COST-BENEFIT ANALYSIS OF TIDAL ENERGY GENERATION IN NOVA SCOTIA: A SCENARIO FOR A TIDAL FARM WITH 300MW OF INSTALLED CAPACITY IN THE MINAS PASSAGE IN 2020

by

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DEPARTMENT OF ECONOMICS

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TABLE OF CONTENTS

LIST OF TABLES vi

LIST OF FIGURES vii

ABSTRACT viii

LIST OF ABBREVIATIONS USED ix

ACKNOWLEDGEMENTS xi

CHAPTER 1 INTRODUCTION 1

1.1 MRE Sources 2

1.2 The Nova Scotia Scenario 3

1.3 Cost-Benefit Analysis 4

1.4 Thesis Outline 5

CHAPTER 2 TIDAL ENERGY TECHNOLOGY 8

2.1 Tidal Energy 8

2.2 In-stream Tidal Energy Technology 10

2.2.1 OpenHydro Turbine 12
2.2.2 Alstom BELUGA 9 Turbine 13
2.2.3 SeaGen “U” Turbine 14
2.2.4 Atlantis AK-1000 Mark II Turbine 16

2.3 Global R&D Advances in Tidal In-Stream Technology 18

2.3.1 United Kingdom (UK) 18
2.3.2 Canada 20
2.3.3 Norway 21
2.3.4 Republic of Korea 23
2.3.6 India 24

2.4 Challenges with Tidal In-Stream Technology 25

2.4.1 Predictability 25
2.4.2 Manufacturability, Installability and Operability 29
2.4.3 Survivability and Reliability 32
2.2.4 Affordability 32
2.4.5 Environmental Issues 34
2.4.6 Social Acceptability 35

CHAPTER 3 TIDAL ENERGY DEVELOPMENT IN NOVA SCOTIA 37

3.1 Electricity Market in Nova Scotia 37

3.2 Nova Scotia Renewable Electricity Plan 39

3.3 Project Analysis 43

3.3.1 TISEC Feasibility Study 44
3.3.2 Strategic Environmental Assessment (SEA) 46

3.4 FORCE 48

3.5 Energy Policy 51

CHAPTER 4 CBA OF TIDAL GENERATION IN NOVA SCOTIA 53

4.1 Scope of the Analysis 53

4.1.1 Purpose 53
4.1.2 Accounting Stance 54
4.1.3 Methodology 54
4.1.4 Economic Efficiency 55
4.1.5 Issues of Equity 58

4.2 Issues with CBA 64

4.2.1 Discount Rate 64
4.2.2 Shadow Pricing 66
4.2.3 Multiplier 67

4.3 Net Present Value 69

CHAPTER 5 COSTS AND BENEFTIS OF TIDAL GENERATION 71

5.1 Costs 71

5.1.1 Construction and O&M Costs 71
5.1.2 Network Upgrade Costs 75
5.1.3 Cycling Costs 76

5.2 Benefits 82

5.2.1 Emission Benefits 82
5.2.2 Co-Benefits of Air Quality Improvement 86
5.2.3 Fuel Savings 87
5.2.4 Capacity Benefit of Tidal Generation 89
5.2.5 Energy Security 93

CHAPTER 6 NET BENEFITS 95

6.1 Net Benefits of Tidal Generation 95

6.2 Sensitivity Analysis 97

CHAPTER 7 CONCLUSION AND DISCUSSION 100

7.1 Discussion 100

7.2 Conclusion 104

BIBLIOGRAPHY 105

APPENDIX A Consumer Price Indexes 111

APPENDIX B NPV Formula 112

LIST OF TABLES

Table 2.1 Summary of Key Challenges Facing a Large-Scale Tidal Farm Installation in the Minas Passage 26

Table 2.2 Minimum and Maximum Feasible Resources (MW) in the Minas Passage..... 28

Table 3.1 Breakdown of FORCE Funding 50

Table 4.1 Areas/Sectors from which Each County Surrounding the Minas Passage Could Benefit from a Commercial Tidal Farm 62

Table 4.2 Literature Review on Job Creation for the Development of Wind Energy Technology 63

Table 5.1 Summary of Cost Estimates 82

Table 5.2 Potential Annual CO2 Displacement from Tidal Generation 85

Table 5.3 Co-Benefit Avoided damage Valuation Estimates for CACs Emissions 87

Table 5.4 Summary of Benefit Estimates 94

Table 6.1 Assumptions in the Calculation of Net Benefits for the Base Case Scenario... 97

LIST OF FIGURES

Figure 2.1 OpenHydro Turbine [NSPI] 12

Figure 2.2 Clean Current Prototype 14

Figure 2.3 Alstom BELUGA 9 Turbine 14

Figure 2.4 SeaGen Turbine at EMEC 16

Figure 2.5 SeaGen "U" in Operational Mode 16

Figure 2.6 MW AK-1000 Mark II Tidal Turbine by Atlantis Resources Corporation 17

Figure 3.1 Nova Scotia Potential Energy Mix in 2015 and 2020 42

Figure 3.2 Eight TISEC Project Sites Surveyed in the TISEC Feasibility Report 45

Figure 3.3 Location of FORCE Test Site 49

Figure 5.1 The Power Output During a Spring and Neap Tide 73

Figure 5.2 Energy Loss Due to EDR Applied as a Cap on Net Tidal Generation Output 74

Figure 5.3 Installed Generation Capacity by Fuel Type in Ireland 79

Figure 5.4 Cycling Costs with Increase in Generation 81

Figure 5.5 Nova Scotia GHG Emissions Trends and Target 83

Figure 5.6 Monetary Value of Annual Fuel Savings 89

Figure 5.7 Capacity Credit of Tidal Generation 92

ABSTRACT

This thesis presents a cost-benefit analysis of tidal power generation with specific reference to the installation of a 300MW tidal farm in the Minas Passage, in Nova Scotia, in 2020, as a case study. Nova Scotia has set aggressive targets to increase the share of renewables in the province's electricity generation mix and tidal energy is considered to be the "sleeping giant" amongst renewable energy sources. After having estimated the many costs and benefits and having calculated the net present value of such a project, it is concluded here that the project should not proceed as its costs greatly surpass its benefits. However, it is recommended that further studies evaluating the costs and benefits at different levels of tidal penetration be conducted for the province.

LIST OF ABBREVIATIONS USED

CBA	Cost-Benefit Analysis
MW	Megawatt
MWh	Megawatt hour
GW	Gigawatt
GWh	Gigawatt hour
MCEDs	Marine Currents Energy Devices
R&D	Research and Development
UK	United Kingdom
FORCE	Ocean Research Centre for Energy
EPRI	Electric Power Research Institute
TISEC	Tidal In-Stream Energy Conversion
FIT	Feed-In-Tariff
FITT	Feed-In-Tariff for Tidal Energy
COMFIT	Community Feed-In-Tariff
UARB	Utility and Review Board
NSPI	Nova Scotia Power Inc.
GHG	Greenhouse Gases
MEUs	Municipal Electric Utilities
SEA	Strategic Environmental Assessment
OEER	Offshore Energy Environmental Research
ACOA	Atlantic Canada Opportunities Agency

EBED	Energy-Based Economic Development
RDAs	Regional Economic Development Authorities
NPV	Net Present Value
Capex	Capital expenditures
Opex	Operating expenditures
O&M	Operation and Maintenance
EDR	Electrical Down Rating
HVdc	High-voltage direct current
CO2	Carbon Dioxide
IPCC	Panel on Climate Change
CACs	Common Air Contaminants
RFF	Resources for the Future
MT	Megatonne
GJ	Gigajoules
LOLE	Loss of Load Expectation
FOR	Forced Outage Rate
LOLH	Loss of Load Hours
NPCC	Northeast Power Coordinating Council
EERE	Energy Efficiency and Renewable Energy
TC	Total Costs
TB	Total Benefits

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CHAPTER 1 INTRODUCTION

With the increase in awareness of climate change as a global issue, governments all over the world have committed to supporting efforts to protect the environment. One of the main causes of climate change is the increase in greenhouse gas (GHG) emissions in the atmosphere, which includes, amongst others, carbon dioxide (CO2). In fact, global atmospheric concentrations of CO2 have increased by about 50% since 1960.[1]A major contributor to the observed concentration increase of CO2 in the atmosphere is the combustion of fossil fuels, such as oil, coal and gas. As a result, the electricity sector has been identified as a key actor in bringing about a global solution to climate change. Moreover, the fact that the electricity industry is highly dependent on fossil fuels leaves it at the mercy of price fluctuations, as fossil fuel resources become more depleted while demand keeps on increasing. Therefore, in a bid to reduce reliance on fossil fuels, while simultaneously reducing electric generation system emissions, there has been a move towards the promotion of clean renewable technologies for electricity generation around the globe.

Canada is also part of this movement and "is working with the provinces and territories to reduce the environmental impact of electric power generation sources both domestically and internationally". (Environment Canada, 2011) Its approach for reducing emissions from electric power generation include "energy conservation and efficiency, climate policy, energy sources with low air emissions and low environmental impacts, and cleaning up sources with high air emissions, such as coal-fired

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[1] Average obtained from data from the Mauna Loa Observatory, Hawaii from http://www.esrl.noaa.gov/gmd/ccgg/trends/

plants."(Environment Canada, 2011). Canada's commitment to increase its supply of clean, renewable energy can be seen through its current research and investment initiatives in wind, solar, biomass, geothermal and hydraulic sources. Of further interest to this analysis is the development of hydraulic or marine renewable energy (MRE) sources.

1.1 MRE SOURCES

Harnessing energy from the oceans has long been of interest to scientists and inventors. However, it was only in the 1970s, following the oil crisis, that research and development of marine renewable energy technologies started to intensify. And it is only more recently, in the mid-1990s, that we have seen more commitment to developing those resources from governments all around the world. The oceans have great potential for harnessing energy as they cover 72% of the earth's surface. Moreover, if properly developed and managed, ocean energy farms can be inexhaustible, i.e. "could be harvested as long as the sun shines and the moon orbits the earth". (Wick et al., 1981) Ocean energy can take on many forms - wind, tides, surface waves as well as thermal and salinity gradients. The focus of this analysis is dedicated to tidal energy. The reasons for this are: 1) Canada has identified that most of its potential for ocean energy could come from creating a hydrokinetic sector[2] and 2) the greatest potential for ocean power generation in the Bay of Fundy comes from tidal currents.

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[2] The world's tides, ocean waves and river currents all contain kinetic and potential energy that can be used to drive turbines and produce electricity—reducing our dependence on fossil fuels. Natural Resources Canada identified "some 190 tidal power sites off Canada's coasts with a total estimated capacity of 42,000

1.2 THE NOVA SCOTIA SCENARIO

Nova Scotia is one of Canada's three Maritimes provinces and is surrounded by three major bodies of water, the Gulf of Saint Lawrence to the north, the Bay of Fundy to the west, and the Atlantic Ocean to the south and east. The Bay of Fundy is known to have the highest tidal ranges in the world, with about 100 billion tonnes of seawater moving in and out every day. Its tides represent an enormous resource of untapped renewable energy and the province of Nova Scotia has taken advantage of its proximity to establish itself has a world leader in tidal energy technology development. It has obtained this status with the creation of the Fundy Ocean Research Centre for Energy (FORCE), a test center for in-stream tidal energy technology, located in the Minas Passage, in the Bay of Fundy.

The Minas Passage is one of several sites to have been identified as having potential to harness energy from the tides. However, it is the one that has been attributed the largest potential in terms of resources available. Although the global development of tidal energy technology is still at an early stage and tidal energy has yet to be harnessed for commercial use, developers have high expectations for future developments. It is therefore based on those expectations that this paper will make an attempt at evaluating the net benefits of adding tidal generation to the province's electricity generation mix. More specifically, a scenario in which a tidal farm possessing 300MW of installed capacity would be built in the Minas passage by 2020 will be used in order to analyze the potential efficiency of such a project.

MW - more than 63 percent of the country's annual total consumption." (Natural Resources Canada, 2011a)

1.3 COST-BENEFIT ANALYSIS

In order to evaluate the net benefits of this project, this paper will perform a cost-benefit analysis (CBA), which is a common tool used for project appraisal in economics. As its name implies, the CBA maximizes the present value of all benefits less all costs in order to evaluate the profitability of a project. The approach adopted in this paper attempts to maximize the social welfare of the province of Nova Scotia and thus, incorporates both direct and indirect costs and benefits into the analysis. It is therefore assumed that the costs and benefits of tidal generation from this specific project are being paid for and reaped by society as a whole.

Several challenges in calculating the costs and benefits arise with this project for different reasons. First of all, since the technology is only at an early stage of development, the costs associated with it, mainly construction costs and operation and maintenance (O&M) costs, are not known for certain. Therefore, most of the costs calculated in this analysis are based on studies that have estimated them with the help of and inputs from, developers and tidal industry stakeholders. In addition, the project being analyzed will have environmental benefits if implemented, and “CBA in relation to the environment faces many challenges, not least in relation to the treatment of long-term effects, irreversibilities, risk and uncertainty.” (Hanley & Splash, 1993) Indeed, there are great debates in the literature about quantifying environment impacts and no agreement has been reached on how to do it as of today. Thus, this study uses theoretical and practical estimates that make the most logical sense in terms of the context in which the project would be implemented. Finally, since tidal generation has yet to become part of any country/region’s generation mix, the costs and benefits associated with the impact on the overall electricity market need to be estimated by using modeling systems built for the specific market that is being analyzed. Since mastering those modeling systems can take years and, consequently, is beyond the scope of this study, some of the costs and benefits estimated in this analysis are based on the modeling system for the Irish electricity market. But Ireland’s and Nova Scotia’s electricity markets differ in several ways and some of the estimates obtained for Nova Scotia will reflect this technical issue. It is therefore recommended that, in the future, a modeling system specifically built for Nova Scotia be used in calculating the cycling costs and fuel savings resulting from tidal generation.

