as a transportation fuel, Singh et al. (2015) mention that similar obstacles such as infrastructure requirements were encountered during the initial stages of the transition to oil and gas, and suggest that commercial and political initiatives to address these challenges will be required for a successful transition to hydrogen to come to fruition.

While hydrogen has tremendous potential to eventually become a prominently utilized transportation fuel, many studies suggest that more research and development is required for this to be realistically achieved. El-Gohary (2013) recommends for the purpose of maritime propulsion, that the use of natural gas should be promoted until a time in which the large-scale utilization of hydrogen becomes feasible. Assertions such as these, along with the CBA results of this study support a transition to the LNG option by the maritime industry.

In addition to the challenges facing the widespread adoption of hydrogen as transportation fuel that were discussed above, hydrogen also faces the obstacle of negative public perception. Although hydrogen has a notable history of being successfully utilized for numerous industrial purposes, and despite a great deal of recent interest in the potential that hydrogen poses as a sustainable fuel for the future, there also exists a sense of skepticism and uncertainty among some of the public regarding the likelihood of hydrogen being a realistic and practical solution to the need for a sustainable transpiration fuel. Najjar (2013) suggests that perhaps one reason for some of the public skepticism about the prospect of the large-scale adoption of hydrogen stems from infamous accidents related to the use of hydrogen in the past, perhaps the most notorious of which is the Hindenburg disaster of 1937.

Natural gas and hydrogen have many characteristics that can actually allow the fuel types to be viewed as complements to each other rather than competing options. The blending of natural gas and hydrogen yields interesting potential for a number of applications. Significant amounts of natural gas infrastructure and equipment are also suitable for utilization by hydrogen, particularly when blended with natural gas. Mariani et al. (2012) note that in applications utilizing a blend consisting of 30% or less hydrogen that a natural gas and hydrogen blend can be distributed through the existing natural gas infrastructure without the requirement of substantial infrastructure modifications.

Navarro et al. (2013) state that combining hydrogen and natural gas can help alleviate certain limitations exhibited by each of the fuel types when utilized alone. While discussing the utilization of natural gas and hydrogen blends for use by gas turbine engine applications, Donohoe et al. (2014) note that mixing hydrogen with natural gas can help improve the combustion characteristics of natural gas. The practice of mixing hydrogen with natural gas also has the potential to facilitate the utilization of hydrogen produced from renewable electricity in a power to gas process. Schiebahn et al. (2015) discuss the prospect of utilizing the existing natural gas grid in Germany in a power to gas scheme by either blending hydrogen produced from renewable electricity with natural gas, or converting the hydrogen into methane prior to induction into the natural gas grid.

As this discussion shows, natural gas can play an important role in efforts to establish hydrogen as a solution for the quest to develop a long-term sustainable fuel option. In certain applications and scenarios, natural gas, and thus LNG, can be viewed by proponents of hydrogen as a practical transition fuel for the evolution to a future in which hydrogen plays a key role in meeting the demand for energy. If policy makers decide that hydrogen will play a role in a sustainable future, certain strategies involving natural gas, and in this case the uptake of LNG as a fuel for maritime propulsion, can play an important role in the transition to such a future being realized.

An examination of previous energy transitions, as conducted earlier in this study, reveals numerous examples of interactions between incumbent and replacement energy types that are encouraging for the prospect of natural gas based fuels such as LNG serving in congruence with the development of hydrogen based fuel technologies to usher in sustainable solutions for future energy demands. For example, Dijk et al. (2015) point to the British canal system that was designed for use by barges pulled by horses later proving extremely practical for use by steamboats. Dijk et al. (2015) also mention how due to shortcomings in early steam engine capabilities, that until the 1880's most steam ships were actually of a hybrid design that utilized both steam and wind technology, and that it was not until later that advancements in steam engine design along with other developments helped steam technology eclipse sailing.

These examples present comparisons to ways in which natural gas can complement the development and implementation of hydrogen technologies. Just as in certain instances, steam technology was able to make use of infrastructure initially designed for use by earlier technologies that it eventually replaced, so to can natural gas infrastructure prove useful in certain instances for hydrogen based applications. With the potential of alternative use in the future, natural gas, in this instance LNG, infrastructure developments should be designed in a way that facilitates this possible employment. The example of early steamship applications relying on a combination of steam and wind technology until sufficient advancements in steam technology allowed steam power to prevail over sailing draws interesting parallels for considerations of how hybrid natural gas and hydrogen applications can help bridge the gap between existing capabilities and future advancements in hydrogen related innovation.

Another Arctic infrastructure related opportunity in which natural gas, and therefore LNG, has the potential to provide improvements is in the form of electricity generation and supply within the region. For many small and remote communities within the Arctic, electricity is generated through the use of diesel fuel (Chade et al. 2015). Despite the Arctic having substantial deposits of oil and gas resources, almost all of these resources are exported to destinations located outside the region (Smits et al. 2016). Therefore the refined fuels that many Arctic communities rely on regularly have to be transported great distances. As Boute (2016) notes, generating electricity in the remote Arctic through the use of diesel fuel is extremely expensive due to the high cost of transporting the fuel great distances in challenging conditions, as well as the inefficiency associated with this method of electrical power generation. As a result of the high cost of relying on diesel for electricity generation, many Arctic communities are reliant on government subsidies to meet their power supply needs (Hamilton et al. 2012). For example, Chade et al. (2015) note that the Arctic island of Grimsey off the northern coast of Iceland received in access of $400,000 worth of government subsidies in the year 2011 for the purpose of diesel powered electricity generation. In addition to the exorbitant expense of generating electricity through the use of diesel fuel, this practice also involves substantial environmental risks, particularly considering the potential risks that the prospect of fuel spills and leaks pose to the Arctic environment (Boute 2016). For these reasons there is great interest in a more suitable alternative for providing the electrical power needs of remote Arctic communities. Findings such as the results of the CBA of this study can provide useful insight for stakeholders and policy makers interested in alternatives to diesel powered electricity generation for the Arctic region.

Natural gas based fuels such as LNG and associated infrastructure have the potential to play a role in the effort to develop a more practical, affordable and sustainable alternative for meeting the electrical power needs of remote Arctic communities. In addition to offering the potential to reduce emissions, natural gas would also lessen the risk of fuel spills associated with the use of diesel fuel for the purposes of electricity generation taking place in rural Arctic communities. Another factor that points to natural gas having the potential to play a role in a transition to a more sustainable system of supplying electricity to remote Arctic populations, is the similarities between natural gas and hydrogen mentioned above.

While analyzing the prospect of a wind to hydrogen system on the Arctic island of Grimsey, Chade et al. (2015) pointed to the success of similar projects based in remote locations such as the Scottish island of Unst, the Norwegian island community of Utsira, and the Canadian village of Ramea. In a study of the prospects for off grid renewable energy solutions for the Russian Arctic, Boute (2016) mentioned that wind-diesel or solar-diesel hybrid systems could potentially serve as a more cost effective and sustainable alternative to conventional diesel powered electricity generation in remote localities. In addition to providing power for electrical generation, schemes such as these also have the potential to provide energy for other uses within their respective communities. For instance, Chade et al. (2015) point out how on the Scottish island of Unst that excess hydrogen produced from the wind to hydrogen system is used as fuel for a small vehicle that operates on the island.

These examples point to the potential role that natural gas utilization can play in not only helping facilitate an improvement in the way in which the energy demands of the Arctic region are provided for but also perform a function in a transition to a more sustainable long-term solution to the energy requirements of the region. A transition to LNG replacing heavy fuel oil as the principal maritime fuel utilized in the Arctic region will help facilitate the use of natural gas for other purposes such as in these examples.

As a transition to LNG for maritime propulsion leads to Arctic stakeholders increasingly engaging in activities related to the use of natural gas, such as the trading, transporting and handling of natural gas products, it will become more practical for the fuel to be utilized in additional capacities in order to help meet the energy needs of the region. With careful planning natural gas has the potential to be combined with other technological and innovative strategies to help reform energy use in the Arctic and assist in a transition to achieving sustainable energy solutions for the region. Information and research such as the results of the CBA section of this study can serve as useful guides for planners challenged with achieving these goals.