1.4 THESIS OUTLINE

This thesis is composed of 7 chapters:

Chapter 2 provides a general understanding of tidal energy and the technologies that have been and are being developed to harness it. More time is spent, however, on explaining the workings of in-stream tidal energy devices and a description of each of the devices that will be tested at FORCE is provided. Moreover, an overview of global R&D advances in in-stream tidal energy technology is given and the general challenges associated with the devices themselves but also with tidal generation in Nova Scotia are summarized.

Chapter 3 gives a detailed description of the tidal developments that have been taking place in Nova Scotia. It provides an overview of the electricity market in the province and describes the efforts being put forward to move away from conventional sources and develop renewable energy sources. It also looks at the different studies that have been conducted in the province to determine the potential to harness tidal energy and gives a description of FORCE, what it has achieved and what it is looking to achieve in the future. Finally, a brief update on the legislative progress for tidal generation is provided.

Chapter 4 covers the basics of the CBA approach for this specific project by explaining the scope of the analysis in terms of its purpose, the accounting stance, the methodology and the concepts of efficiency and equity. It also summarizes the general issues faced when using CBA and explains the ways in which they are dealt with in this paper.

Chapter 5 describes the costs and benefits that will be included in this analysis, explains how they are being estimated and attributes a monetary value to each of them. The costs that are described include construction costs, O&M costs, network upgrade costs, cycling costs, and costs related to additional reserve requirements. The benefits include emission reductions, co-benefits from air quality improvement, fuel savings, capacity benefits and energy security benefits.

Chapter 6 combines the results obtained for the benefits and the costs to calculate the net present value of the net benefits of including tidal generation in the province's electricity generation mix. The result gives a large negative net present value, which indicates the project is not viable and that it should not be approved; this is mainly due to the large capital cost that needs to be incurred at the beginning. This result is then tested in a sensitivity analysis where a higher discount rate and a lower capital cost are used in the calculation of the net present value. But even with such changes, the net present value remains large and negative. Finally, the capital cost at which the project would yield zero net benefit is estimated in order to assess the feasibility of such a project by 2020.

Chapter 7 presents a discussion of the issues raised in this thesis, summarizes the main conclusions, and provides directions for possible future research.

CHAPTER 2 TIDAL ENERGY TECHNOLOGY

Tidal in-stream technology, much like most ocean energy technologies, is in an early development stage. It is therefore important to understand the technology itself and its stage of development in order to envision the possibility for the project being proposed in this analysis. The first section of this chapter provides a general description of what tidal energy entails and the ways in which it can be harnessed. The second section focuses on in-stream tidal energy technology and provides a detailed description of the devices that will be tested in the Bay of Fundy. The third section compares the different advances in in-stream tidal technology between global leaders in this industry. Finally, the fourth section outlines the main challenges that in-stream tidal technology is facing.

2.1 TIDAL ENERGY

"Tidal energy exploits the natural ebb and flow of coastal tidal waters caused principally by the interaction of the gravitational fields of the earth, moon and sun". (EMEC, 2012)It has the potential to offer a valuable source of renewable energy[3] in the future. Already, many economically viable sites[4] for generating tidal energy have been identified around the world. The most desirable locations for harnessing energy from tidal currents are usually sites where "narrow straits occur between land masses or are adjacent to headlands where large tidal currents develop". (Rourke et al., 2010a) More specifically, sites with a current velocity of 2.5 m/s or more have been identified as

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[3] There is an estimated 3 TW of tidal energy capacity available worldwide but less than 3% of this is located in areas suitable for power generation. (DTI, 2010)

[4] The major tidal currents can be found in the following locations: Arctic Ocean, English Channel, Irish Sea, Skagerrak-Kattegat, Hebrides, Gulf of Mexico, Gulf of St Lawrence, Bay of Fundy, Amazon, Rio de la Plata, Straits of Magellan, Gibraltar, Messina, Sicily and Bosporus. (Rourke et al., 2010a)

having the highest energy resource. Moreover, a great advantage of tidal energy is that it is predictable, unlike other renewable sources such as solar and wind. This advantage makes it less challenging to connect tidal power generation devices to existing electricity grids and more manageable when used together with other renewable sources as part of a regional generation mix.

There are two ways in which tidal energy can be harnessed: 1) from tidal barrages, i.e. dams, and 2) from marine currents energy devices (MCEDs). Currently, the majority of installed tidal energy capacity in the world comes from tidal barrages that have been constructed between the 1960s and the 1980s.The construction of tidal barrages is a well-known technology, which utilizes the potential energy of the tides. It has been developed on several large-scale commercial projects in the past. The largest one is the La Rance tidal barrage in France, which was constructed in 1967 and possesses a generating capacity of 240 MW. Such a facility can also be found in the Annapolis Valley in Nova Scotia. It was built between 1980 and 1984 as a government pilot project in the Bay of Fundy and has an installed capacity of 20MW. However, despite their proven success, barrage-based tidal projects have not been widely developed, mainly because of their environmental impacts[5] and high construction costs[6]. Since a brighter future for harnessing tidal energy in Nova Scotia seems to be possible with the development and use of MCEDs, tidal barrages as an option to harness tidal energy in the

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[5] "Building a dam across an estuary or bay may change the flow of tidal currents, affecting the marine life within the estuary and fisheries. Water quality within the basin may also be affected such as sediment transportation, resulting in changes in water turbidity. Maritime traffic will also be affected." (Rourke et al., 2010b)

[6] The construction of a tidal barrage requires a vast quantity of material, which puts the cost of construction far above the costs of constructing other renewable energy facilities.

future will not be further discussed in this paper.

The rest of this paper will be focusing on MCEDs, which unlike tidal barrages, are still at the prototype stage and have yet to be commercialized. However, from the knowledge accumulated so far, their environmental impact appears to be minimal and their long-term construction costs have been estimated to be cheaper than tidal barrages and even comparable to other renewable energy sources. Overall, "the high density of water and the predictability of the tides suggest that tidal turbines should be able to produce a large amount of reliable power, while the flexibility of individual turbines should make turbines more economically and ecologically attractive than tidal barrages". (Karsten et al., 2008) Generally speaking, the technology uses tidal current turbines, which are similar to windmills but deployed underwater, to extract kinetic energy in moving water. Basically, in order to harness in-stream tidal energy power, the turbines need to be installed in regions of high tidal flow. At present, several demonstration sites have deployed tidal current turbine prototypes with various degree of success[7]. Since MCEDs are the main focus of this analysis, more will be said about the technology, its challenges and global advances in the industry in the following sections.

2.2 IN-STREAM TIDAL ENERGY TECHNOLOGY

Since this analysis won't use any specific brand of MCED as a basis for calculating costs related to installing a commercial tidal farm in the Minas passage, but will rather use an average of available estimates that can be found for different in-stream

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[7] "Recent advances have translated into down-scaled models and full-scale prototypes of tidal current turbines" (Rourke et al., 2010b)

tidal devices at the commercial stage, the technology will be explained in its simplest form using a general model. On the other hand, since there are already four developers that have been chosen to deploy their prototype devices in the Minas Passage, a description of those devices will be provided for the reader to be able to picture what a future commercial tidal farm project of 300MW could look like.

There exist two common methods of tidal current energy extraction: 1) Horizontal axis tidal current turbine in which "blades rotate about a horizontal axis which is parallel to the direction of the flow of water" (Rourke et al., 2010b) and 2) Vertical axis tidal current turbine in which "blades rotate about a vertical axis which is perpendicular to the direction of the flow of water". (Rourke et al., 2010b) Regardless of the method used, there are three main components to a turbine: 1) a rotor, which is composed of blades mounted on a hub, 2) a gearbox, which connects the rotor to the generator and 3) a generator. Simply put, the moving water that passes through the blades causes the rotor to rotate, which in turn makes the generator turn. Finally, the electricity generated is then transmitted to the land to the connection grid through subsea cables.

In addition, those devices need to be mounted to a support structure in order to survive the harsh environments in which they are placed. There are three main kinds of support structures that exist today. The gravity and piled structures are both underwater and made of cement and steel. The difference between them is that the former is attached to the base of the device to achieve stability while the latter is pinned to the seabed using beams. The third option, the floating structure, is moored to the seabed by chains or wire and the turbine is fixed to a "downward pointing vertical beam", which is in turn fixed to the floating structure. As previously mentioned, the government of Nova Scotia has recently elected four turbines to be deployed at the demonstration site in the Minas Passage in the Bay of Fundy: a description of each device is presented below.

2.2.1 OpenHydro Turbine

The first device, designed by an Irish company called OpenHydro Ltd., is one of the world's most promising tidal current turbines for commercialization in the future. In 2006, it was the first company to install its turbine[8] at the European Marine Energy Centre (EMEC) demonstration site located in Orkney, Scotland. It also became, in 2008, the first to connect its turbine to the UK national grid and to generate electricity. In 2008, Open-Hydro Ltd. partnered with Nova Scotia Power Inc. to deploy a 10-metre, 1MW horizontal axis in-stream tidal turbine moored to the seabed by a piled structure in the Minas Passage. The turbine was the first one to be deployed at the site in 2009 for testing but was removed due to damage a few months later.

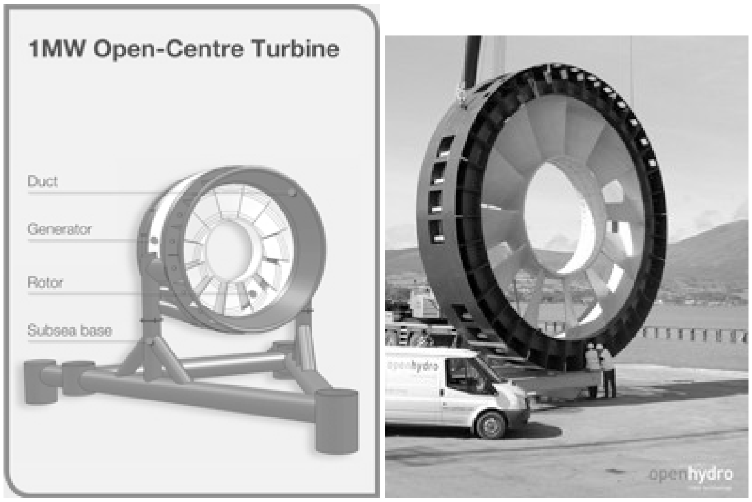

Figure 2.1 OpenHydro Turbine [NSPI]

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[8] Unlike the one installed in the Bay of Fundy, the turbine installed in Scotland is smaller with a height of 6 meters and a capacity of 0.25MW.

2.2.2 Alstom BELUGA 9 Turbine

In 2006, Clean Current Power Systems Incorporated, a Vancouver-based company and the designer, builder and operator of the only Canadian tidal in-stream energy conversion device, installed its prototype turbine at the Race Rocks Tidal Power Demonstration Project[9] site in Race Rocks, British Columbia. It was the first in-stream tidal device to be deployed in North America. However, due to technical issues, it was removed in 2007. After having some of its components redesigned, the current prototype, as shown in figure 2.2, was reinstalled at the demonstration site in 2008 for testing. During the same year, the company was selected to participate in the Bay of Fundy demonstration project and subsequently signed a technology-licensing contract[10] with Alstom Hydro, a power generation company with its headquarters located in France. It is only recently that Alstom revealed the BELUGA 9 turbine model, which is planned to be deployed in the Bay of Fundy in 2012. The BELUGA 9 model, as depicted in figure 2.3, is intended for very powerful currents (up to 4.5 meters per second). The turbine, which is also a horizontal axis tidal current turbine, has a diameter of 13 meters, a total height of 20 meters and a capacity of 1MW.

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[9] The official name of the project is Pearson College - EnCana - Clean Current Tidal Power Demonstration Project at Race Rocks since it is a joint project of the Lester B. Pearson College, EnCana Corporation and Clean Current Power Systems Incorporated.

[10] "The terms of the agreement between Alstom Hydro and Clean Current Power Systems Incorporated include an exclusive worldwide license for ocean and tidal stream applications for Clean Current's patented technology. The agreement also includes provisions for continued close cooperation between both parties in order to further develop technology, deploy demonstrator units and subsequently position Alstom Hydro as both an equipment and turnkey provider for tidal stream farms". (FORCE, 2011)

Figure 2.2 Clean Current Prototype
[Alstom]

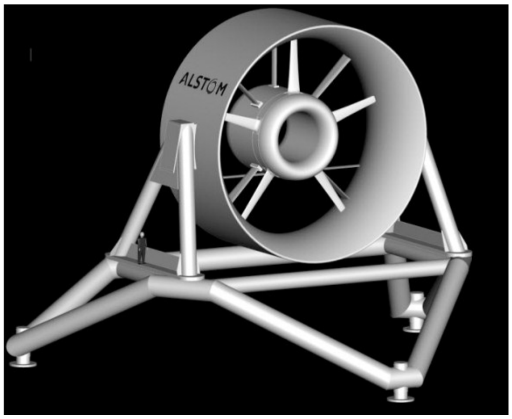

Figure 2.3 Alstom BELUGA 9 Turbine
[Alstom]

2.2.3 SeaGen "U" Turbine

In January 2008, the Minas Basin Pulp and Power Co. Ltd.[11]was awarded the right to construct the FORCE demonstration and research facility for tidal energy by the Nova Scotia Provincial Government. Following this award, the company partnered with Marine Current Turbines Ltd., a UK-based company, to test the SeaGen technology at the

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[11] The Minas Basin Pulp and Power Co. Ltd is "based in Hantsport, Nova Scotia, produces 100% recycled paperboard products, such as linerboard and coreboard, and is committed to the greening of Nova Scotia's energy sector." (Minas Basin Pulp and Power, 2012)

demonstration site. The SeaGen turbine was the first commercial scale tidal current turbine to be successfully installed in the UK in 2003 (See figure 2.4).Indeed, the 1.2MW horizontal axis turbine was connected to the grid in Northern Ireland in 2008 and has, since then, successfully operated at full power.