Additions and modifications to the energy infrastructure of the Arctic can be expected as a result of increased utilization of natural gas within the region. The changes and the rate and scale at which they take place will be driven by the demand for natural gas within the region. Although the initial transition can be supported by existing infrastructure, future natural gas and LNG infrastructure development will be driven by demand and will be heavily influenced factors such as traffic levels, fuel efficiency, competition between ports in the future (Calderon et al. 2016; Yumashev et al. 2017; Le Fevre 2018). Innovations and advancements in the natural gas supply chain such as floating LNG and ship-to-ship bunkering will also influence the rate and characteristics of future natural gas infrastructure development in the Arctic region

(Hunter 2018; Park et al. 2018). The uncertainty and complexity of projecting natural gas LNG related infrastructure developments as well as the complex evolving nature of natural gas markets resulting in the decision that the costs related to LNG infrastructure developments were beyond the purview of this particular study and therefore these costs not included in this CBA (Rogers 2012; Chen et al 2016). However an examination of infrastructure and related costs associated with an energy transition in the Arctic region would be a noteworthy subject for future research, particularly considering that researchers such as Kim et al. (2019) point to a need for additional academic research on the topic of LNG bunkering.

6.3. Social & Cultural

As in the earlier examination of previous energy transitions, a discussion of the CBA results of this study can be framed in the context of social and cultural dynamics such as economic, political and geographic factors associated with the transition to the utilization of LNG as a maritime fuel in the Arctic region. A discussion of how these social and cultural dynamics are associated with the transition to LNG as a maritime fuel provides interesting insights concerning not only the transition to LNG but also energy governance as well as the ongoing broader transition towards a sustainable future, which is an increasingly imperative concern for not only researchers and policy makers but society as a whole.

The results of the CBA performed in this study can be viewed on several different levels, for instance from the perspective of a firm, as well as from the national or regional perspective. The CBA results of this study also offer some interesting considerations connected to the broader issues of maritime economics and global trade.

6.3.1 Economic

The results of the CBA indicate that the policy of adopting LNG as a maritime fuel should be accepted based on the steps carried out in the CBA process and according to the criteria of the net present value test. From the perspective of a firm, which in this case would be an organization involved in the operation of ships, perhaps one of the most pertinent economic issues related to the decision to adopt LNG as a maritime fuel, would be the price of LNG fuel in comparison to the status quo option of heavy fuel oil. Although the results of the environmental CBA conducted in this study suggest the acceptance of LNG as a maritime fuel, the criteria analyzed did not explicitly examine the price deferential between LNG and the status quo heavy fuel oil. The decision to exclude this fuel price component was based on a number of factors. Principally, as mentioned earlier and as noted in Hanley and Barbier (2009), the goal of environmental CBA is to determine if society is better off as a result of accepting a policy or project.

Similarly, the objective of the analysis conducted in this study is focused on ascertaining whether or not society would be better off as a result of LNG being utilized as a fuel for ships operating in the Arctic region. This investigation was framed, organized and conducted with the goals and objectives of recent policy and regulatory undertakings such as fuel sulphur content limits, the establishment of emissions control areas, and current as well as proposed fuel oil bans, which were aimed at reducing the harmful effects of shipping emissions, not reducing or controlling the cost of vessel operations for maritime shipping firms. Likewise, the focus and purpose of this study was not to serve as an analysis of how the prospect of electing to utilize an LNG option as an alternative to a heavy fuel oil status quo, would effect the operating costs or profitability of a ship operating firm.

While the focus of this study is primarily concerned with analyzing the transition to LNG as a maritime fuel in the Arctic region from the perspective of society as a whole, firms engaged in vessel operation within the Arctic region are certainly important stakeholders involved in this transition. As with any analysis of energy transitions, it is prudent to consider the perspective of key stakeholders, especially stakeholders who play such a vital role in the transition, such as shipping firms in the transition to LNG. Therefore conducting an examination of the results of the CBA and the implications of a transition to LNG as a maritime fuel for the Arctic region from the perspective of shipping firms would be an astute undertaking to be included in the future research agenda.

6.3.2 Geographic

While discussing the history of maritime trade, Stopford (2009) mentions that throughout history the locality considered to be the prominent global hub of maritime commerce has moved from being located in Mesopotamia around 3000 BC then over the next 5000 years, progressively shifting westward along what Stopford (2009) characterizes as the "Westline", onward to the Pacific with China emerging as powerful player in maritime commerce in the 1990's. Looking at how the focal point of maritime trade has shifted over the past 5000 years offers some interesting insights into the future of global shipping. For example, just as the trajectory of maritime trade has moved along a gradually westward pathway, it will surely continue to shift in the future. As Arctic shipping routes become increasingly viable, perhaps the future will see a northern shift take place, as well as the continued westward trajectory.

The history of maritime commerce and the shifting focal point of maritime trade along a westward trajectory over time offer some interesting implications for the Arctic region and the prospect of a transition to LNG as a maritime fuel. In his overview of the history of commercial shipping, Stopford (2009) highlighted three lessons, each of which can be related to the transition to LNG utilization in the Arctic region, and indeed to the results of the CBA carried out in this study.

The first lesson emphasized by Stopford (2009) is that even from the earliest of times, maritime shipping has always played an important role in the global economy. Having been an integral part of international trade since the early days of commerce, maritime shipping will always be a crucial aspect of the global economy and this role can only be expected to increase in importance in an ever more globalized economy. As the importance of maritime trade continues to increase, the pursuit of strategies that maximize shipping, such as exploiting Arctic sea routes will become even more intensified. Such developments will make the results of the CBA from this study and similar research findings even more relevant. Indeed as trends such as increased globalization amplify the importance of maritime trade, research and development related to shipping emissions and policy will continue to be an increasingly important issue not only for the Arctic region, but also for all localities participating in international commerce.

The second lesion that Stopford (2009) highlights is that although certain aspects of shipping such as technologies, agents and the circumstances in which they operate have transformed, that the underlying economic principles that drive shipping such as supply and demand, have changed little over the 5000 year history of maritime commerce. This lesson relates to the CBA results of this study and similar analyses, as a reminder that while aspects such as technologies and advancements, which in this case is new fuel types, or policies and regulations, which in this example are efforts aimed at emissions reduction, are certainly now as always, important facets of shipping, that these aspects are part of a larger complex global process that is maritime trade. It is important to keep this lesson in mind when developing and considering strategies and polices aimed at achieving sustainability in shipping, as the effectiveness and ultimate success of such strategies will surely benefit from doing so.

The third lesson highlighted by Stopford (2009) in his reflection on the history of maritime trade is that shipping seems to flourish more in times of political stability. The prosperity enjoyed by maritime trade in the Mediterranean during the era in which the Roman Empire was able to ensure safe passage and the subsequent waning of both this assurance and trade in the third century, is offered by Stopford (2009) as an example from history of the positive relationship between political stability and the prosperity of maritime trade. Stopford (2009) argues that political stability is so fundamental to the prosperity of maritime trade that geopolitics as opposed to economics should be the focal point of analyses concerning the future of maritime trade. As revealed in the earlier discussions regarding energy governance, Arctic governance, and historic energy transitions contained in this investigation, the relationship between geopolitics and maritime trade is uniquely evident in the Arctic region. A more detailed examination of the political relationship to maritime trade and how it correlates to the prospect of a transition to LNG taking place in the Arctic region follows in the ensuing section.

An increasingly important aspect of Arctic affairs is the increasing interest of Asian nations, and China in particular in the region. As has been mentioned, one of the primary drivers of recent interest in the Arctic region is the allure of trade between the East and the West being conducted via Arctic sea routes. With some studies stating that a vessel traveling between Northeast Asia and Europe could reduce the distance traveled by 24% or more by navigating the Northeast Passage route through the Arctic as opposed to a route via the Suez Canal (Buixadé Farré et al. 2014), it is understandable that Asian interest in the Arctic would be extensive.

In 2013 at the Kiruna Ministerial meeting the eight Arctic states granted the non-Arctic states of Japan, China, India, South Korea, Singapore and Italy observer status to the Arctic Council (Ingimundarson 2014). The awarding of observer status to the Arctic Council to these nations is indicative of the growing influence that Asian states have within the Arctic region, as well as the recognition of this influence by the eight Arctic states. Asian interest in the Arctic is certainly not a recent phenomenon. Ingimundarson (2014) lists the significant contributions and investments of many Asian states in matters such as Arctic research and lists China, Japan, South Korea and India having research stations at Svalbard as illustrations of these commitments.