However, since the Bay of Fundy has much more powerful currents, Marine Turbines Ltd. is planning to install the latest model of the SeaGen turbine, the SeaGen "U" system, in the Minas Passage. "Fronted by a trio of 20-metre-diameter, bi-directional rotors feeding power units scaled up from those used on the original SeaGen, the new machine is rated at 3MW in 2.4m/s flow, putting it in pole position to be the most powerful tidal-energy system in the world when switched on". (Sniekus, 2011) See figure 2.5 for a physical representation of the SeaGen "U" system. In addition, the technology differs from the previous two models mentioned above: while the other devices use blades that are housed in a duct, the SeaGen "U" device uses three reversing pitch propellers, just like a conventional wind turbine. The deployment of this technology in the Minas Passage is planned for 2012.

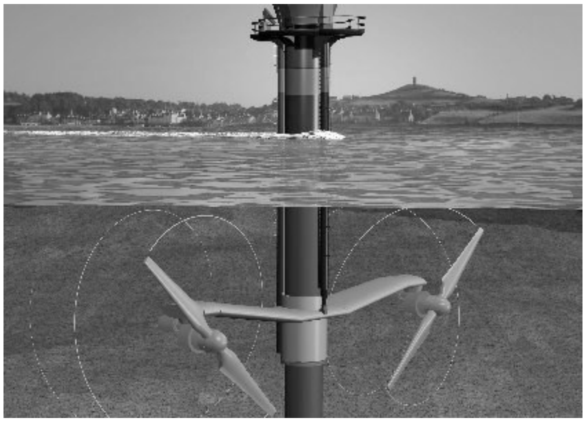

Figure 1.4 SeaGen Turbine at EMEC

[Marine Current Turbines Ltd.]

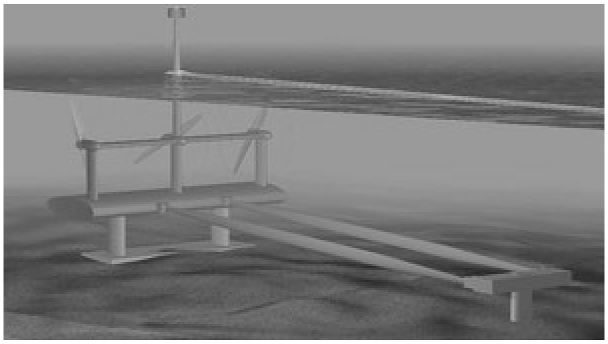

Figure 2.5 SeaGen "U" in Operational Mode
[Marine Current Turbines Ltd.]

2.2.4 Atlantis AK-1000 Mark II Turbine

More recently, in 2011, the four berth of the FORCE demonstration site was attributed to Atlantis Resource Corporation, based in Singapore, who partnered with Lockheed Martin and Irving Shipbuilding for the development and fabrication[12] of their one megawatt AK-1000 Mark II turbine. The horizontal axis turbine is designed for deployment in hostile environments. It is the largest tidal current turbine in the world: it stands at 22.5 meters tall, has a rotor diameter of 18 meters and has a water velocity of 2.65 meters/sec. "Atlantis AK series turbines feature a unique twin rotor set with fixed pitch blades", as portrayed in figure 2.6. (Atlantis Resource Corporation, 2009) The deployment of the turbine in the Minas Passage is also scheduled for the summer of 2012.

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[12] The partnership includes activities such as customizing, building, deploying and monitoring the turbine.

Figure 2.6 MW AK-1000 Mark II Tidal Turbine by Atlantis Resources Corporation (Government of Nova Scotia, 2011)

Moreover, Atlantis successfully connected its AK-1000 turbine to the grid at the EMEC in August 2011. The technology will be tested at the demonstration site for the next two years. If everything goes well with the testing, Atlantis is planning to develop a tidal farm with a capacity of 10MW in the inner sound of Pentland Firth[13], to which it was awarded the development rights by The Crown Estate[14] in the UK. The ultimate goal of this project would be to develop a fully operational tidal plant with a capacity of 398MW by 2020.

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[13] "It is estimated that in the United Kingdom, there is 18TWh/yr of technically extractable tidal current resource. 40% of this technically extractable resource is concentrated in the far north of Scotland (Pentland Firth and Orkney Islands)" (Atlantis Resource Corporation, 2009)

[14] The Crown Estate is a diverse property business valued at more than £7 billion, which possess over half the foreshore and almost all of the seabed around the UK. (Crown Estate, 2012)

2.3 GLOBAL R&D ADVANCES IN TIDAL IN-STREAM TECHNOLOGY

Since generating electricity from renewable energy sources is more expensive than electricity generation from conventional sources, the research and development of new renewable energy technology requires government support in order to accelerate innovation and allow development of the technologies on a larger scale. Marine renewable energy is not an exception to the rule and countries which have been able to provide assistance to developers whether in terms of funding, capital grants, tax incentives and legislative changes have been the ones fostering greater innovation and faster development of technologies. Moreover, those countries are usually the ones that are committed to reducing greenhouse gas emissions by increasing the share of renewables as part of their electricity generation mix.

There has been significant research and development on tidal current energy around the globe, but only a few countries/regions have actually demonstrated tidal current technology in ocean zones that have been assessed and deemed viable for tidal current energy generation. The best demonstration sites can be found in the UK, Canada and South Korea. Norway is also worth looking at in terms of technology innovation. Finally, India seems to be taking a path that many will take in the future.

2.3.1 United Kingdom (UK)

With its aspiration to have 20% of its generation mix provided by renewables in 2020 and with one of the world's best tidal energy resources, the UK is at the forefront of the renewable marine energy industry in the world. In fact, in the UK alone there is potential for 5 to 16GW in tidal current energy capacity, which could account for up to

15% of the UK's electricity generation capacity in the future.[15]

The UK has achieved its leadership through the creation of research and development (R&D) programmes and test facilities. Research initiatives created by academic consortia include the SuperGen Marine Research Program[16], the Peninsula Research Institute for Marine Renewable Energy[17], and the Low Carbon Research Institute Marine Project[18]. Moreover, the EMEC was the first facility of its kind to be established in the world. It is a test and research centre that was formed by a grouping of public organizations and that focuses on wave and tidal power development. Not only does it allow developers to test full-scale grid connected prototype devices in a site that has been identified as ideal for harnessing tidal and wave energy, it also monitors the operations of the devices and their impacts on the environment.

As mentioned in the previous section, several prototype devices have already been deployed at the EMEC test site and two of them, the OpenHydro and SeaGen turbines, are connected to the UK Grid. “At the end of March 2011 the UK had an installed capacity of 3.4MW of marine energy, consisting of 1.31 MW of wave energy capacity and 2.05 MW of tidal stream capacity”. (Renewable UK, 2011) Future development objectives for the industry include the development of small arrays, from 3MW to

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[15] DTI report

[16] “The overall aim of the program is to complete generic research on the potential for future exploitation of the marine energy resource. The second phase SuperGen Marine Research Consortium, a four year £5.5 million project which commenced in October 2007, includes five core academic institutions – the University of Edinburgh, Heriot Watt University, Lancaster University, Queens University Belfast and the University of Strathclyde – along with a number of affiliate institutions”. (Renewable UK, 2011)

[17] The creation of this institute is “a response from the Universities of Exeter and Plymouth to the challenges facing businesses involved in marine renewable energy.”(Renewable UK, 2011)

[18] The Low Carbon Research Institute Marine Project is “a £7 million three year program that aims to enable, support and help build a sustainable marine energy sector in Wales. The project consortium consists of Swansea, Cardiff, Bangor, Aberystwyth and Pembrokeshire universities”. (Renewable UK, 2011)

10MW, within the next 4 years. This includes the Sound Islay project, a demonstration tidal array of ten 1MW tidal devices to be placed in the Sound of Islay, Scotland. Further medium- to long-term ambitions are to deploy arrays with a capacity of 100MW. The ultimate goal is to establish anywhere from 1.3GW to 2.17 GW of installed capacity by 2020. Amongst the different scenarios, the Crown Estate's aggregated planned delivery of the Pentland Firth and Orkney sites represents a total installed capacity of 1.6GW.

2.3.2 Canada

Canada's commitment to develop renewable energy sources, coupled with the fact that it possesses the longest coastline in the world, shows the promise for considerable marine energy development in the country. On a national level, there are several government-funded institutions that are engaged in conducting R&D in the marine renewable energy industry.[19]At the regional level, the Nova Scotia's Offshore Energy and Environmental Research (OEER) Association is also involved in R&D and has performed numerous studies including assessments of potential tidal power in the Minas Passage and Minas Basin, as well as assessments of environmental impacts of proposed tidal power energy conversion devices. Moreover, Acadia University, located in Wolfville, Nova Scotia, announced in September 2011 the creation of the Acadia Tidal Energy Institute. "This Institute is the only research institute in North America focused solely on assessing tidal energy resources and the associated environmental challenges and socio-economic opportunities". (Acadia University, 2011)

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[19] They include CanmetENERGY (Natural Resources Canada (NRCan)), the Geological Survey of Canada (NRCan), the Institute for Ocean Technology (National Research Council (NRC)), the Canadian Hydraulic Centre (NRC), the Bedford Institute of Oceanography (Fisheries and Oceans Canada (DFO)), and the Centre for Offshore Oil, Gas and Energy Research (DFO). (OES, 2010)

In terms of demonstration sites for tidal current technology, there are different projects that are looking at river current technology and that have deployed their river current turbines in the St. Lawrence River.[20] On the east coast of Canada, FORCE is Canada's research centre for in-stream tidal energy. It is located on the Bay of Fundy in Nova Scotia. Similar to the EMEC, FORCE is a testing and monitoring facility where developers can test their tidal current devices and researchers are on site to monitor them. More will be said about FORCE and tidal current R&D in Nova Scotia in the next chapter. In addition, several demonstration projects can also be found on the west coast of Canada in British Columbia. The Race Rocks Ecological Reserve tidal demonstration project hosted the first in-stream tidal device in North America: the Clean Current turbine with an installed capacity of 65kW was deployed at Race Rocks, near Vancouver Island, in 2006. Finally, the commissioning of a 500kW tidal demonstration site in Canoe Pass, British Columbia, is planned for the spring of 2012. If the testing is proven to be successful, the site could be in full operation and connected to the grid by the fall of 2012. [21]

2.3.3 Norway

In 2010, Norway signed an agreement with Sweden for a joint green certificate market[22] to be in place by January 1, 2012. Even though Norway's tidal energy resource

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[20] The projects include Renewable Energy Research, a subsidiary of Group RSW, with their 250 kW TREK technology (Kinetic Energy Recovery Turbine) and Verdant Power Canada with the deployment of their horizontal axis turbine. (OES, 2010)

[21] Canoe Pass Tidal Energy Corporation (2010)

[22] Such certificate promotes green energy by offering producers of electricity from renewable sources a green certificate for every MWh of electricity produced, which can then be sold.

has yet to be officially assessed, different estimates[23] show that it possesses a palpable tidal energy capacity. And even though there are no special policies or programs dedicated to ocean energy in the country, significant research and development on tidal current energy have been included as part as the overall renewable energy policies. More precisely, the research cluster in Trondheim, comprising the Norwegian University of Science and Technology and SINTEF/MARINTEK, has been active in different areas of ocean technologies[24].

In terms of technology demonstration, Norway was actually the first to have a grid-connected offshore underwater turbine even though this achievement is often given to the OpenHydro prototype. The 300kWHammerfest Strøm turbine, the HS300, was installed in 2003 and connected to the grid in 2004 in Kval Sound, Northern Norway. It was tested until 2009 and was proven to be reliable. Based on the prototype, Hammerfest Strøm developed a large-scale 1MW turbine, the HS1000, over the next few years. Just recently, in January 2012, the HS1000 was installed at the EMEC for testing. The HS1000 turbine is also a candidate technology for the Sound Islay project. Indeed, if its testing is proven to be successful, 10 devices could be manufactured for the project in the near future. In the longer term, the HS1000 is even being considered to be part of the Pentland Firth Development project.

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[23] Froberg (2006) and Grabbe et al. (2009)

[24] Their activities include technology screening and verification, control systems, mooring, marine structures, safety, optimal design of devices and load modeling. (OES, 2010)

2.3.4 Republic of Korea

Like most of the leaders in marine renewable energy, Korea has been involved with research and development in both tidal and wave energy. There are many R&D institutes in the country working on ocean energy projects including the Maritime and Ocean Engineering Research Institute and the Korea Institute of Energy Technology Evaluation and Planning. Furthermore, in 2009, a national program funded by the Ministry of Land, Transport and Maritime Affairs was initiated to promote ocean energy education, research and development in universities.[25]

In May 2009, the country completed its first tidal current power plan, which possesses a capacity of 1MW. The Uldolmok plant, located in Uldolmok Passage in Jeollanam-do, southwest Korea, is equipped with two turbines of 500kW built by Hyundai Heavy Industries. After two years of testing, the trial site was successfully proven to produce target power generation.[26] Future development plans include the scaling up of tidal power generators to install large tidal farms in different sites across Korea. In 2007, the U.K. Company Lunar Energy and the Korean firm Midland Power have agreed to build a 300 MW tidal current power plant in the Wando Hoenggan Water Way, off the South Korean coast. The project will be made possible by the fabrication and installation of a 1MW prototype turbine by Hyundai Heavy Industries, which is the scaled up version of the 500kW turbines used in the Uldolmok plant. The project is

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[25] "The Korea Maritime University and Inha University are beneficiaries of the program. Also, Kwandong University, Wonkwang University and Pohang University of Science and Technology are partially supported to provide ocean energy courses for graduate students". (OES, 2010)

[26] Hyundai Heavy Industry press release 2011

expected to be reaching full capacity by December 2015.[27]Another project is the Inchon Tidal current farm, near Deokjok Island, which is to be having a capacity of 200MW and be generating around 613GWh annually by 2016.