Over the past four decades China has experienced an extraordinary level of economic growth. As an illustration of how the economy of China has transformed in recent history, Zhu (2012) notes that in 1978 China's gross domestic product was merely one fourteenth that of the United States, but by 2012 China's gross domestic product had risen to one fifth that of the United States. Over that same period of time China has gone from being considered one of the poorest countries in the world to becoming the second largest economy in the world (Zhu 2012). Some researchers such as Jorgenson and Vu (2011) predict that China is on pace to eventually replacing the United States as the largest economy in the world in terms of gross domestic product. In 2015 the top three regional destinations for Chinese exports of manufactured goods according to the World Trade Organization were Asia, North America, and Europe respectively, with China having a trade surplus equal to $1.6 trillion for the year (WTO 2017). Athukorala (2012) credits the practice of global production sharing, particularly China's role as a leading assembly site, as playing a crucial role in the exceptional growth of Asian economies over the past four decades and predicts that such international specialization will continue to drive increased levels of trade and economic growth for the region in the future.

As a nation poised to experience continued unprecedented growth and intensifying global influence, China is particularly concerned with Arctic affairs. Wright (2014) states that the attraction of the Arctic to China is derived primarily from an interest in Arctic navigational routes, followed by natural resources located within the Arctic, scientific research conducted in the Arctic, and the an overall concern with climate change. Ingimundarson (2014) lists numerous high profile official visits to Arctic states and a highly publicized 2012 icebreaker voyage via the Northern Sea Route as examples of China endeavoring to increase their level of geopolitical influence within the Arctic. Bekkevold and Offerdal (2014) note the increasingly important relationship between Norway and China, with China becoming Norway's eight largest trading partner in the year 2012 and China becoming an increasingly valuable destination for Norwegian fish exports, as an example of China's increasingly important economic association with the Arctic region.

As the economy of China continues to expand, the nation will become increasingly reliant upon global trade to maintain the trend of growth. This reliance on trade will make the prospect of the Arctic being a viable option for maritime trade between the East and the West an imperative issue for China. As a nation, China will want to insure that it is able to take steps to maximize any advantages that increased maritime trade via the Arctic might yield in the future, in order to maintain growth and insure competitiveness.

The need for environmental protection policies and regulations as a result of the prospect of increased maritime traffic taking place in the Arctic and the associated transition to LNG being utilized as a maritime fuel offer opportunities for China to exert an increased amount of influence within the Arctic region and to also be better positioned to benefit from global trade being conducted via the Arctic. As the level of maritime trade being conducted in the Arctic increases, massive commitments and investments in infrastructure to support this trade will have to take place. By making investments in infrastructure projects that are anticipated to take place in the Arctic, China would be able achieve a markedly increased amount of influence in the region. As substantial investors in Arctic infrastructure developments such as port facilities, China would be able to achieve a means of having a physical presence in the Arctic while lacking any actual Arctic territory. Such a strategic achievement would be extremely valuable for China from a geopolitical standpoint and help to additionally solidify the status of the nation as a global power.

A transition towards the utilization of LNG as a maritime fuel unfolding in the Arctic will also inevitably be impacted by the growing demand for energy in Asia. As mentioned previously Asia has experienced unprecedented levels of growth in recent decades and this economic trend is projected to continue well into the future. As these historic levels of growth continue to materialize, the demand for energy in Asia will also increase dramatically. The IEA predicts that by 2040 developing countries in Asia will account for as much as two thirds of the growth in future global energy demand (IEA 2017).

Just as China will play an exceptionally crucial role in the future economic growth in Asia, so too will the country play an increasingly imperative role in the energy demands of the region. As the IEA notes, China's historic growth has been realized by an emphasis on the export of manufacturing good, infrastructure development and heavy industry, and through an energy system that is dominated by the utilization of coal, which despite allowing for enviable economic gains, has unfortunately resulted in serious environmental difficulties (IEA 2017). As China attempts to meet future energy demand while also addressing the severe environmental problems related to an over reliance on coal, natural gas will become an increasingly important energy source for the country.

The IEA predicts that for countries such as China and India, that currently rely heavily on coal to meet their energy demand needs, natural gas will play a progressively important role as such nations attempt to continue to meet energy demands while also accounting for the need to mitigate environmental damage as well as striving to meet future sustainability goals and environmental targets (IEA 2017). Recent Asian demand for natural gas has already had a notable influence on the global gas trade, particularly in the case of global LNG trading dynamics. As Kim (2017) states, the Asian LNG market has traditionally been characterized by the custom of long-term contracts and an oil linked pricing mechanism known as the Japanese Custom-cleared Crude (JCC) which is sometimes also referred to as the Japanese Crude Cocktail, which usually entailed Asian LNG buyers paying a premium price for cargos, which is further exacerbated by factors such as shipping distances and related expenses.

The 2011 Fukushima nuclear disaster in Japan had a profound impact on the LNG trade in Asia and beyond. Komiyama and Fujii (2017) point to the significant increase in Japanese LNG imports following the Fukushima disaster in 2011, with LNG eventually accounting for close to half of the power generation energy mix as a result, with Japan being the largest LNG consuming nation in the world. Despite the

LNG trade traditionally being characterized by the prevalence of long-term contracts, this dynamic has started to change recently. Although the majority of LNG trading continues to consist of long-term agreements, there has been a noticeable trend towards more flexible trading arrangements, which has had a particular impact on regional LNG import markets (Rogers 2012).

Increased flexibility in the LNG market has seen the conventional connection between LNG prices and the price of crude oil diminish, as buyers are increasingly able to take advantage of more short term contractual agreements in a spot market (Kim 2017). This increased flexibility in the LNG market has been illustrated by the diversion of cargos on the flexible spot market away from European buyers towards destinations in the Asian import market (Rogers 2012). As the global LNG market continues towards an inclination of increased flexibility enabled by spot markets, the trend of cargo diversions away from markets such as Europe and being steered instead towards the Asian market in a case of cargos going to the highest bidder, will likely persist. Such a trend will not only have an impact on the price of LNG in non-Asian markets but will also alter the nature of the LNG trade within the Asian market as well.

According to Rogers and Stern (2014) a number of factors including the drastic rise in oil prices 2008, the increased demand for LNG as a replacement for power generation following the Fukushima nuclear disaster of 2011, and the tremendous strain on national wealth during this period due to expensive LNG purchases all influenced the Japanese government to explore the prospect of an alternative to the crude oil linked JCC pricing mechanism, such as the futures market or the establishment of an Asian market hub. The move by Japan and other Asian LNG consumers to establish a more flexible alternative to the crude oil linked JCC pricing mechanism, would follow and intensify the recent trend in the global LNG trade towards more liberalization and flexibility. A move towards establishing a more liberalized and flexible market environment by such a prominent LNG consuming region, particularly being led by Japan as the largest LNG importing nation, would set the stage for a future of the LNG trade characterized by increased short term trading and featuring a heightened degree of flexibility in a globalized market.

If natural gas does indeed play a considerably more important role in meeting the energy demand obligations of Asia in the future, it will surely have an impact on the transition to LNG utilization as a maritime fuel in the Arctic and elsewhere. As the case of the post Fukushima situation in Japan demonstrates, substantial increases in the demand for natural gas, and LNG in particular, can cause a dramatic strain on the global marketplace. Although the situation following the Fukushima nuclear disaster was severely exacerbated and intensified by the sudden and unexpected spike in demand that the disaster caused, a large scale and rapidly occurring adoption of LNG by maritime operators, even merely a regional implementation such as within the Arctic in lieu of a broader global adoption, would have significant ramifications on the global LNG market.

In reality, the uptake of LNG as a fuel option by the global shipping industry, or even by regional maritime actors such as Arctic stakeholders, would not have near the immediate and drastic market impact that the Fukushima disaster had on the global LNG trade. Yet, a transition to LNG becoming the prominent fuel used for maritime propulsion on a significant scale, be it regionally or globally will certainly have a notable impact on the global LNG trade and it can be expected to see the dynamics of supply and demand take place in both the short and long term in the marketplace.

The large scale adoption of LNG by the maritime industry would create a new demand source for the energy type and would make LNG an even more important part of the global energy mix than it previously is. The recent trend towards a more liberalized LNG market featuring increasingly flexible trading schemes should help facilitate a potential transition to LNG as a maritime fuel. A flexible LNG market will allow shipping operators to quickly react to market fluctuations and demand requirements to meet their fuel needs in a competitive environment. An increasingly flexible LNG market is likely to attract additional buyers that view the amplified ability to react to market pressures and demand requirements afforded by such a trading environment as making LNG a more attractive option to meet their energy needs.