2.3.6 India

Although India doesn't have much going on in terms of R&D and demonstration sites for tidal current energy, the government of the Indian state of Gujarat recently signed a memorandum of understanding with Atlantis Resources Corporation from England and Gujarat Power Corporation Ltd. to build a 50MW tidal farm on India's west coast. After running a global study of tidal power in 2008, Atlantis Resources Corporation identified the Gulf of Kutch in India as a site where the resource could match the capacity of the turbines. If the project follows as it is planned, the fifty Atlantis AK 1000 turbines would be installed in the Gulf with the construction starting sometime this year with the hope of being completed in 2013.[28] Even though this is less about India and more about the UK in terms of technology, these types of projects, in which already-tested technology is being used in tidal farm developments all over the world, are likely to be seen more and more in the near future.

As those projects reflect, there is much happening in the tidal current energy industry. Innovation is moving quickly and developers are almost in a race to commercialization. However, the development of tidal energy technology is confronted with many challenges and there is still much uncertainty as to whether the timelines set for future projects can be met.

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[27] Jo et al. (2010)

[28] Black (2011)

2.4 CHALLENGES WITH TIDAL IN-STREAM TECHNOLOGY

There are several issues confronting the development of tidal current devices. Table 2.1summarizes the key challenges facing a large-scale tidal farm installation in the Minas Passage. Overall, survivability and reliability are the most significant technical challenges due to the costs related to their failures.[29] Other challenges include affordability, social acceptability and environmental issues.

2.4.1 Predictability

Predictability refers to our ability to predict the resource and the energy capacity that can be extracted from it. More precisely, being able to predict the sensitivity of sites to energy extraction is crucial since it has been shown that extracting power from a channel can cause a reduction in flow speed, which in turn can result in a decrease in the energy flux.[30] Moreover, being able to predict the behavior of the tides is important in order to choose adequate demonstration sites where devices can be deployed but also to strengthen investor confidence in the ability of the devices to respond, perform and survive in the chosen location. Modeling techniques for wave and tidal current are constantly improving. Today, "…complex 2D and 3D representations and visualizations are now produced by animation houses from numerical models, including extreme events. Hydrodynamic modeling of the marine devices and their interaction with the complex sea surfaces and flow patterns is also improving, but it is not yet able adequately to represent the non-linear conditions in the forces acting to produce power and on the device." (Mueller & Wallace, 2008)

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[29] Carbon Trust (2006)

[30] Bryden and Couch (2006).

Table 2.1 Summary of Key Challenges Facing a Large-Scale Tidal Farm Installation in the Minas Passage

CHALLENGES	
Predictability	• Difficulty in predicting the sensitivity of sites to energy extraction • For the Minas Passage, three studies with different prediction based on different modeling systems: 1) Triton Consultants Ltd (2006) – 1903MW 2) EPRI (2006) – 300MW 3) Karsten et al. (2008) – 2500MW
Manufacturability, Installability and Operability	• Capacity to manufacture large number of turbines within short periods of time • Finding seabed characteristics on a large surface that meet the needs for the installation of large scale tidal farms • Spacing required between the turbines mainly for maintenance purposes • Maintenance is always complex as the need for a ship is required for routine maintenance as well as repair of the devices
Survivability and Reliability	• Ability to survive hostile environments such as the Bay of Fundy
Affordability	• High capital and O&M costs • Need to develop cost prediction mechanisms for specific technologies so that they can be compared in the future • Implement a FIT for tidal energy that meet the expectation of developers/investors • Obtain financing for projects
Environmental issues	• Impact of the turbines on fish and marine mammals • Environmental impact monitoring with arrays
Social Acceptability	• General public concerns about impacts on fish and marine mammals and landscape/seascape changes. • Lobster fishers concerns about the displacement of lobster trap setting activities as well as effects on migrating lobsters during construction as a result of noise, vibrations, or sediments.

Source: Adapted from Mueller, M. &Wallace, R. (2008)

In 2006, Triton Consultants Ltd. conducted a study on the Potential Tidal Current Energy Resources in Canada as the first phase of the Canada Ocean Energy Atlas. Although it was background research that was aimed at estimating the potential resources rather than the economically feasible resources, it concluded that near-term modeling studies should concentrate on three specific areas in Canada, which included the Minas Basin in Nova Scotia, in order “to improve the definition of the tidal current resources available, provide estimates of extractable energy and to make an initial evaluation of the environmental impact of tidal energy extraction”. (Triton Consultants Ltd, 2006) The study evaluated the mean potential power of the Minas Basin at 1903MW and, like the study that will be discussed next, only considered kinetic energy.

As will be discussed in further detail in the next section, the Electric Power Research Institute (EPRI) tidal in-stream energy conversion (TISEC) feasibility study is another study that has attempted to predict the resources available in the Minas Passage. The study suggests that 166 MW could be taken from Minas Passage and 100 additional MW from the Minas Channel. Since those two can’t be separated from each other, together the study estimated the resource to be close to 300 MW for the entire area. The EPRI method, however, only considers kinetic energy and does not address the impact of extracting the power. By extracting power, the flow through the passage can be changed, thus impacting the tides. The tidal currents through a passage are driven by the difference in water height at the two ends of the passage, which is called the tidal head. This difference is critical in estimating the correct amount of power that can be extracted and, when considered, the result of available resources can change dramatically as shown in the next study.

Karsten et al. (2008) from Acadia University examines the large tidal flow of the Minas Passage and concludes that more than 7000 MW of power could be extracted from it. This is a huge difference compared to study mentioned above. However, unlike the Triton Consultants Ltd. and EPRI studies, Karsten et al. (2008) looked at tidal flow and amplitude and found that by extracting the maximum amount of power (7000MW), the tides in the Minas Passage and Minas Basin would decrease by 36%. This would have a serious impact on the Bay of Fundy-Gulf of Maine system. Therefore, they use two-dimensional, finite-element, and numerical simulations of the Bay of Fundy-Gulf of Maine system to calculate the amount of power that could be extracted from the passage while limiting the impacts on the tides. They find that "2500MW of power can be extracted with at most a 5 per cent change in the tidal amplitudes." (Karsten et al., 2008) Even though there is still much to do to predict the extractable power more accurately[31], this study is the first of its kind to be done for the Minas Passage.

Assumptions for the maximum and minimum possible power extraction feasible for the Minas Passage, which are based on those three studies, are set out in Table 2.2 below.

Table 2.2 Minimum and Maximum Feasible Resources (MW) in the Minas Passage

High (Karsten)	Medium (Triton)	Low (EPRI)
2500MW	1903 MW	300MW

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[31] More specifically, the ongoing research is looking to use a "to extend the current results to the power potential of a farm of realistic isolated turbines using a higher-resolution, three-dimensional model of the Minas Passage". (Karsten et al., 2008) Moreover, much research still needs to be conducted to understand and examine the effectiveness of turbines downstream of other turbines.

2.4.2 Manufacturability, Installability and Operability

Issues arise with the devices when manufacturing, installing and operating them. Generally speaking, issues in manufacturing happen when developers decide to scale up their devices to commercial prototypes. In the case of the developers that have been awarded the berths at the FORCE, however, this issue seems to have been overcome as they all have commercial-scale prototypes with an installed capacity of 1MW ready for testing. But commercialization brings an even greater challenge: the capacity to manufacture large number of turbines within short periods of time. Presently, there are no developers that possess the capacity to manufacture turbines for commercialization. OpenHydro, for example, can only build one at the time and with only 20 employees, it would take the company years to be able to build 300 turbines (if we assume 300 1MW turbines will be need to built a tidal farm with 300MW of installed capacity). At the same time, there are bigger companies out there, such as Hammerfest Strøm and Marine Current Turbines that could invest huge amounts of money to scale up their manufacturing capacity. Another option could be the manufacturers of wind turbines, which could expand to manufacture tidal turbines. The issue with this option, however, is that there is already a long waiting list for wind turbines to be built. This analysis will assume that, by 2020, developers will have been able to expand their manufacturing capacity.

The installation of in-stream tidal devices, which includes fixing the foundation to the seabed and installing the devices, needs to be designed for ease and speed of installation since there is often only a short period of slack between tides. Luckily, some of the installation issues have been addressed by other offshore energy technologies. So far, only the OpenHydro device was installed in the Minas passage. The installation was a success and the turbine was lowered into its intended location within one hour. Both the barge used to deploy it and the deployment method were designed by the developer, while the mooring structure was fabricated locally.[32] There are some limitations, however, that can occur with the installation of turbine arrays. Basically, the seabed must meet two criteria: 1) it must be solid enough to have a turbine installed on top of it and 2) it must be flat. Those limitations do not usually represent a challenge when installing one turbine only. However, for a tidal farm composed of 300 turbines, such as the project that will be proposed in this analysis, it can become a challenge to find those characteristics for larger sites. Since the Minas Passage seabed is mostly rocky[33], it will be assumed that it is possible to find a site to install 300 turbines that possess both these characteristics. Furthermore, an interview with Professor Karsten confirmed that it would not be an issue to find space for that many turbines to be installed in the Minas Passage considering how vast of an area it covers.

One of the most considerable issues, however, with the installation of tidal arrays is the spacing required between the turbines, mainly for maintenance purposes. Indeed, turbines that are downstream from each other should be deployed at a greater distance[34] to avoid the risks of collision between them during maintenance due to the force of the tides. At the same time, turbines that are side-by-side but not downstream from each

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[32] OpenHydro (2009)

[33] Almost the entire seafloor of the Minas Passage is exposed bedrock with gravel deposits close to shore on either side. (Hagerman et al, 2006)

[34] A minimum distance of 200m is required (interview with Dr. Karsten, 2011).

other require a shorter distance between them in order to run the subsea cable as close together as possible and therefore minimize costs. The issue of spacing still has to be resolved, although some developers have already started to come up with different designs where one support structure can hold several turbines at a set space. It will be assumed that, by 2020, developers will have found a solution to this challenge and will be able to deploy several turbines together in one site.

Operability issues arise with maintenance and electricity transmission. In the case of a tidal farm in the Minas Passage, however, the challenges related to electricity transmission are lessened due to the proximity of the site to the transmission grid. Moreover, since the Nova Scotia government is already planning to upgrade the provincial grid to import hydro electricity from Lower Churchill by 2017, this analysis will assume that no extra costs will be associated with provincial grid updates to allow for tidal power to be distributed. More will be said about the Lower Churchill project in the next chapter. On the other hand, maintenance is always complex as the need for a ship is required for routine maintenance as well as repair of the devices. Furthermore, replacing large components requires calm waters and good weather. As a response to maintenance challenges, different concepts have been proposed, “most of which include the rising of the turbine above the water level to allow for maintenance from a platform or a ship”. (F.O Rourke et al, 2010a) Moreover, since there are several ports surrounding the Minas passage, having access to boats and repair facilities for maintenance would not be a huge issue. However, since no turbine has been in full operation due to the survivability issue, maintenance costs in the Minas Passage at this stage cannot be completely assessed.[35]

2.4.3 Survivability and Reliability

Survivability and reliability are the biggest challenge developers testing their devices are facing due to the economic consequences of failures and extended periods of unavailability.[36] This is the case for the OpenHydro at FORCE, which was only deployed for a month before its blades broke due to the high velocities[37]of the tides. This is a good example of a prototype which did not survive the hostile environment it was in. It is well known that the Bay of Fundy has the strongest tides in the world and therefore the devices that are being tested at FORCE must be designed to resist such an environment. However, since the prototypes are being tested in a monitored environment, which possesses the exact same conditions in which the commercial tidal farms would be installed, it is now easier to acquire knowledge about the different components' performance and to better the design for future testing.

2.2.4 Affordability

Affordability is definitely an issue at this stage as it is very expensive to develop tidal in-stream technology mainly in terms of capital costs. However, there are a lot of advantages associated with tidal generation including, amongst others, carbon emission reductions and energy security benefits. This issue is the one that is at the center of this paper and it will be discussed in greater detail in Chapters 5 and 6, where the costs and

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[35] At this point, only assumptions about maintenance costs can be made. More will be said about maintenance and costs in chapter 5.

[36] Carbon Trust (2006)

[37] "Shortly after the unit was recovered OpenHydro reported that blade damage appeared to be the result of peak velocities of up to 2.5 times stronger than originally predicted." (FORCE Annual Report, 2011)

benefits will be valuated and the net benefits of tidal generation in Nova Scotia will be determined. Moreover, the challenge of cost reduction for a number of devices in the long run has been addressed by different studies for the UK[38]. Indeed, by using a "progress ratio" that can be applied over time to costs, the learning process and the economies of scale that are achieved at the commercial stage can be reflected in the costs. However, estimates for progress ratio are highly uncertain at this stage. This analysis uses a progress ratio of 13% for capital and O&M costs based on Ernst and Young (2010). In addition, there is a need to develop cost prediction mechanisms for specific technologies so that they can be compared in the future. Otherwise, the construction of tidal farms may be hindered by the lack of knowledge about device-specific costs.

As well, there are still uncertainties around regulation and permitting of tidal energy projects. More specifically, whether or not tidal projects will be put forward will depend heavily on the feed-in-tariff (FIT) that the province will implement for tidal generation. If the FIT is not enough to cover the costs and meet the rate of return that the developers/investors are looking to obtain, no project will be developed. This is why cost reduction in the future is a priority for the development of tidal energy industries. Although the province has already implemented a community (for small-scale projects) feed-in-tariff for tidal generation (COMFIT), whether it is a good reflection of the actual costs of those community projects has yet to be proven since it is based on estimates only and no such project has been developed in the province yet. More will be said about the COMFIT and FIT for tidal generation in Nova Scotia in Chapter 3.

Such uncertainties further hinder advances in project developments as they make

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[38] Carbon Trust (2006) and Ernst and Young (2010)

them inherently risky, which in turn limit the financing options available for developers. Indeed, for "in tidal energy and renewable energy development in general, financing has been identified as a major barrier. Lending or equity raising terms can be prohibitive in many cases, i.e. high interest rates or expected returns on equity put pressure on project development timelines or returns on energy production. This pressure can result in project failures should minor alteration from the project plan arise". (Howell et al., 2011) Although it is important to mention it, no more emphasis is going to be put on this challenge in the rest of this paper since it is encountered at the company level and this analysis focuses on the challenges faced by the industry and provincial levels.

2.4.5 Environmental Issues

Environmental assessments need to be performed before any project is approved, especially to establish the risks to marine life, particularly with respect to noise and physical interaction with marine mammals. Since the Minas Passage is a relatively unused part of the Bay of Fundy[39], meaning that there is no shipping, no recreation and few fisheries activities, the potential impacts of a tidal farm are lessened. Moreover, there are very few mammals living or going through the passage[40], which also facilitates the monitoring of the interaction of turbines with marine mammals. The biggest issue so far in the Minas Passage is the impact of the turbines on fish; whether fish would avoid the turbines or would collapse with them still is an issue that has yet to be investigated. Fish monitoring is at a very early stage at the demonstration site: the types of fish that can be found in the passage still need to be identified as well as any fish migratory paths if

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[39] Interview with Dr. Karsten, 2011

[40] Porpoises can be found in the Minas Passage (Interview with Karsten, 2012)

they exist.[41] As will be mentioned in more detail in the following section, before approving the Minas Passage as a demonstration site for tidal energy technology, the government commissioned a strategic environmental assessment of the site. According to the assessment, it appears that the devices will have minimal impact on the environment. However, much monitoring is left to be done with the deployed prototypes in the future. It is also unsure how the environment would be impacted by an array of turbines: monitoring the impact of one turbine on the environment is likely to give very different results than monitoring the impact of 300 turbines on the same environment. Therefore, installation of tidal farms should be made progressively and monitoring should continuously take place as more and more turbines are being installed on the seabed.

2.4.6 Social Acceptability

The public is usually supportive of renewable energy technology developments mainly because there is an increased awareness of climate change and the environmental issues it creates. However, concerns arise with the potential issues related to environment impacts of in-stream tidal energy devices such as the impact on fish and marine mammals and landscape/seascape changes.[42] Social acceptability might also be harder to achieve from those who are involved in commercial activities, in this case fisheries. Although there are only a few lobster boats[43] that operate in the Minas Passage during the open seasons, the concerns of the lobster fishers are important to take into consideration. They include concerns about the displacement of lobster trap setting

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[41] Interview with Richard Karsten, 2011

[42] Howell et al. (2011)

[43] "There are a dozen license holders operating out of Parrsboro, four from Delhaven, and another eight from Halls Harbour, that are involved in this fishery during the open seasons" (Whitford, 2008)

activities as well as effects on "migrating lobsters during construction as a result of noise, vibrations, or sediments". (Whitford, 2008) As with the impacts of turbines on fish, research is required to assess the impacts of these factors on lobster populations. If the impacts that are assessed are as serious as to require the fishermen to be displaced, then financial compensation is likely to be required. Moreover, the visual impact of turbines, especially turbines such as the SeaGen model, which has a part showing out of the water, was identified as a potential cause of concern from the public. However, after consultations with the communities, visual impact has not been identified as a potential issue with the installation of turbines in the Minas Passage.[44] Finally, other concerns might arise from the interaction of a tidal farm with recreational activities. However, it doesn't seem to apply to the installation of a tidal farm in the Minas passage since, as mentioned previously, recreational activities in the passage are non-existent.

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[44] EPRI (2006)

CHAPTER 3 TIDAL ENERGY DEVELOPMENT IN NOVA SCOTIA

This chapter gives a detailed description of the tidal developments that have been taking place in Nova Scotia. Section 3.1 provides an overview of the electricity market in the province. Section 3.2 describes the efforts being put forward to move away from conventional sources and develop renewable energy sources as stated in the Nova Scotia Renewable Electricity Plan. Section 3.3 looks at the different studies that have been conducted in the province to determine the potential to harness tidal energy and section 3.4 gives a description of the FORCE, what it is has achieved, and what it is looking to achieve in the future. Finally, in section 3.5 a brief update on the legislative progress for tidal generation is provided.

3.1 ELECTRICITY MARKET IN NOVA SCOTIA

In Canada, the electricity sector is within the jurisdiction of provinces and territories as part of their control over their natural resources. As a result, all provinces and territories have utilities boards that regulate transmission and distribution rates. The Nova Scotia Utility and Review Board (UARB) is the entity responsible to perform such tasks in the province of Nova Scotia. Furthermore, provinces and territories have different arrangements when it comes to power generators/providers and distributors. While many are government owned across the country, Nova Scotia Power Inc. (NSPI), a subsidiary of Halifax-based Emera[45], is the largest power generating and delivery

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[45] Emera is a global electricity company, which generates and distributes electricity around the world. It possesses energy services and infrastructure in the Northeastern US, Atlantic Canada, St. Lucia, Grand Bahama and Barbados. It has a diversified portfolio of $6.8 billion in assets which include “a pumped

company in the province and is privately owned. Indeed, the company provides 95% of the generation, transmission and distribution of electricity in Nova Scotia. As a result, NSPI owns the majority of generating facilities as well as the transmission and distribution facilities. Their generating facilities include thermal generating stations[46], two wind farms[47], a tidal plant[48] and thirty-three hydro plants. Those stations account for the generation of 2,368 MW. As well as generating their own electricity, NSPI also buys electricity from independent power producers from wind, hydro and biomass. In terms of transmission and distribution systems, NSPI owns and manages 5,200 km of transmission and 25,000 km of distribution lines across Nova Scotia. Even though the province basically granted NSPI a virtual monopoly over the electricity sector, there still exist a few small public distributors all over the province.[49] However, most of those municipal distributors purchase their power from NSPI, although they are allowed to generate their own. Moreover, they are also regulated by the UARB. As will be discussed in more details in this chapter, the government of Nova Scotia has been encouraging small independent producers to develop power generating facilities of renewable energy by establishing community feed-in tariffs.

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storage hydro-electric facility, natural gas pipelines, a gas-fired power plant, an energy services company and a renewable tidal energy company." (Emera, 2011)

[46] They include the Lingan generation station (coal and light oil), Point Aconi generating station (coal and light oil), Point Tupper generating station (coal and light oil), Trenton Generating Station (coal and light oil), Tufts Cove generating station (natural gas) and combustion turbine in Burnside, Victoria Junction and Tusket (light oil). (NSPI, 2011)

[47] "There are currently two Nova Scotia Power-operated wind farms, located on Nuttby Mountain and Digby Neck as well as two individual wind turbine sites, located in Grand Etang and Little Brook". (NSPI, 2011)

[48] The Annapolis tidal plant, which is generating electricity from a tidal barrage.

[49] There are six regulated municipal electric utilities ("MEUs"), all of which are owned and operated by a municipality or a separate commission. (UARB, 2011)

Today, Nova Scotia's electricity is the dirtiest in the country when measured in per-megawatt capacity. Indeed, 80% of the province's electricity comes from imported coal and other fossil fuels. While the province has seen some improvements over the last two years and has been slowly moving away from coal by investing into natural gas and renewables, rising prices of fossil fuels and energy security concerns are still driving the province to find new ways to generate electricity from local sources. Moreover, concerns with reducing the emissions of greenhouse gases (GHG) have also been driving the need to develop cleaner and newer sources of energy to generate electricity. Indeed, the province's target is to reduce emissions by 10% below 1990 levels by 2020.[50]

Therefore, motivated by the desire to achieve greater energy security and to prevent climate change, the province has adopted a series of measures and has taken on several initiatives to reach these goals. The next sections will review the province's renewable energy targets and other objectives contained in its Renewable Electricity Plan as well as specific steps that have already been taken in order to develop the tidal energy technology sector in the Bay of Fundy.

3.2 NOVA SCOTIA RENEWABLE ELECTRICITY PLAN

In April 2010, Nova Scotia published its Renewable Electricity Plan, which outlines the path it wants to follow in order to insure greater energy security, reduce carbon emissions and move to greener energy sources in the future. More specifically, the province has established a short-term commitment of having 25% of its electricity generation mix provided by renewable sources by 2015 and a longer-term goal of 40% by

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[50] Nova Scotia Department of Energy (2010)

2020. See figure 3.1 for the province's expected generation mix in the future. The difference between the commitment of 2015 and the goal of 2020 is that the former is backed by the force of law and any failure to meet it will be penalized, while the latter is not a legal requirement.

In 2009, the province energy mix included renewables[51] (11.3%), natural gas (13.3%), and other fossil fuels[52] (75.3%). Today, renewable energy sources account for around 14% of its energy mix with providing around 1700 GWh/year of electricity demand. Considering those future amounts are forecasted based on 12,000 GWh/year of total provincial electricity sales, renewables should account for at least 3,000 GWh/year by 2015 and for 4,800 GWh/year in 2020.

The government of Nova Scotia is adopting two distinct approaches in meeting the 2015 commitment and the 2020 goal. More precisely, the 2015 commitment is planned to be reached mainly by installing wind power capacity backed by a limited amount of biomass, while the 2020 goal has a much broader scope and includes tidal and wind energy power backed by natural gas, more biomass capacity and imports of clean energy from neighboring provinces. The latter refers primarily to the development of Lower Churchill Hydro in Labrador, which is briefly mentioned in the Plan as a longer-term solution to provide clean, low-impact renewable energy imports to Nova Scotia. In fact, not long after the Plan was released, Emera and Nalcor Energy announced an agreement to develop Muskrat Falls as the location for the Lower Churchill Hydroelectric Project. "This $6.2 billion project has available an anticipated 800-megawatts of

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[51] Includes hydro, wind, biomass and tidal.

[52] Includes coal, pet coke, oil, diesel and other non renewable imports

electricity, enough to transmit electricity to Atlantic Canada and the New England markets." (Government of Nova Scotia, 2012) If developed as planned, it would provide the infrastructure necessary to the province to allow for an increased capacity in electricity transmission and would allow large-scale renewable energy projects to be more easily and cheaply connected to the grid. This project and its implications for this analysis will be discussed further in chapter 5. Finally, tidal energy is, as the plan calls it, the sleeping giant amongst Nova Scotia's renewable energy sources due to the identified energy harnessing capacity found in the tides of the Bay of Fundy. As mentioned previously, it is estimated that there could be anywhere from 300MW to 2000MW of extractable energy potential in the Bay of Fundy.[53]

As indicated in the previous chapter, the province has already taken some initiatives to develop what could rapidly become a worldwide energy industry. As an expansion of the support that started with the creation of FORCE, the plan is making a commitment to establish a feed-in-tariff for tidal energy (FITT). Since we know from prior studies' estimates that producing electricity from tidal energy is more expensive than producing it from conventional sources, it is imperative that the province shows support to tidal energy development. Therefore, by setting a community-based feed-in tariff (COMFIT) for small tidal projects that are connected to the grid and ready for distribution, the province is showing its commitment to greener community development. In addition, if the demonstration site, which will be discussed at greater length below, proves that in–stream tidal devices can be successful in harnessing tidal energy in the Bay of Fundy on a large scale, the province is also committing to authorizing "a special FIT

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[53] Hagerman et al. (2006), Triton Consultants Ltd (2006), Karsten et al. (2008)

for the development of tidal arrays connected at the transmission level. This FIT, which would be designed for commercial scale projects, would reflect both the cost of the turbines and their deployment and would provide incentives for investments in the industry. Moreover, the province is also looking to make it easier for developers to set forth those projects by developing a marine renewable energy legislation, which would include “appropriate licensing procedures, environmental protection, worker and public safety, and resource conservation…” (Nova Scotia Department of Energy, 2010) Except for the COMFIT that has recently been announced, these legislative additions are all still being drafted.

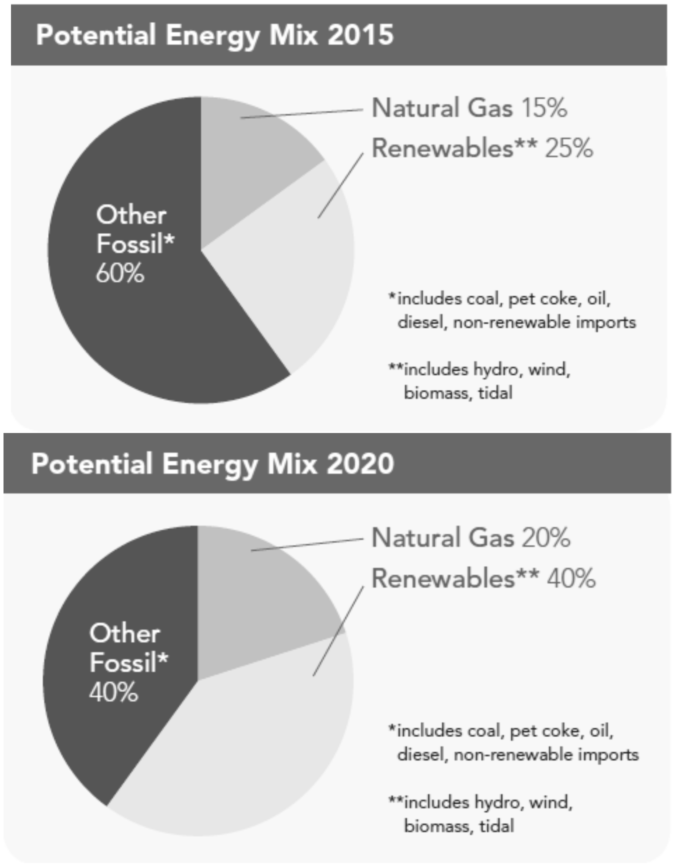

Figure 3.1 Nova Scotia Potential Energy Mix in 2015 and 2020
(Nova Scotia Renewable Electricity Plan, 2010)

The Plan also commits to continuing to identify sites that would be economically viable to harness tidal energy for projects. It has already done so by commissioning the EPRI feasibility study, which identified eight potential sites, but will continue its efforts in the future. This study, along with other initiatives that have already been taking place in the province, will be covered in more detail in the following section.