Utilization as a maritime fuel would be a source of attraction to LNG playing an increased role in national energy mixes, in addition to the already demonstrated function of being an alternative to nuclear and an environmentally preferable replacement for coal use in power generation. The presence of flexible LNG trading agreements increases the likelihood of natural gas playing the role of a true transition fuel that bridges the gap between higher polluting options such as coal and an eventual sustainable alternative in the future, rather than becoming established as the primary long term energy source. LNG trading carried out through the use of short-term contracts in a flexible market place allows buyers and policy makers more ability to utilize LNG as a true transition fuel, much more so than under the previous market environment that was characterized by long term contracts often requiring commitments of years or more to be agreed upon. The increased usefulness of LNG brought about by a transition towards the utilization of the fuel by the maritime industry could help accelerate LNG replacing higher polluting types of energy such as coal and petroleum based fuels.

An acceleration of LNG replacing outdated types of energy coinciding with the uptake of LNG utilization by the maritime industry has tremendous potential for rapidly developing nations, particularly within the Asian region. As developing nations strive to fulfill the increasing energy demands of their economic growth, especially growth that is heavily reliant upon international trade, they must also strive to be mindful of pollution and other environmental concerns. LNG offers a practical option for meeting energy demand requirements while at the same time strategically endeavoring to meet environmental goals and climate targets.

An increase in the utilization of LNG to meet domestic energy demand needs by developing nations, would also help facilitate the commitment to infrastructure and related development that will be required for a large scale adoption of LNG by the maritime industry. If LNG related infrastructure is increasingly seen to offer advantages in not only meeting energy demand needs for such purposes as power generation but also as being beneficial, if not crucial, to global trade, then stakeholders and governance actors will be more likely to commit to the development of such projects. Even in a future scenario in which having served as a transition fuel and having been replaced by sustainable alternatives such as renewables, LNG has ceased to be utilized for purposes such as power generation, LNG supply chain infrastructure would still be of use should the fuel continue to be utilized for the purposes of maritime propulsion. Considering the unique challenges and limitations of potential alternatives for maritime fuel, such a scenario in which natural gas use for power generation has concluded, yet LNG is still being utilized by the shipping industry is entirely plausible. As was considered earlier, a great deal of LNG infrastructure could potentially remain useful for certain applications in a scenario in which LNG has been replaced by hydrogen after having functioned as a transition fuel.

6.3.3 Political

The unique geopolitical environment present in the Arctic region, which was mentioned in earlier sections of this study plays an interesting part in the future of maritime trade taking place in the region, as well as the associated transition to LNG being utilized as a maritime fuel in Arctic waters. Once again, an example from history can provide important parallels to the current political and governance conditions of the Arctic region, and how such conditions might transform in the future. While reviewing the history of maritime trade, Stopford (2009) reflected on how through the acceptance of Byzantine suzerainty and concentrating on maritime trade, Venice was able to control trade between the East and the West, while also attaining desirable benefits such as privileged tax rates and special trading rights as well. The circumstances under which Venice was able to propel itself into a position of prominence through a devotion to maritime trade offers some intriguing comparisons for the prospects of the Arctic region in the future. The Arctic has long been characterized as a region that is governed by governments with seats of power far removed from the region in distant capitals located outside the actual Arctic region.

The Arctic has long experienced the reality of being a region whose assorted ruling governments have seats of power located in far removed, distant capitals located well outside the actual Arctic region. Indeed, each of the respective eight Arctic nation capitals of Copenhagen, Helsinki, Moscow, Oslo, Ottawa, Reykjavik, Stockholm, and Washington D.C. are all located outside the Arctic Circle. Even in the case of Greenland, which is in reality a constituent of Denmark, the capital city of Nuuk lies outside the Arctic Circle.

This reality of being represented and governed by distant legislatures undoubtedly is a challenge for the Arctic region, but perhaps it is a challenge that a heightened emphasis on maritime trade can help to lessen. Just as Venice was able to increase its international influence and exercise a greater degree of self-sufficiency through the advantages gained for itself through a concentrated commitment to fulfilling an opportunistic role in maritime trade, so too can the Arctic region increase its influence and level of autonomy through a careful and dedicated approach to becoming a prominent actor in the future of global trade. The increased interest in maritime trading activity via the Arctic offers the region the opportunity to not only increase its influence at the international level, but the potential heightened importance that the growing interest in shipping operations within the Arctic also presents an opportunity for the region to increase its influence in relation to the eight respective representative nations of the region as well.

The prospect of increased levels of maritime trade taking place inside the Arctic offers the opportunity for stakeholders and governance actors within the region to elevate their level of influence and associated power in relation to their respective national governments. Through engaging in strategies and measures that serve to facilitate the success of maritime trade within the region, Arctic stakeholders have the opportunity to significantly increase their degree of influence within their respective national administrations. Being able to exercise an enhanced level of influence within their respective representative national governments would afford Arctic governance actors not only the opportunity to achieve desirable outcomes in issues related to maritime operations, but to also ensure that a variety of advantageous policy undertakings develop in ways that serve to benefit the region. While discussing the complex relationship between Greenland and the European Union, Gad (2014) mentions that Greenland has used the prospect of future Arctic development opportunities to exhibit an heightened since of sovereignty and as a means to lessen Danish control.

As recalled from the earlier discussion on Arctic governance contained within this analysis, the unique political environment of the Arctic tends to necessitate cooperation among governance actors of the region. As mentioned earlier, numerous instances exist as examples of regional cooperation among governance actors, through institutions such as the Arctic Council, to achieve desirable outcomes for the Arctic region. Rottem (2015) highlights the importance of the 2011 search and rescue agreement and the 2013 oil spill preparedness agreement as serving as symbolic examples of stakeholders within the Arctic region cooperating and collaborating to craft a binding international agreement. Hong (2012) argues that heightened interest in energy resources located in the Arctic serves as an opportunity for Arctic stakeholders to engage in regional cooperation. Perhaps the prospect of increased shipping activity taking place in the Arctic and the associated need for a transition to an alternative maritime fuel such as LNG could also be viewed as an opportunity to foster additional cooperation among stakeholders and governance actors within the region.

Similar to the above of examples of potentially expedited political influence through Arctic governance, so too is it possible for Arctic stakeholders to increase the political influence of the region through maritime governance. As mentioned in the discussion of Arctic and maritime governance earlier in this study, maritime governance plays an extremely important role in the Arctic region. The mere nature of maritime governance lends itself to being a useful vehicle through which the Arctic region can increase its political influence in ways that allows the region to exercise greater degrees of autonomy and authority. As mentioned earlier, one of the fundamental institutions of maritime governance is the IMO. As Karim (2015) states, the IMO process of advancing the implementation and modification of policy instruments for the prevention of maritime pollution from ships is a distinctive process that involves a diverse array of actors including both states and non-state actors. The prospect of increased maritime trade taking place in the Arctic as well as a transition toward LNG being utilized as a maritime fuel within the region serve as opportunities for the Arctic region to increase its political influence through the IMO, through the exploits of both state and non-state actors.

Stopford (2009) made the interesting comparison between ancient Venice benefiting from wielding expertise in maritime trade to the later practice of utilizing an independent flag state. The ability of flag states to wield considerable influence in the IMO policy process, despite often being states with small populations and otherwise relatively small amounts of geopolitical influence or power, serves as a lesson for the

Arctic region. Through involvement in the IMO policy crafting process, small flag states such as the Marshall Islands are able to maximize their role in international maritime trade to wield a substantial amount of influence, often above and beyond that which they would be able to in other geopolitical settings. This lesson points to the opportunity that increased interest in engaging in maritime trade within the Arctic region, as well as a transition to LNG, presents for the Arctic to increase the amount of influence and political power it can exert.

Increased interest in maritime trade via the Arctic and a transition to LNG becoming utilized as a maritime fuel in the region offer the opportunity for Arctic state actors to increase the political influence through the IMO policy crafting process. As the role the Arctic region plays in international maritime trade increases, the influence and power wielded by Arctic state actors in the IMO policy crafting process will certainly increase. Environmental efforts aimed at reducing air pollution from ships and a related transition to LNG offers a particular opportunity for Arctic state actors to exercise their influence as well as an instance to demonstrate a heightened level of such influence. Due to the sensitive environmental nature of the Arctic region, the importance of pollution prevention measures, such as regulations regarding shipping emissions, are particularly important to the region. The prospect of increased maritime trade within the region offers Arctic state actors a valuable opportunity to utilize their amplified influence in the IMO policy process to insure that regulatory undertakings are shaped in a way that help ensure the protection of the Arctic environment.