3.3 PROJECT ANALYSIS

There are different phases to public project work, including project identification, feasibility studies and cost-benefit analysis[54]. The province of Nova Scotia appears to have gone through the first two phases for the creation of FORCE tidal demonstration site. However, more studies of the kind will have to be conducted as the development of tidal technology evolves and tidal arrays of greater capacity can be installed. This analysis represents one of the phases that would need to be conducted for a large-scale tidal development project in the Bay of Fundy.

The project identification phase aims at satisfying high priority uses of the region's resources in order to meet important development objectives of the region. With the potential of the Bay of Fundy for tidal energy, it is only logical that the development of tidal in-stream technology has been identified, as potential projects could meet the province's future electricity generation targets.

The second phase has been conducted with the commissioning of the TISEC feasibility study, which evaluates different sites to develop a demonstration pilot project

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[54] Roemer and Stern (1975)

first and eventually commercial development projects. Moreover, since this project is one of the first of its kind in the world, many uncertainties about the environmental impacts of such project were unknown. Therefore, a strategic environmental assessment of Fundy tidal energy was also conducted. Although most of the environmental impacts still can't be predicted and there exist several information gaps, the study provided a series of recommendations to the government on the best ways to develop the project.

3.3.1 TISEC Feasibility Study

In 2006, the Nova Scotia Department of Energy and NSPI funded a TISEC Feasibility Study for Nova Scotia that was performed by the EPRI. The study identified the eight most promising sites in the province for the development of a pilot demonstration project to test a single tidal in-stream energy conversion device, as well as for future commercial developments. See Figure 3.2 for a map identifying those sites. More specifically, the report provided the basis for selecting a site for a pilot demonstration project that could produce 1,500 MWh/year (500kW) and a commercial tidal farm with a production capacity of 30,000 MWh/year (10MW). (ERPI, 2006) Since tidal current energy is a predictable but still variable energy source, those production capacities were evaluated with a 40% capacity factor. The cyclical nature of the tides and the need to assume a capacity factor will be explained further when the costs associated with tidal generation will be described. Furthermore, most of the eight selected sites met the specific criteria for channel depths, seafloor properties, grid interconnection, maritime infrastructures, and environmental issues. Amongst the eight sites, the Minas Passage was the one identified with the most potential capacity for installed TISEC, with 300MW of potential installed capacity. However, only the Minas Passage and one other site, the Digby Gut, were identified to be fit for commercial use. The Cumberland Basin might be another site, but since it does not meet all the criteria for the installation of TISEC devices, it requires more examination.

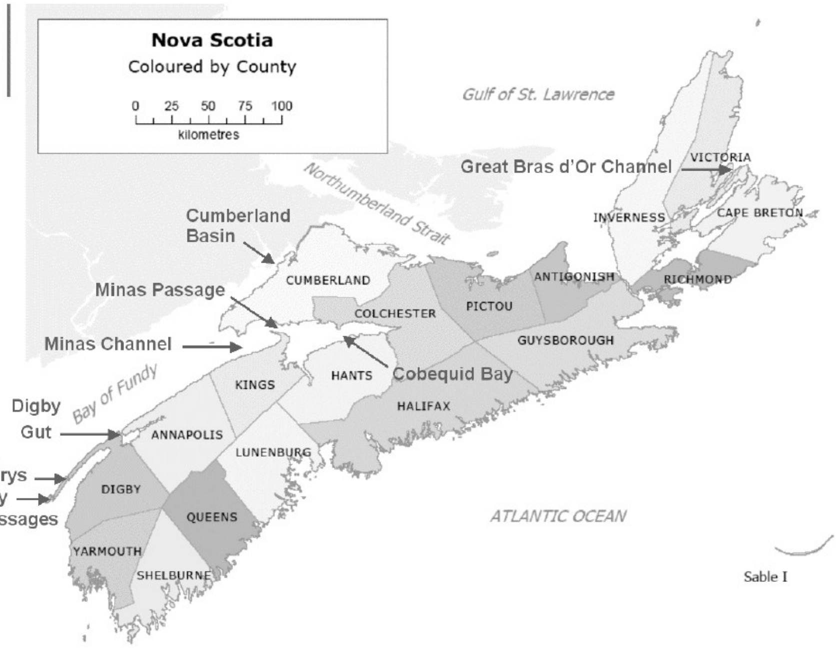

Figure 3.2 Eight TISEC Project Sites Surveyed in the TISEC Feasibility Report (Hagerman et al., 2006)

For each site, they look at the following criteria: 1) Tidal In-Stream Energy Resource, 2) Seafloor Bathymetry and Geology, 3) Utility Grid Interconnection, 4) Maritime Support Infrastructure, 5) Environmental considerations and 6) Unique opportunities, most of which have already been discussed in section 2.4. In terms of unique opportunities, the study states that if tidal power generation from the Minas Passage is realized, it would have “substantial spin-off benefits likely to be supported by regional agencies responsible for economic development and infrastructure provision". (Hagerman et al., 2006) This will be discussed later when the benefits of the tidal project proposed in this analysis will be examined.

3.3.2 Strategic Environmental Assessment (SEA)

In 2007, the Nova Scotia Department of Energy commissioned the Offshore Energy Environmental Research (OEER) to conduct a strategic environmental assessment of Fundy Tidal Energy. The objectives were to assess the potential economic, social and environmental effects of installing marine renewable energy technology in the Bay of Fundy and to further provide advice on whether or not, and if so when and how, a demonstration pilot project and future commercial plants should be allowed. More precisely, it emphasized the need for assessing the environmental impacts on marine ecosystems and coastal environments, the socio-economic impacts on fishers and fisheries, and the potential contributions to the community and regional economic development of Nova Scotia. The study evaluated all the possible options for marine renewable energy technology, which included wave, offshore wind, tidal in-stream and lagoon energy conversion technologies, but the SEA's focus was on TISEC devices.

In order to support the SEA, the OEER Tidal Advisory Group commissioned a background report to be conducted under the leadership of Jacques Withford. The report had three well-defined objectives: (1) to draw together existing information on the environment, the socioeconomic context, and marine renewable technologies, (2) to address potential interactions with the technologies, and (3) to identify information gaps (Whitford, 2008). Overall, the background report assessed and explained the state of the different marine renewable energy conversion technologies and further developed an analysis of the impact they would have if developed in the Bay of Fundy. More specifically, the impacts they would have if deployed in the Minas Passage and the Digby Gut were analyzed. Choosing those two sites made the assessment of the environmental impacts easier to conduct, as specific environmental conditions could be determined. Although the report analyzed socio-economic and environmental impacts with much detail and scrutiny, the conclusion still emphasizes the lack of understanding of such impacts due to the early development stage of marine renewable energy conversion devices and more specifically of the TISEC devices. It was unclear at the time of the study, and still is today, how the different phases of a commercial project implementation would interact with the environment, and the development of more advanced research tools are recommended. The same appears to be true for economic development prospects. The report does a good job at identifying the potential impact of developing commercial tidal energy conversion sites on community and regional development but again, it is difficult to quantify those effects since no commercial sites have been developed yet in the world. The report does recommend, however, that the first step in understanding those effects is to set up small pilot projects with strong monitoring and adaptive management plans that could eventually evolve into demonstration projects and later on into commercial scale developments.

It is based on this background report that the SEA made its recommendations for future developments of tidal energy in the Bay of Fundy for Nova Scotia. The final report was submitted in 2008 and provided a set of 29 recommendations on principles of sustainability to be included in the legislative framework of Nova Scotia for renewable marine energy, in research programs and studies, in the implementation of demonstration sites, on the processes for commercial development of marine energy projects, on coastal zone management and on interactions with fisheries and communities for regional development. This final report was what the province required to move on with the creation of a demonstration site for marine energy technology.

3.4 FORCE

FORCE is Canada's lead test centre for tidal energy technology. It is described as "a public/private partnership that enables developers, regulators, scientists and academics to study the performance and interaction of tidal energy turbines with the Bay of Fundy environment". (FORCE, 2010) The government has elected four participants to test their turbines in the four berths available at the demonstration site: Nova Scotia Power, ALSTOM, Minas Basin Pulp and Power and Atlantis Resources Corporation, all in collaboration with turbine developers as mentioned previously. The FORCE test site is located in the Minas passage, 10 kilometers west of Parrsboro (see Figure 3.3 below).

FORCE receives funding from both the provincial and the federal government as well as from the private sector. See table 3.1 for the breakdown of funding. The initial funding came from ecoNova Scotia[55], a program that supported projects that reduce air emissions, and provided FORCE with $6.8 million for 6% of total funding. Federally, it received money from the Atlantic Canada Opportunities Agency (ACOA)'s Community

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[55] "In March 2007 the Government of Canada distributed the Clean Air and Climate Change Trust Fund, about $1.5 billion, to the provinces and territories based on population. Nova Scotia's share of the trust fund was just under $42.5 million. The Nova Scotia government formed ecoNova Scotia to administer these funds. ecoNova Scotia officially ended on March 31, 2011". (ecoNova Scotia, 2011)

Adjustment Fund[56], a fund created in 2009 to help create jobs and employment opportunities in communities affected by the global recession, and from the Natural Resources Canada clean energy fund, which is investing in "large-scale carbon capture and storage demonstration projects and smaller-scale demonstration projects of renewable and alternative energy technologies". (Natural Resources Canada, 2011) Private investments include a $3 million zero-interest loan from Encana Corporation towards common costs. Moreover, "these investments leverage significant additional investment from participating FORCE developers, each of which is expected to spend between $10 and $20 million to build and install each tidal turbine, and contribute $1 million towards FORCE's common costs". (FORCE Annual Report, 2011)

Figure 3.3 Location of FORCE Test Site (FORCE, 2011)

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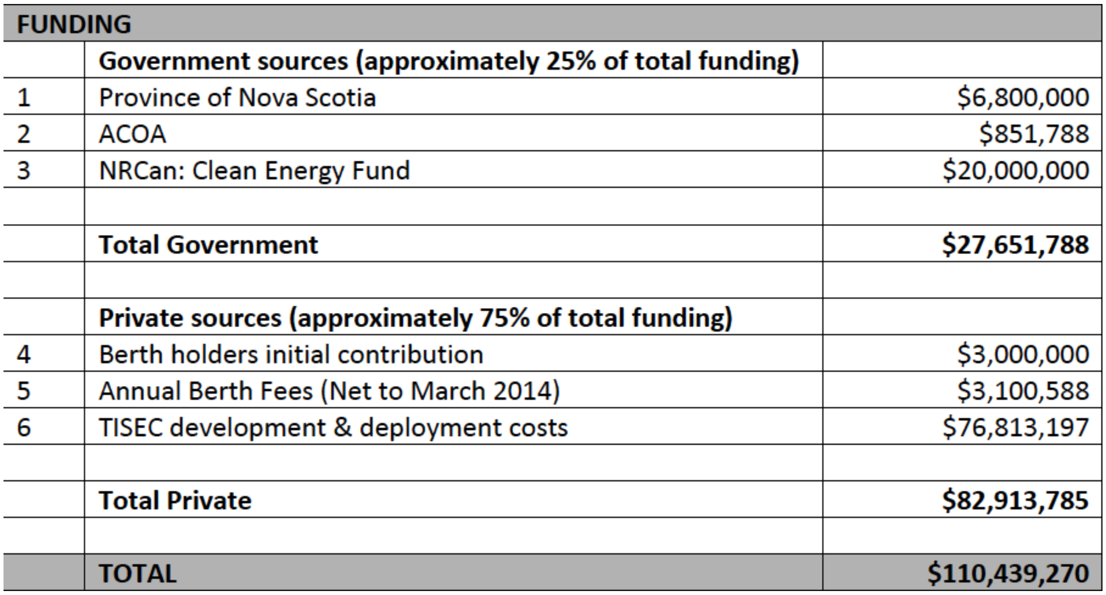
[56] Atlantic Canada Opportunities Agency (2012)

Table 3.1 Breakdown of FORCE Funding



FUNDING		
	Government sources (approximately 25% of total funding)	
1	Province of Nova Scotia	$6,800,000
2	ACOA	$851,788
3	NRCan: Clean Energy Fund	$20,000,000
	Total Government	**$27,651,788**
	Private sources (approximately 75% of total funding)	
4	Berth holders initial contribution	$3,000,000
5	Annual Berth Fees (Net to March 2014)	$3,100,588
6	TISEC development & deployment costs	$76,813,197
	Total Private	**$82,913,785**
	TOTAL	**$110,439,270**

Source: FORCE Annual Report, 2011

Several developments have taken place since Minas Basin Pulp and Power was awarded the contract to lead FORCE development in 2008. As mentioned in previous sections, the OpenHydro turbine was deployed and retrieved. In addition, the subsea cables were ordered from Italy and delivered, secure underground vaults and concrete conduit were constructed to house the subsea cables, the FORCE observation facility was constructed and the visitor exhibit was designed and installed. Another important development was the signing of a strategic agreement between EMEC and FORCE to help advance the marine renewable energy industry worldwide. Moreover, there are also many activities planned for 2012, which include the construction of an electrical substation[57] and a transmission line[58], the installation of the subsea cables and

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[57] For the substation, FORCE selected a design that could be operated at 5MW but was capable of being upgraded with the least waste should the need arise. (FORCE Annual Report, 2011)

the deployment of devices. Once installed, “the cables will give FORCE the largest offshore transmission capacity of any in-stream tidal energy site in the world”. (FORCE, 2011)

3.5 ENERGY POLICY

Even though, the process of commercialization seems to be held back from a technical design point of view, the province is making progress on paper. In 2010, the province put the tidal FIT into regulation and in July 2011, it announced the rates for the COMFIT tariffs. As established in the 2010 Renewable Plan, the UARB is responsible for setting and periodically reviewing the FIT and COMFIT rates according to criteria established by the provincial government. In the process of developing Renewable Energy Community Based Feed-in Tariffs, Synapse Energy Economics Inc. acted as a consultant for the UARB to submit proposals for COMFIT. Their proposal for the tidal COMFIT is based on cost estimates assessed by different studies.