The heightened interest in Arctic shipping and the prospect of a transition to LNG not only affords Arctic state actors involved in the IMO policy process the opportunity to increase their influence among the other IMO member states but also within their own respective delegations. As mentioned earlier, as the role of the Arctic increases in geopolitics, so too does the importance to the Arctic in terms of the role that the region plays in the respective governments of Arctic states. Arctic related issues have long been afforded a high level of attention when it comes to the involvement of Arctic state governments involved in the IMO policy shaping process, especially in relation to environmental issues. The recently heightened interest in Arctic shipping and maritime pollution regulation offers the opportunity for state actors tasked with representing the concerns of the Arctic to have an unprecedented level of influence within their own respective national delegations involved in the IMO policy and regulatory process.

Arctic non-state actors also have an opportunity to increase their influence through the IMO policy process as a result of increased interest in Arctic shipping and a transition to LNG. As noted in the discussion on Arctic and maritime governance earlier in this study, non-state actors in the Arctic have a history of involvement in Arctic governance, with many nongovernmental organizations successfully achieving observer status with the Arctic Council. Under certain circumstances the IMO allows nongovernmental organizations to act in a consultative status and according to Karim (2015) seventy-seven international nongovernmental organizations have been granted such status by the IMO. In this capacity Arctic non-state actors have the opportunity to exercise their influence in maritime governance through the IMO policy process, and this ability will undoubtedly increase as interest in Arctic shipping grows and regulatory actions aimed at preventing maritime pollution, including shipping emissions, become increasingly important.

As the above discussion indicates, the recent heightened interest in increased maritime trade taking place in the Arctic, as well as a transition to LNG being utilized as maritime fuel present challenges for the region, but also represent opportunities for the region as well. As the rest of the world wants to increasingly utilize the Arctic region for the purposes of maritime trade, Arctic stakeholders and governance actors have the opportunity to safeguard that this trade and the related development activity are conducted in a manner that is conscious of the interests of the region. As has been stated, Arctic governance actors have the ability to address this opportunity through playing an increasingly important role in their own national legislative systems. Maritime governance in the form of the IMO policy crafting process, also affords Arctic governance actors the ability to seize this opportunity through engagement at the international level. Global interest in increased maritime trade taking place in the Arctic region and a transition to LNG offers both state and non-state actors of the Arctic the opportunity to increase the level of geopolitical influence of the region.

Simply put, through the processes and procedures alluded to above, Arctic governance actors can help ensure that any future increase in maritime trade related activities taking place in the Arctic is shaped and conducted in a way that takes into account the interest and concerns of the region. By paying careful attention to the interest and concerns of the region before the level of maritime trade significantly increases in the Arctic, regional governance actors can help ensure that the resulting benefits for the region are maximized, while safeguarding against the related risks. The transition to LNG being utilized as a maritime fuel in the Arctic offers an early opportunity for Arctic governance actors to exert influence in order to model a future increase in maritime activity within the region on their terms.

As a result of heightened interest in maritime trade taking place in the region, Arctic governance actors have an unprecedented opportunity to utilize the mediums mentioned above to lobby for regulations and policy endeavors that could be viewed as favorable to the Arctic. Perspective economic development or environmental protection proposals that Arctic governance actors have perhaps struggled in the past to gain support for from the wider geopolitical community might now become more achievable. The viability of such policy proposals would become more likely as a result of the Arctic having a strengthened negotiating status due to global trade interest in the region.

A policy option that has often been debated is that of a regulatory action aimed at eliminating the use of heavy fuel oil and other high sulphur content fuels. Such a ban on the burning of heavy fuel oil is currently in place for ships operating in Antarctic waters. Shah (2013), credits efforts by the Antarctic Treaty Consultative Parties along with the IMO for helping facilitate the achievement of the heavy fuel oil ban in the Antarctic entering into force in 2011. The prohibition of heavy fuel oil use in the Antarctic is a strong policy undertaking aimed at the protection of the Antarctic environment.

While a ban on heavy fuel oil in the Arctic, similar to the one existing in the Antarctic would be more difficult to enact due to the level of shipping activity in the Arctic being substantially higher, such a policy has been regularly debated. A ban on heavy fuel oil use in the Arctic would necessitate the transition to a compliant alternative form of fuel. One such option for a compliant fuel source under such a ban would be LNG, which the results of the cost-benefit analysis conducted in this study indicate would be favorable strategy. While a ban on heavy fuel oil use in the Arctic would have faced stronger opposition and therefore been harder to enact in the past, the increased interest global interest in maritime trade via the Arctic could make the prospect of such a policy gaining the requisite amount of approval more likely today and in the future.

Previous hurdles to a policy such as the Antarctic heavy fuel oil ban being adopted for the Arctic region might be more likely overcome in the current situation. The prospect of significantly more maritime traffic navigating through Arctic waters makes environmental protection and safety oriented policies such as a heavy fuel oil ban more necessitated today than in times past. As projections in the levels of maritime traffic in the Arctic increase, so too does the associated risks to the environment of the region. The need for policies and regulations designed to protect the Arctic environment are more demonstrable now than ever before. Research findings such as the results from the CBA conducted in this study are useful tools for Arctic governance actors to articulate the need for policies such as a heavy fuel oil ban and garner a higher level of international support for the adoption of such strategies than has been previously conveyed.

Another policy option that would accomplish similar aims as a heavy fuel oil ban would be to designate parts or all of the waters of the Arctic as an emission control area (ECA). Ghosh and Rubly (2015) consider the possibility of expanding the existing northern latitude emission control areas under IMO MARPOL Annex VI as a strategy option for effectively abolishing the use of heavy fuel oil in the Arctic region and expedite the use of emissions reducing compliance options such as LNG. In the absence of the designation of all Arctic waters an emissions control area, expanding the northern reaches of existing emission control areas such as the North American emission control area would be a means of intensifying the level of environmental protection for segments of the Arctic.

Expanding existing northern latitude emissions control areas to an extent that protects sectors of Arctic waters, would not only serve to protect areas of the Arctic located within the expanded emission control area, but would also benefit the wider Arctic region, even areas located outside the control zone. As many of the types of pollution generated by the burning of heavy fuel oil by ships is transboundary in nature, regulatory and policy efforts that protect part of the Arctic, such as expanding existing emission control areas, would also be advantageous for the environment of the entire region. Even if an expanded emission control area were to leave some sections of Arctic waters outside of the area covered by regulation, in reality, it is unlikely that ship owners and operators interested in engaging in maritime trade within the region would enlist the use of vessels that would not be compliant to operate in all areas of the region. Therefore, although from an environmental protection standpoint an emission control zone that covered all of the waters in the Arctic region would be the preferred policy option, the expansion of existing emission control areas to protect at least some of the Arctic maritime areas would in reality be a policy decision that would benefit the entire region.

As has been referred to earlier, the increased interest in Arctic maritime operations elevates the stature of the region in terms of geopolitical influence. Perhaps now, unlike in the past, Arctic stakeholders are in a position to exert their recently elevated influence to gain support from partners in the international community for policies such as a heavy fuel oil ban in the Arctic, that have previously been met with resistance. Heartened by the increased interest in maritime trade via the Arctic, governance actors representing the region have various means and strategies with which they can help encourage and incentivize members of the international community to support and embrace policies and regulatory efforts aimed at safeguarding the Arctic environment.

One strategy that Arctic governance actors could utilize in an effort to gather support for environmental protection policies such as a heavy fuel or ban or an emission control area being implemented in the region is to promote the development of infrastructure that would support maritime trade under the conditions of such directives. If the level of maritime traffic taking place in the Arctic is to dramatically increase, there will need to be substantial amounts of infrastructure developed in order to support the increased vessel traffic. Many of the third party support services that vessels depend on such as search and rescue services, communications infrastructure, repair and maintenance facilities, and weather forecasting services need to be expanded in order to accommodate a substantial increase in the level of maritime activity taking place in the Arctic region, with Buixadé Farré et al. (2014)

commenting that the scarcity of ports currently possessing repair and maintenance capabilities in the region is of a particular concern.

Arctic governance actors and stakeholders could strategically link a commitment to the development of infrastructure projects needed to support an increase in the level of maritime traffic in the region to the to the promotion of policies designed to protect the Arctic environment, such as a heavy fuel oil ban or establishment of emission control areas. By insisting that approval for development projects related to increasing and improving infrastructure to support increased shipping in the region be contingent upon enhanced environmental protection policies being enacted beforehand, Arctic governance actors have the opportunity to not only achieve policy safeguards for the Arctic environment but to also establish and exercise a heightened level of control and supervision over the future of development activity taking place within the region.

Once completed, infrastructure projects such as port and vessel support facilities can further promote environmental safeguards and protection strategies. Port facilities and vessel support service providers can offer inducements such as preferential tax rates and discounted or waived fees for vessels that utilize emissions reducing options such as alternative fuels like LNG, as a way to incentivize the adoption of emissions reducing technologies and strategies. Even under a scenario in which policies such as a heavy fuel oil ban or an emissions control area are in place, a policy of utilizing incentives such as discounted fees or tax reductions would serve as a continuous means of encouraging the adoption of the most current and advanced emissions reducing technologies and strategies. An incentive based approach to emissions reductions would also have the advantage of being easily updated and enhanced by Arctic stakeholders as deemed expedient, which would serve as a practical strategy of environmental protection in addition to more formal regulatory efforts. Individual Arctic states would be able to enact a system of emissions reduction incentives such as these unilaterally, without having to acquire a consensus of other Arctic states or the wider international community. Arctic states that were to act as early adopters of emissions reduction incentive platforms could reap a competitive commercial advantage and other Arctic states would thus be tempted to adopt similar strategies.

The promotion of environmental protection policies and strategies such as these represent an opportunity for Arctic governance actors to establish a heightened level of autonomy over commercial and development activity within the region, and doing so could prove to pay dividends for the region well into the future. The Arctic region is facing the prospect of entering a period of unprecedented change, not only of a physical nature but also culturally and socially as well. It is important that Arctic governance actors address the challenges of these oncoming changes proactively rather than waiting to respond to them after the changes have occurred. By seizing the opportunity to establish an increased level of autonomy through the promotion of environmental protection policies at the onset of these changes, Arctic governance actors will be better positioned to cope with these changes in the future.

6.4. Maritime Specific

6.4.1 Maritime Insurance

It is important to consider the results of the CBA of this study, which are in favor of the utilization of LNG as a maritime fuel for ships operating in the Arctic, in conjunction with the contemplation of governance covered in chapter 2 of this study. A useful task would be to examine ways in which these CBA results and the discussion regarding governance contained within this study can be merged together with practical issues and practices related to the maritime industry. By exploring ways in which the results of the CBA relate to the appraisal of governance we can identify ways in which the findings of this study can be used by relevant stakeholders and actors to initiate an actual transition away from heavy fuel oil.

A domain that offers the ability to achieve authentic transformation based on the outcomes of this investigation is the practice of maritime insurance. A recent example of the relationship between increased interest in Arctic shipping and the maritime insurance industry is the development of the Polar Code, which provides a useful framework for underwriters evaluating the risks associated with vessel operations in the Arctic region (Lloyd's 2017; Fedi et al. 2018; Mukherjee & Liu 2018). To gain further insight into how the practice of maritime insurance can serve to foster a transition towards LNG in the Arctic region we can examine the fundamental premise of maritime insurance as well as some underlying themes behind this vital aspect of the contemporary maritime industry.

Despite the associated complexities and related details, at the basic core of the practice of maritime insurance is the concept of a contractual arrangement in which a party known as an underwriter is paid an amount of money described as a premium, for agreeing to take on the maritime associated risks of either a vessel or a cargo, and in some instances both (Kingston 2007). Governance and a desire by maritime stakeholders to address genuine dilemmas with practical solutions plays a crucial role in the of the practice maritime insurance. A ship and cargo represent a significant capital commitment that faces numerous risks while at sea such as severe weather conditions, piracy, and capture during times of war, among numerous others perils (Kingston 2014). In the remote icy waters of Arctic region, risks such as navigational hazards and environmental harm are of heightened concern (Liu 2016). In the Arctic, as elsewhere, parties engaged in maritime trading seek to strategically reduce their exposure to maritime related risks through the practice of maritime insurance.

A brief inspection of maritime insurance divulges some concepts present within the practice that are particularly applicable to the current situation regarding the prospect of a transition to LNG for the Arctic region. The first is the use of informal governance as opposed to government legislation that has so often been utilized throughout the history of maritime insurance to enact reform within the practice as well as the wider maritime industry as a result (Kingston 2014). This lesson offers a guide for ways in which governance actions on behalf of the maritime insurance market can help initiate changes within the maritime industry in the absence of more formalized legislative actions being enacted on behalf of states or representative bodies. As a practice that is crucially vital to the continual operation of the global maritime industry and one that by design is intended to operate in the best interest of the involved stakeholders, the maritime insurance market is uniquely positioned to enact change, particularly when such a transition is considered to be in the best interest of maritime stakeholders.

If it is accepted, as the results of the CBA conducted in this study suggest, that it is in the best interest of society to embrace a transition away from heavy fuel oil towards LNG as a maritime fuel for use in the Arctic region, maritime insurance and associated fields can help enact this transition. Through the use of informal governance, in lieu of formal legislation, the maritime insurance marketplace along with institutions such as classification societies can take actions that will help instigate a transition away from heavy fuel oil towards more preferable options, such as LNG, for ships wishing to conduct operations within the Arctic region (Miller 1997; Boyce 2012). Research finding such as the results of the CBA reported earlier, might influence classification societies to update the requirements and standards for ships wishing to be classified as suitable for operating in Arctic waters and exclude ships that operate on heavy fuel oil from this categorization, thus facilitating a transition to LNG. Through such actions, classification societies would in effect be able to require a transition within the Arctic regardless of legislative actions or the lack thereof. Likewise, stakeholders engaged in the maritime insurance marketplace might be convinced by information and research findings such as the CBA results of this study, that it is in their best interest to require vessels wishing to be insured for maritime operations within the Arctic region to utilize a more preferable alternative to heavy fuel oil, such as LNG. If so, the insurance marketplace would be able to initiate a transition away from heavy fuel oil towards LNG to take place in the Arctic region by itself without having to rely on more formalized legislative actions to be enacted.

Another important theme of the practice of maritime insurance is the importance of information to the practice and how such information is relied upon and utilized by stakeholders in order to maintain confidence in the maritime industry (Behrendt & Solar 2014). The maritime insurance industry relies on the appraisal and dissemination of important and relevant information to make decisions and safeguard stakeholders. Likewise, the maritime insurance industry welcomes pertinent information such as the results and findings of this CBA, as well as related research on contemporary challenges facing Arctic shipping (Lloyd's 2017).

Information and data from contemporary research, such as the CBA results in this study, are useful to the maritime industry, and are the latest examples of how information has been vital to the industry throughout history (Solar 2016). As research such as this study, enables the maritime industry to have a better understanding of the concerns and challenges facing the industry, it enables industry stakeholders to be able to better craft strategies designed to address such challenges in the future. As research such as this CBA facilitate the issue of emissions from shipping activities to become better understood, industry stakeholders are increasingly better equipped to design strategies and policies to more adequately address the issue in the future. Under the current prospect of heightened shipping activity taking place within the Arctic region in the very near future, relevant information such as the CBA results of this study are of vital importance for stakeholders such as the maritime insurance marketplace and associated factions.

Another important aspect of maritime insurance is the vital reliance on trust (Kingston 2014). In order for the practice of maritime insurance to successfully function, there must exist an underlying appreciation of trust and confidence between all involved parties and associated stakeholders. This foundation of trust and confidence is a vital principle on which maritime insurance and the broader maritime industry that it supports relies upon. In order for this trust to be maintained, all parties involved must be able to have confidence that each party is acting in good faith, relying on honest and accurate information, and acting in a manner that takes into account any risks to safety of not only the involved parties but also any risks to society at large. Thus the open deliberation and dissemination of contemporary research findings, such as the CBA in this study, is important for maintaining a fundamental sense of trust and confidence among the broader maritime industry. In the instance of this study, maintaining a sense of trust is particularly important for Arctic stakeholders.

According to the results of the CBA of this study, society is better off if the LNG option is elected as an alternative to the heavy fuel oil status quo option for ships operating in the Arctic region. Based on these findings, it can be argued that stakeholders involved in Arctic shipping, such as the maritime insurance marketplace and associated parties such as classification societies, would also conclude that society as a whole would be better off as a result of adopting the LNG option. If so, it would be reasonable to assume that in order to preserve the foundation of trust and confidence that the maritime insurance marketplace and the wider maritime industry has relied upon over the centuries, that stakeholders would likewise embrace such a transition towards LNG as a replacement for heavy fuel oil in the Arctic region. The CBA conducted in this study and similar research has the potential to inform and motivate stakeholders to address the issue of shipping emissions in the Arctic region.

Through the measures proposed above and by advocating a transition towards LNG as an alternative maritime fuel for the Arctic region, stakeholders such as the maritime insurance industry would be maintaining a long held foundation of trust and confidence while working together to take into account and mitigate not only risks to parties actively involved in the maritime industry but also society at large.