[59]Based on this report, the UARB has set the COMFIT rates at $0.652/kWh. This tariff is based on a 500-kilowatt installation employing one or more in-stream tidal generators.[60]For larger commercial projects, however, the array of FIT rates have yet to be announced; the UARB is planning to have something ready in 2012. If the results of this analysis for the development of a tidal farm with 300MW of installed capacity would have been favorable for the approval of the project, the results could have been used to

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[58] Similarly to the substation, FORCE chose a transmission line that would meet their immediate needs but that could be upgraded if needed without significant stranded investment. (FORCE Annual Report, 2011)

[59] Estimates used were assessed by Ernst & Young (2010), Fundy Tidal, Champlain Tidal Energy and The Canoe Pass project. (Synapse Energy Economics Inc., 2010)

[60] UARB (2011)

help set a FIT for tidal development (FITT) in the province. However, since the conclusions are unfavorable to the project, the FITT should be based on a different scenario, more likely a tidal farm with a lower installed capacity.

CHAPTER 4 CBA OF TIDAL GENERATION IN NOVA SCOTIA

This chapter covers the basics of the CBA approach for this case study. Section 4.1explains the scope of the analysis in terms of its purpose, the accounting stance, the methodology and the concepts of efficiency and equity. Section 4.2 summarizes the general issues faced when using CBA and explains the ways in which they are dealt with in this paper. Section 4.2 explains the evaluation criteria that will be used in this analysis.

4.1 SCOPE OF THE ANALYSIS

4.1.1 Purpose

This thesis will analyze the social costs and benefits associated with the commercial installation of a tidal farm in the Minas Passage possessing an installed capacity of 300MW in 2020. Such a farm would account for an approximate 11% share of the Nova Scotia electricity generation mix assuming that the total Nova Scotia generation will stay constant at 12,000 GWh per year until then. The decision to choose this project is based on estimates from studies on the potential resources to extract tidal power from the Minas Passage while taking into consideration the timeline of the project. Moreover, tidal development plans in different parts of the world are already planning to build plants of more than 300MW by 2020. Finally, an interview with Melanie Nadeau, senior manager of sustainability at Emera, confirmed that it is quite realistic to be thinking about developing around 300 MW of tidal power in Nova Scotia between now and 2020. Her main concern was regarding the site selection, but as explained in the previous chapters, this analysis will assume that the Minas passage is economically viable for the installation of commercial projects and that its seabed conditions would allow for an array of 300 turbines to be deployed.

4.1.2 Accounting Stance

The accounting stance refers to the people that will be affected by the project. For the sake of time and simplicity, the accounting stance will be accrued to a specific area, which is the province of Nova Scotia. Since the tidal farm would be located in the province, it would most directly affect the population of Nova Scotia. Moreover, the province is a supporter of the project and has committed some public funds to this development project. In addition, since the province of Nova Scotia has traditionally been considered a have-not province, the particular effects of this development project on the province are of greater interest for the purpose of this thesis.

This is not to say, however, that the effects of developing tidal energy farms won't spread to the rest of Canada and the rest of the world. Actually, a cost-benefit analysis claiming to make accurate measurements of every effect related to the project would have to add those two extra accounting stances in its analysis.

4.1.3 Methodology

Generally speaking, there are two basic approaches that can be used in a cost-benefit analysis. The general equilibrium approach involves the identification of all the gains and losses, direct and indirect, related to a project. It basically says that with any reallocation of resources necessary to implement a new project, it is inevitable that some individuals will gain and others will lose. In this case, the benefits of a project can be referred to as the maximum that the gainers from a project would be willing to pay to receive the advantages offered by the project. The costs, on the other hand, would refer to the minimum amount the losers would need to be compensated in order to keep their utility level at the same level as it was prior to the reallocation of resources. So, if the benefits are large enough to compensate every loser and if some money is left over to make at least one person better off, than the investment in the project would be supported.

The partial equilibrium approach, on the other hand, looks at the willingness to pay by all individuals to receive the direct outputs from the project. “Similarly, costs would be measured by the total amount individuals would be willing to pay for the goods and services that could be rendered if the resources to be employed by the project were instead used in their next highest value”. (Anderson & Settle, 1977)

In the end, both approaches will likely results in the same conclusion. However, the main difference between the two is the effects measured. While the general equilibrium approach involves all of the effects related to the project, the partial equilibrium only involves the direct effects and excludes the indirect ones. This analysis will adopt the partial equilibrium approach.

4.1.4 Economic Efficiency

Before getting started with the cost-benefit analysis, it is important to understand the underlying economic principles on which it is based and their limitations. A cost-benefit analysis is applied welfare economics, the main focus of which is to understand how society can allocate scarce resources in the most efficient ways. Therefore, the driver of a cost-benefit analysis is to determine a project’s economic efficiency. Overall, a project or activity will be economically viable if it results in an increase in the value of the goods and services produced throughout the economy. This value can be measured by people's willingness to pay for those goods and services.

4.1.4.1 Willingness-To-Pay

There are, however, some limitations in using the willingness to pay to measure economic efficiency. The first is that we are assuming that people know what is best for them. Some people have argued against this assumption by pointing at things such as drug addictions as well as other expenditures spent on harmful goods such as alcoholic beverages. Even though this is a reasonable argument, there are very few options available other than having people making their own decisions, unless a "benevolent dictator" who knows what's best for the whole of society can be appointed to make all allocation decisions, which seems very unlikely. Therefore, the assumption that people want what is best for them will be carried on throughout this analysis.

The second issue with the willingness-to-pay assumption is its direct relation with the distribution of income. Indeed, "using the criteria of economic efficiency, a desire is counted for nothing unless it is backed with money to translate it into actual willingness." (Anderson and Settle, 1977) That means that given a different income distribution for a chosen accounting stance, the weights given to different goods would probably change a lot if more and different people would have the income to back their desires in terms of goods and services consumption. However, since there is no way in economics to determine which income distribution would be better or what changes would take place if an income distribution would be changed, economists have accepted the existing income distribution of an accounting stance for any project as the standard. This is another assumption that will be carried out throughout this analysis.

Finally, another issue that arises with the willingness-to-pay criterion is the fact that some goods and services have no economic market associated with them. Since we are using dollars as a common denominator, those goods and services to which no dollar amount can be attributed, such as clean air, for example, can be difficult to measure in the analysis. However, this is becoming less of an issue over time as more and more tools have been developed to measure goods and services that were previously considered "intangibles". In this analysis, a monetary value will tentatively be attributed to those "intangibles" as their impact on the decision-making process of project appraisal can be crucial.

4.1.4.2 The Pareto Criterion

The Pareto Criterion suggests that economic efficiency can only be reached when goods and services are allocated such that no person can be made better off without making somebody worse off. The main issue with this criterion is that it is very restrictive and almost no public sector projects can satisfy it, since most projects will leave some people less satisfied or worse off than they were prior to the implementation of the project. Based on such a criterion, very few projects could be shown to be economically efficient and therefore not many would be approved. There exists, however, a more practical criterion called the Hicks-Kaldor criterion or Potential Pareto Optimality, which states that a project or activity is economically efficient if the benefits produced are large enough that the people who are made better off can compensate those who are made worse off and still achieve an improvement in utility.

Since a cost-benefit analysis is used to determine whether the social benefits of a project exceed its social costs, then an analysis that would be favorable to a project would be one that would provide enough benefits to compensate those who would be made worse off. The analysis, however, does not account for the redistribution of these benefits and it is a reasonable to assume that some transfers would never be made, therefore leaving part of the accounting stance worse off or with lower utility levels.

4.1.5 Issues of Equity

As mentioned in the previous section, efficiency is the primary objective of a cost-benefit analysis. However, decision-makers also often care about equity and the redistributional effects that a project can have on certain areas. It might be even of greater importance for projects that are taking place in rural areas where there are higher unemployment rates and greater poverty levels. If this is the case, analysts might want to include a section showing which segments of the accounting stance bear the benefits and which ones bear the costs. In this study, however, it will be assumed that all costs and benefits accrue to society in general rather than any participant in particular. Indeed, the project's benefits will bring the whole of society improved air quality and greater energy security as well as savings on the overall electricity system in Nova Scotia. As for the costs, everybody in the accounting stance will bear the costs of building, operating and maintaining the tidal farm, which will probably be reflected in slightly higher electricity costs in the province based on the FIT that the province will agree to attribute to tidal generation.

However, the UARB should be aware that although the FIT required to encourage tidal generation in the province is higher than the FIT in place for conventional sources, building tidal farms in the Bay of Fundy and, in this case, a tidal farm with an installed capacity of 300MW in the Minas Passage, will not only improve the lives of all its citizens but will also encourage regional economic development in the rural areas surrounding the farm. A qualitative analysis of the benefits accruing from income distribution for this project is provided below.

4.1.5.1 Regional Economic Development

"Renewable energy projects are often discussed in terms of the benefits they can provide to the communities where they are situated. Renewable energy resources, such as wind and hydrokinetic energy from waves and tides, tend to be located in peripheral and rural areas. Wind and tidal energy need to be used at their source as opposed to biofuels, which can be transported to combustion facilities as necessary. The consequence of having to utilize some renewable energy *in situ* is this necessitates the development of infrastructure around the resource itself, which in many cases are in small and rural communities. This suggests communities that are close to resources should be able to gain some level of benefit from the development of renewable energy industries". (Howell & Drake, 2012)

This is true for the installation of a large-scale tidal farm in the Minas Passage. Indeed, benefits from increased employment, improved infrastructure and knowledge spillovers might occur in four of the counties surrounding the Minas Basin: Colchester, Cumberland, Hants and Digby[61]. The bulk of job creation would happen throughout the construction phase of the project itself but also during the construction of the infrastructure needed to support tidal energy developments in the different counties. The Marine Renewable Energy Infrastructure Assessment that was prepared for the Nova Scotia Department of Energy looks at both infrastructure and supply chain requirements for long-term in-stream tidal projects. First of all, deployment facilities along the Bay of Fundy and more specifically within 150 km of the Minas Passage will be required. "Most developers have indicated a "wet port" is considered essential for deployment as well as operation and maintenance. However, some developers have stated that it is not necessary to have a "wet port" [62] for most operations; "dry ports"[63]could also be suitable. (Marine Renewable Energy Infrastructure Assessment, 2011) The most suitable "dry port" in Nova Scotia is the port of Digby. However, as it stands today, the port would not be able to accommodate the deployment as well as the maintenance of larger tidal in-stream devices. Therefore, the construction of a new major wharf facility in Digby Harbor would be considered advantageous.[64] Moreover, the ports of Hantsport and Parrsborro, located in Hants and Cumberland counties respectively, are "wet ports" and appear to be strategically located for the deployment of piled base tidal devices.

Furthermore, Nova Scotia possesses the expertise necessary for the fabrication

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[61] Kings County has great potential for economic development through the construction of small-scale tidal projects since Fundy Tidal Inc. recently received COMFIT approval for a tidal project. However since this analysis looks at a large scale tidal project, the counties it will focus on are Colchester, Cumberland, Hants and Digby.

[62] A "wet port" is a port which has water at low tide. Wet ports would be more suitable for devices with gravity base structure.

[63] A "dry port" is a port which has no water at low tide. Dry ports are more suitable for devices with pin/pile base structure.

[64] Marine Renewable Energy Infrastructure Assessment (2011)

and assembly of tidal structures. Indeed, Cherubini Metal Works, a Dartmouth-based company, fabricated the gravity base structure used in the deployment of the OpenHydro turbine at the demonstration site. Although the employment benefits from this are not directly felt in the counties surrounding the Minas passage, it does benefit the province as a whole. Moreover, "for turbine manufacture and a host of other skills and services, Nova Scotia has a considerable ocean-related industry sector" (Marine Renewable Energy Infrastructure Assessment (2011), which includes many companies located in Colchester County. Also, the Minas Basin Pulp and Power, which is located in Hants country, has already expressed its intention to fabricate turbines in the future. The final assembly of the devices, which requires more skills and staff, needs to take place at the deployment wharf. Table 4.1 summarizes the areas/sectors in which each county could benefit from the development of a commercial tidal farm.

Although, as mentioned before, the bulk of job creation will happen during the construction phases, other jobs will be sustained with the operation and maintenance of tidal devices over the life of the projects. Since operation and maintenance will have to be done *in situ* and at the deployment wharfs, then the communities surrounding the Minas Basin will also be benefiting from those jobs. Moreover, long-term infrastructure will be put in place and knowledge spillovers from research and experience will all allow for greater regional economic development.