6.5. CBA Strengths & Weaknesses

A consideration of the strengths and weaknesses of CBA and how they relate to the results of the analysis conducted within this study is useful for not only reflecting upon the results of this particular study but for also examining ways in which the work of this study can be expanded upon in the future.

Many of the concerns and criticisms directed at the use of CBA are related to the issue of uncertainty. As noted earlier, much of the uncertainty surrounding CBA is linked to the selection and quantification of impacts (Hickman & Dean 2018). Critics point to quantification problems in CBA often emerging in instances in which impacts are not included, when impacts are included but assigned negligible values, or when impacts prove extremely difficult to quantify and monetize (Hickman & Dean 2018). Identifying and assigning values to relevant impacts, particularly non-market goods or services, is among the most debated and controversial aspects of environmental CBA (Kuosmanen et al. 2009; Hwang 2016).

Another highly contentious aspect of CBA is the use of discounting and the discount rate (Atkinson & Mourato 2008). Utilizing too low of a discount rate will increase the present value of the benefits of projects under evaluation and thus increase the likelihood of the projects being accepted based on the criteria of the net present value test (Annema &Koopmans). The concept of net present value and discounting can seem complex, thus it is often difficult to explain and communicate, particularly to audiences unfamiliar with the procedure (Berman & Knight 2013).

CBA remains an extremely useful decision making tool despite these criticisms and weaknesses. The issue of uncertainty has been mentioned frequently throughout this study. As a novel application of CBA, uncertainty is indeed a challenge encountered by this study. To address uncertainty related to the Holland and Watkiss (2002) estimates utilized in the study a sensitivity analysis was performed. Like most examples of CBA, the valuation of benefits in this study involves uncertainty. As mentioned in the chapter 4, due to time and budgetary constraints, secondary data was utilized by this study instead of performing an original valuation exercise. The use of secondary sources of data in CBA is frequently used in instances when a lack of time or resources makes performing an original valuation study impractical, and analyzes incorporating secondary data have been regularly used in decision making processes (Atkinson et al 2018). An additional criticism of CBA is that it provides limited information, however even limited information is still useful in a policy making process (Kling et al. 2012). While critics might contend that CBA fails to capture and convey everything that needs to be known for policy-making decisions, CBA can indeed tell decision makers important information about a policy or project under evaluation (Hanley 2001).

Hockley (2014) observes that CBA has the potential to identify areas where additional research funding is needed to reduce uncertainty in policy related areas. The ability of CBA to identify and highlight areas where additional research is needed is particularly relevant to this study. Challenges such as limited information and uncertainty that were encountered by this study highlight excellent areas of opportunity for future research. Given unlimited resources to conduct further research, the work contained within this study could be expanded upon to address areas of uncertainty and voids of information in relation to the prospect of an energy transition occurring within the Arctic region.

Atkinson et al. (2018) highlight the report by Willis et al. (2003) that has proved exceptionally useful over time for forestry project appraisals in the United Kingdom as an example of a study that considerably facilitated additional research. Similarly given appropriate time and resources, it would be anticipated that a comprehensive, multidiscipline body of research might follow from the work contained within this study that would ultimately prove useful to policy makers in the future. There is ample opportunity for future research collaborations expanding on the work of this study. Expansion of this study could involve collaborations with researchers across a breadth of disciplines in the natural and social sciences. It is hoped that the approach taken by this study to examine a transition to LNG as a maritime fuel in the Arctic will facilitate future multidiscipline collaboration across the fields of geography, political science, economics and a broad range of other disciplines.

CBA provides a tool for examining energy transitions from a societal perspective. Examining energy transitions based on the criteria gains or losses to society can help prevent the implementation of energy transitions in which society becomes worse off. Large-scale hydroelectric projects in Brazil, which have been beleaguered with negative impacts such as severe deforestation and the displacement of indigenous populations are examples of what some would argue are energy transitions that have resulted in society becoming worse off and the transitions environmental CBA can help avoid (Riethof 2017). The ability to evaluate projects and policies from a societal view can be considered a strength of CBA as a decision making tool.

CHAPTER 7: CONCLUSION

7.1. Overall Conclusions

This final chapter summarizes and concludes the research presented in the earlier chapters of this study. Having answered the first two research questions by identifying and valuing the costs and benefits of the transition to LNG in the Arctic region, the third research question was then answered by the results of the CBA process based on the criteria of the net present value test. In chapter 5, all of the scenarios considered in the CBA process indicated that the LNG option should be accepted. Therefore in response to the third research question, it can be concluded that the benefits of the transition to LNG for shipping in the Arctic region are greater than the costs. Furthermore, based on the benefits being greater than the costs, it can be considered that society will be better off as a result of the transition to LNG in the Arctic being accepted as a policy.

The results of the CBA, which were that the strategy of utilizing LNG as a replacement for heavy fuel oil for ships operating in the Arctic region should be elected, present many interesting issues for discussion. These points of discussion draw many parallels with the earlier considerations of governance and energy transitions contained within this study. An examination of how the CBA results relate to the assessments of governance and energy transitions highlight some important policy and strategy implications.

Many of the lessons from previous energy transitions parallel the issues surrounding the transition to LNG in the Arctic region. As previous energy transitions have shown, the technological, cultural, and social context surrounding the transition to LNG, and the ways in which stakeholders respond to these issues will ultimately determine if the transition is a success.

While the CBA results of this study indicate that the LNG option should be accepted, LNG is not the only pollution abatement approach or option available to stakeholders. Some additional pollution abatement measures could be utilized in conjunction with the LNG option. Market based measures such as emissions trading schemes, innovative approaches such as improved ship designs, and other alternative fuels such as hydrogen, can all be utilized together with the LNG option. While some alternative pollution abatement strategies can be viewed as compliments to the LNG option, others are considered competitors to LNG utilization as a maritime fuel. As with all abatement strategies, these options will have positive and negative attributes to be considered by decision makers.

Examples from historic energy transitions indicate that incumbent forms of energy can often compliment the development of the replacement option. The possibility of LNG facilitating the development of hydrogen based energy solutions was reviewed. Similarities in infrastructure and handling procedures make the possibility of LNG acting as a facilitator of the development of hydrogen based energy systems an intriguing contemplation. For Arctic governance actors interested in the possibility of LNG acting as a transition fuel to hydrogen based energy solutions, the CBA results of this study would be emboldening.

The utilization of LNG as a maritime transportation fuel could facilitate the use of LNG in the Arctic for other purposes. LNG also has the potential to act as an alternative fuel for power generation as well as other purposes in the Arctic. LNG could also be combined with clean energy technology and strategy options to reform energy use in the Arctic. Examples of wind to hydrogen applications in rural communities were discussed to illustrate ways that LNG could play a role in transforming energy use in the Arctic beyond maritime applications. Research findings such as the CBA results from chapter 5 would be useful for policy makers contemplating the pursuit of these types of bold energy reform strategies for the Arctic.

The history of maritime trade offers some interesting lessons that correlate to the current governance situation in the Arctic. As history has shown, maritime transport has always been important and will only become more vital to the world economy as a result of globalization. As the importance of shipping continues to increase, so to will the impact that the sector has on the Arctic region. This projection only magnifies the importance and usefulness of this analysis and similar research findings.

Strategies for achieving sustainability in the maritime sector must be mindful that these strategies will be part of the extremely vast and complex practice of international shipping. Decisions regarding sustainability strategies aimed at the shipping industry must be mindful of the sophisticated broader context of the maritime sector in order for the strategies to be successful. Historically, political stability has played an important role in the success of the international shipping sector, and this lesson also speaks to the conditions in which a transition to LNG in the Arctic would be best supported.

The increasing influence of Asia, and China in particular, in Arctic affairs will have a substantial impact on the future of the Arctic, including the prospect of a transition to LNG as a maritime fuel taking place in the region. As trade between the East and the West continues to grow, the interest and influence of Asia in Arctic affairs will undoubtedly intensify. This enhanced influence is illustrated by a number of Asian nations recently being granted observer status by the Arctic Council. The transition to LNG as a maritime fuel in the Arctic presents an opportunity for Asian stakeholders to exert additional influence in the region. By investing in infrastructure and development projects associated with the transition to LNG, Asian stakeholders have the opportunity to establish a type of physical presence in the Arctic region.

The increasingly important role that Asian energy demands play in the global natural gas marketplace has implications for the transition to LNG as a shipping fuel in the Arctic. Natural gas is predicted to play an increasingly important role as developing nations attempt to transition away from a reliance on coal. The heightened demand for natural gas in Asia is reflected in the premium price paid by Asian buyers. Additional trends related to Asian LNG demand are increased flexibility in the natural gas marketplace and a decoupling of natural gas prices from crude oil prices. These types of reforms in the natural gas marketplace would help facilitate a transition to LNG being utilized as a maritime fuel.

An increased commitment to Arctic shipping and the related transition to LNG is an opportunity for the region to increase the amount of influence it is able to exert both globally and also within the respective governments of the eight Arctic states. The governance arrangement of the Arctic necessitates cooperation and there are numerous examples in which stakeholders of the region have successfully done so.

The transition to LNG as a maritime fuel will require extensive cooperation among Arctic governance actors. The transition also offers Arctic governance actors a unique opportunity to cooperate on an energy related issue that is not related to the exploration, extraction, and production of oil and gas resources located within the region. Research finding such as the results presented by this study can help encourage Arctic governance actors to engage in the level of cooperation that will be required for a successful energy transition in the Arctic region.

The transition to LNG as a maritime fuel is an opportunity for the Arctic region to increase the geopolitical influence of the region. One pathway for seizing upon the opportunity to wield a greater degree of influence as a result of the transition to LNG is through the maritime governance and the IMO policy crafting process. Maritime governance guided through the IMO policy shaping practice affords actors a unique opportunity to exert a higher level of influence than might otherwise be feasible in other settings. The example of small flag state nations being able to perform a considerable role in the IMO policy development process is offered as an example of significant maritime governance influence being exercised in this capacity.

The transition to LNG as a replacement for heavy fuel oil utilization by ships operating in the Arctic is an opportunity of governance actors of the region to insure that future development activity related to shipping operations in the region is conducted in a manner that is attentive to the best interest of the region. As the earlier discussions in this study indicate, the predictions of increased development and commercial activity taking place in the Arctic region in the near future are real possibilities. It is important that Arctic stakeholders are proactive in crafting policies and strategies for addressing the prospect of increased development activities in the Arctic region.

7.2. Policy and Strategy Implications

For Arctic stakeholders acting proactively to address the probability of heightened development in the Arctic region, research findings such as the CBA results of this study would have compelling policy and strategy implications. The transition to LNG in the Arctic region is an opportunity for governance actors to succeed in achieving policy and strategy objectives where previous efforts have failed in the past. Whereas previous environmental protection and pollution abatement efforts such as a proposed Arctic heavy fuel oil ban similar to the Antarctica ban, have failed to garner sufficient support, the transition to LNG has the potential to succeed. Findings such as the CBA results of this study can be influential in gathering the support that is necessary for the transition to LNG to be a success. For instance, proposed policies such as the establishment of an Arctic ECA would be supported by the CBA results of this study.

An initial commitment to infrastructure and service requirements related to the transition to LNG by Arctic stakeholders would greatly facilitate the transition becoming a success. The CBA results of this study and similar research findings can help Arctic policy makers justify commitments to infrastructure related to LNG utilization in the region. Policy makers could devise strategies that link the approval of LNG related infrastructure commitments to the adoption of additional environmental protection enhancements in an effort to increase the level of environmental protection throughout the Arctic region.

An intriguing sphere of the maritime industry in which governance actors could advance the transition to LNG as a maritime fuel for the Arctic is through the practice of maritime insurance. An overview of the maritime insurance industry and the important role the practice has played in the evolution of the maritime sector highlights ways that the industry can facilitate the transition to LNG being implemented in the Arctic. Throughout history, the maritime insurance industry has sought to provide practical solutions to dilemmas encountered by the maritime sector. By acting through the use of informal governance rather than formal legislation, the maritime insurance industry is uniquely positioned to enact change in the maritime sector. Over the years the practice of maritime insurance has continually evolved in order to respond to new challengers faced by the maritime industry. As the challenges of environmental protection and pollution from shipping become intensified for the Arctic region, maritime insurance once again has the potential to respond to challenges faced by the industry that depends upon it.

Since the earliest days of maritime insurance, the practice has been based on an underlying concept of trust between all involved parties, such as merchants, underwriters and brokers. This foundation of trust and confidence that is vital to maritime insurance has long relied on the exchange of accurate and reliable information pertaining to issues surrounding the maritime sector. Early examples of the reliance of maritime insurance on the exchange of information include the newsletters distributed in the earlier days of Edward Lloyd's coffeehouse in London.

Information and research related to the contemporary maritime sector is crucial in maintaining a sense of trust and confidence that risks to the maritime industry and society are being adequately mitigated. Predominant actors in modern maritime insurance such as classification societies and protection and indemnity clubs rely on the latest research findings concerning shipping related issues in order to make informed and judicious decisions. Information such as the results of the CBA of this study, which indicate that the LNG option should be accepted, and therefore society would be better off as a result of a transition to LNG in the Arctic, would be of great interest to parties involved in maritime insurance. The CBA results of this study would prove useful to the maritime insurance industry in devising policies and strategies designed to mitigate the risks associated with shipping pollution in the Arctic region. Support from the maritime insurance industry would prove instrumental for a transition to LNG taking place in the Arctic region.

7.3. Future Research Agenda

There are several opportunities for future research that can build upon the analysis conducted in this study. The research structure and framework contained in this study can be utilized with additional data such as different cost estimates to build upon and enhance the analysis conducted by this study. The research structure utilized by this study can also be employed to analyze shipping emissions in other areas of the world beyond the Arctic.

From a methodological standpoint there is an excellent opportunity for further research that incorporates qualitative research methods such as discourse analysis. The findings of this study can be incorporated with discourse analysis in order to gain an understanding of how different governance actors at the firm, country/regional and regulatory levels view not only the CBA results of this study but also the greater transition towards LNG being utilized as a fuel for maritime transportation in the Arctic. Future research using discourse analysis for interviews in order to consider what is said beyond the content of what is merely spoken but to also further analyze the context and background in which the communication is taking place in order to detect underlying themes of dynamics such as power, understanding or cultural norms would greatly contribute to an understanding of the broader issues surrounding a transition to LNG in the Arctic.

Additional future research would involve collaboration with other researchers from a diverse set of backgrounds in order to gain a more sophisticated understanding of dynamics related to energy transitions. Through collaboration with experts in various fields of physical and social science the research produced by this study can be expanded upon in order to make additional contributions to knowledge.

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UNIVERSITY OF ST ANDREWS
TEACHING AND RESEARCH ETHICS COMMITTEE (UTREC)

SCHOOL OF GEOGRAPHY & GEOSCIENCES
PRELIMINARY ETHICS SELF-ASSESSMENT FORM

This Preliminary Ethics Self-Assessment Form is to be conducted by the researcher, and completed in conjunction with the Guidelines for Ethical Research Practice. All staff and students of the School of Geography and Geosciences must complete it prior to commencing research.

This Form will act as a formal record of your ethical considerations.

Tick one box **STAFF project** . **POSTGRADUATE project** . **UNDERGRADUATE project** .

Title of project Name of researcher(s) Name of supervisor (for student research)

OVERALL ASSESSMENT (to be signed after questions, overleaf, have been completed)

Self audit has been conducted **YES NO**

There are no ethical issues raised by this project

This form must be date stamped and held in the files of the Lead Researcher or Supervisor. If fieldwork is required, a copy must also be lodged with appropriate Risk Assessment forms. The School Ethics Committee will be responsible for monitoring assessments.

Geography & Geosciences Preliminary Ethics Self-Assessment Form

Research with human subjects
Does your research involve human subjects or have potential adverse consequences for human welfare and wellbeing?
YES NO
If YES, full ethics review required

For example:
- Will you be surveying, observing or interviewing human subjects?
- Will you be analysing secondary data that could significantly affect human subjects?
- Does your research have the potential to have a significant negative effect on people in the study area?

Potential physical or psychological harm, discomfort or stress
Are there any foreseeable risks to the researcher, or to any participants in this research? **YES NO**
If YES, *full ethics review required*

For example:
- Is there any potential that there could be physical harm for anyone involved in the research?
- Is there any potential for psychological harm, discomfort or stress for anyone involved in the research?

Conflicts of interest
Do any conflicts of interest arise? **YES NO**
If YES, *full ethics review required*

For example:
- Might research objectivity be compromised by sponsorship?
- Might any issues of intellectual property or roles in research be raised?

Funding
Is your research funded externally? **YES NO**

If YES, does the funder appear on the 'currently automatically approved' list on the UTREC website?

YES NO

If NO, you will need to submit a Funding Approval Application as per instructions on the UTREC website.

Research with animals
Does your research involve the use of living animals? **YES NO**
If YES, your proposal must be referred to the University's Animal Welfare and Ethics Committee (AWEC)