Table 4.1 Areas/Sectors from which Each County Surrounding the Minas Passage Could Benefit from a Commercial Tidal Farm

County	Employment Opportunities
Colchester	Location of a number of ocean supply chain companies to provide different skills and services for the development of tidal projects
Cumberland	FORCE: • R&D • Constant monitoring of projects Port of Parsborro: • Deployment of pile based tidal devices • Ongoing operation and maintenance of turbines
Hants	Minas Basin Pulp and Power: • Fabrication of turbines Port of Hantsport: • Deployment of pile based tidal devices • Ongoing operation and maintenance of turbines
Digby	Port of Digby: • Construction of a new major wharf facility • Assembly of turbines • Ongoing operation and maintenance of turbines

To give policymakers an idea of what job creation benefits could take place in those counties, it is useful to have a quick look at the literature on "energy-based economic development"(EBED)[65]. In recent years, economic development professionals and supporters of renewable energy sources have come together to form an emerging discipline, EBED, in which a main foci is on "the role of energy-related industries, technologies, and processes to drive job creation and industry retention […] to promote robust economic development and improve standards of living". (Carley et al., 2011) Many of those EBED studies attempt to estimate an average number of jobs created per MW depending on the energy technology being developed since direct employment from

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[65] Carley et al. (2011)

renewable energy deployment has been assessed to be the most important contribution to local sustainability. Since no estimates exist for tidal energy technology, a few examples from wind energy technology are given in table 4.2. The estimates are wide ranging and depend on a variety of factors such as the availability of skilled labor in the local communities[66] and government incentives to hire local labor. Moreover, most authors agree that more jobs are created during the construction phase than for operations and maintenance.

Table 4.2 Literature Review on Job Creation for the Development of Wind Energy Technology

Reference	**Jobs per energy output (jobs per MW)**
Moreno and Lopez (2008)	13.2
Simons and Peterson (2001)	2.57 construction , 0.29 O&M
Pedden (2005)	0.36 to 21.37
Kammen et al. (2006)	0.71–2.79 jobs/MWa*

*MWa refers to average installed megawatts derated by specified capacity factor of the technology.

Source: Adapted from Carley et al. (2011)

In Nova Scotia, regional development is a key concern for the government in developing policies and the province shows its commitment through its support for the province's 13 Regional Economic Development Authorities (RDAs) and through the Regional Community Development Act. Therefore, the impact from the development of tidal projects on local communities is likely to play an important role in the policies that

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[66] The skills required for the deployment of wind technology are considered to be medium to high and the same can be said for tidal technology. (Interview with Matthew Lumley)

are made in the future and the approval of projects.

4.2 ISSUES WITH CBA

4.2.1 Discount Rate

The discount rate is an important component of a cost-benefit analysis as it is designed to overcome the issue of comparing investments requiring large initial financial outlays over a period of time. It is so important that a choice of a lower discount rate compared to a higher discount rate might change the value obtained in the net present value calculation of a project and make it more favorable for approval. Indeed, “higher discount rates will yield lower benefit-cost ratios or lower net present values.” (Anderson and Settle, 1977) This is especially true in the case of a project affecting climate change as the benefits are received over longer periods of time, while the major costs are incurred early on in the project. When asked: “What real interest rate do you think should be used to discount the (expected) benefits and costs of projects being proposed to mitigate the possible effects of global climate change?” (Weitzman, 2001), the answers in a poll of 50 acknowledged experts varied from 0% to 15%. Quite often, “the assignment of values to effects expected to take place many years in the future involves little more than educated guesswork at best.” (Anderson and Settle, 1977) This is why the discount rate chosen for this analysis will be based on previous studies and a sensitivity analysis assuming a different discount rate will be performed.

There are three different approaches that can be used to determine a social discount rate. One approach is based on time preference and considers the different valuation of consumption in the present and in the future. Another approach is based solely on the opportunity costs of foregone investments, with no consideration for time preference. The third approach is combination of the first two alternatives and uses "a weighted average of the economic rate of return on private investment and the time preference rate for consumption". (Treasury Board of Canada Secretariat, 2007) This is the approach that is used by the Treasury Board of Canada Secretariat and the one that will be used in this analysis. Recently, the social discount rate for Canada was estimated, based on Jenkins and Kuo (2007), at approximately 8% rather than the 10% recommended by the Treasury Board of Canada Secretariat in 1998, with sensitivity rates recommended at 3% and 10%.

Furthermore, studies on the costs of generating electricity from marine renewable energy[67] attribute different discount rates to tidal in-stream projects based on the timeline of the project. Unlike the rate determined by the Treasury Board of Canada Secretariat, their discount rates are based solely on the opportunity cost of capital. The Carbon Trust (2006) uses a rate of 8% while Ernst and Young (2010) use a rate of 9%. In both studies, those rates are characterized as longer-term rates for commercial or "becoming commercial" projects set forth in 2020. Since the technology will still be relatively new then and potential investors may require a greater rate of return due to risks and uncertainty, this analysis will adopt the more conservative approach and use a 9% discount rate. Since this analysis in particular may depend on the discount rate chosen[68],

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[67] Carbon Trust (2006) and Ersnt & Young (2010)

[68] The discount is even more crucial when evaluating "projects with long-term effects such as woodland planting, toxic waste disposal and research and development of alternative energy sources". (Hanley & Spash, 1993)

a sensitivity analysis is performed with both a lower (1%) and higher discount rate (15%).

4.2.2 Shadow Pricing

In a perfectly competitive economy, domestic market prices usually form the basis of the evaluation of costs and benefits, expressed in monetary terms, which can be attributed to a project. However, in practice, no markets are perfectly competitive, as is the case of the market economy of Nova Scotia. As reported by Abelson:

> The market price would represent the true value of goods and services if the law of supply and demand operated freely, under perfect competitive conditions, with full employment of all resources and complete mobility of factors. If because of any interference, obstacles or regulations these conditions do not exist, then the price system will be distorted, it will not correspond to that ideal system of equilibrium nor represent the value of factors from the point of view of the community as a whole. [69]

There is, therefore, a need for correcting the divergence between social costs and market prices. This can be done by establishing the appropriate shadow prices (or accounting prices) when evaluating the costs of projects. However, no one-size-fits-all solution exists to correct this difference and the use of shadow prices depends on the specifics of a project.

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[69] Abelson (1979)

In this analysis, the project, which is located in a rural area of Nova Scotia, has the potential to affect workers in four different counties: Cumberland, Colchester, Hants and Digby. On average, the unemployment rates in those regions are around 9.5%[70], about 2% higher than the unemployment rate in the urban area of Halifax. Therefore, it would seem reasonable to use shadow prices when calculating the costs of labor employment in rural counties in Nova Scotia directly affected by the project. However, a distinction between the types of workers that a project will require is necessary. In the case where a project, such as a commercial tidal farm, will be hiring mainly medium to high-skilled workers, it might be safe to ignore shadow prices, as market wages are usually satisfactory measures of employing skilled labor.[71]For this analysis, labor costs will be taken as given by recent studies made on similar projects and therefore will not be calculated on their own. Moreover, since the farms would be built and operated by private companies, shadow pricing is not included in their cost modeling.[72]It is therefore assumed that both labor and material costs are calculated at market prices.

4.2.3 Multiplier

While the presence of unemployment may lead analysts to correct costs by using shadow prices, it can also encourage them to use multipliers to augment the benefits received from a project. The rational for using multipliers is that, if a project employs labor that would otherwise be unemployed, then "the expenditures of the newly employed workers may raise employment and incomes in other sectors of the economy

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[70] This rate was taken at from the period of Feb 5 2012 – March 10 2012. (Human Resources and Skills Development Canada, 2012)

[71] Abelson (1979)

[72] Interview with Melanie Nadeau, senior manager of sustainability at Emera Inc.

where labor and other factors of production would otherwise be involuntary idle, and so on in a chain reaction”. (Treasury Board, 2007)

There are several arguments against the use of multipliers where unemployment prevails, but the Treasury Board of Canada has put forth the most relevant one to this analysis. This is as follow: one major issue with applying multipliers to project benefits where resources are unemployed is the need to eliminate similar consequences, which are common to alternative courses of government action. Since the government subsidizes electricity generation, any projects undertaken in any rural areas in the province are likely to result in secondary benefits accruing to Nova Scotia. The fact that the government of Nova Scotia subsidizes electricity generation, is committed to developing renewable energy sources and that most electricity generation projects from renewables are likely to take place in rural areas where levels of unemployment are higher, indicates that the likelihood of such commercial projects, with secondary benefits accruing to the province, happening in the future is high. For this reason, this analysis will not be adding multiplier effects to the benefits received from the installation of a commercial tidal farm in the Minas Passage.

4.3 NET PRESENT VALUE

The principal evaluation criterion for project appraisal is the NPV method[73] and it is the one that will be used in this analysis. The NPV is the present value of estimated benefits net of costs and can be expressed as follow:

$$\sum_{t=1}^{n} \frac{TB - TC}{(1+r)^{t}} \qquad (4.1)$$

Where TB and TC are benefits and costs in each period t=1n, and r is the selected discount rate. In this specific case, the formula would look like:

$$\sum_{t=1}^{23} \frac{TB - TC}{(1+0.09)^{t}} \qquad (4.2)$$

Since the project life of a tidal generating plant is assumed to be 20 years and the construction phase 3 years, then the net benefits will be discounted on a period of 23 years. The discount rate, as mentioned above, is assumed to be 9%. A positive NPV indicates that the estimated total benefits exceed the estimated total costs. Therefore, a positive net present value means that the project is economically viable and that society is better off with its implementation.

Often, with environmental projects, not all the benefits are included due to difficulties in quantifying them. However, this analysis will attempt to put a monetary value on benefits that have historically been omitted from cost-benefit analysis for

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[73] "Two other evaluation criteria are used in project appraisal and are closely related to NPV: the internal rate of return (IRR) and the benefit-cost ratio (BCR)." (Abelson, 1996) However, since they will not be used in this analysis, they won't be covered in this section.

environmental projects. They include emission benefits in terms of the reduction in CO2 emitted, co-benefits from air quality improvement relating to better health and living standards of society, as well as benefits from greater energy security derived from the reduction in the need to import coal. Obviously quantifying those effects is very challenging and debates on how best to estimate those benefits are at the core of the current literature on environmental economics. Therefore, it will be important to keep in mind that there is a lot of uncertainty with the benefit estimates. More will be said about both the costs and benefits and their estimates in chapter 5.

CHAPTER 5 COSTS AND BENEFTIS OF TIDAL GENERATION

This chapter attempts to estimate the magnitude of the costs and benefits associated with the installation of a 300MW in-stream tidal farm in the Minas Passage in 2020. The costs that are described include construction costs, O&M costs, network upgrade costs, cycling costs, and costs related to additional reserve requirements. The benefits include emission reductions, co-benefits from air quality improvement, fuel savings, capacity benefits and energy security benefits. As this study represents a social welfare-maximizing analysis, all the costs associated with in-stream tidal generation are assumed to accrue to society in general rather than to any individual in particular.

5.1 COSTS

5.1.1 Construction and O&M Costs

Estimates for capital costs and maintenance and operation costs have been taken from an Ernst and Young (2010) study which assesses the best-estimate generation costs for future commercial tidal stream generation projects.[74] The reason for using this specific study is that it has been one of the bases used by the UARB to determine the COMFIT for tidal power. Therefore, it is assumed that these costs are reasonable to use in the Nova Scotia, Bay of Fundy, context and it is likely that the same study will be used to determine the FIT for commercial tidal projects in the future.

Tidal generation has zero fuel costs, thus, its costs are based mainly on "its

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[74] These costs are based on a base case scenario for shallow tidal stream costs where the water depth is less than 50m, the mean power (energy density) is 3m/s, the typical project life is 20 years and construction phase is 3 years. The base case scenario for shallow tidal stream is used rather than the one for deep tidal stream since the Minas Passage has an average depth of 40m. (Interview with Matthew Lumley, Communications Director at FORCE)

construction costs and O&M, which make up over 80% and 50% of total capital expenditure and annual operating costs respectively". (Ernst and Young, 2010) Capital expenditures (Capex) and Operating expenditures (Opex) are therefore considered base costs. Capex costs include construction costs, electrical system and infrastructure costs as well as predevelopment costs. According to Ernst and Young (2010), the Capex costs of commercial projects are between $4.3 million and $6.2 million per MW. Following the methodology used for determining the COMFIT, in this analysis, the average cost of $5.25 million/MW will be used. Opex costs, on the other hand, include operating and maintenance costs (O&M), insurance costs, de-commissioning costs[75] and other costs. In Ernst and Young (2010), they are estimated to be between $191,000 and $302,000 annually. The average of $246,500/year will be used in this analysis.[76]

5.1.1.1 Assumptions

It is important to note that these costs have been calculated with an assumed load factor[77] of 35%, which means that, in this case, the maximum power output realized is 195MW although there are 300MW of installed capacity. This assumption is considered reasonable and even conservative considering the fact that many tidal generation studies

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[75] De-commissioning costs are not always included in the Opex costs. Indeed, the Carbon Trust (2006) does not include them in their estimates since their "current estimates indicate these will be small compared to initial capital costs, and because they fall at the end of a project, the present value in a discounted cash flow analysis is low and has only a marginal effect on cost of energy". (Carbon Trust, 2006)

[76] The original cost figures were expressed in pound sterling. To convert them into Canadian dollars, an exchange rate of 1.59177012 was used according to the 2010 average annual nominal exchange rate determined by the Bank of Canada. The capital and O&M costs are expressed in real 2010 terms.

[77] "The power output from a turbine or group of turbines will only reach its maximum output during a spring tide, which occurs for a short time twice a month. Therefore it is not envisaged that developers would consider it economically viable to rate the electrical equipment to harness all of the energy available at a spring tide. Instead, the maximum power from the turbine would be down rated by altering the pitch of the blades. This has been termed Electrical Down Rating (EDR)." (Denny, 2007) In this analysis the EDR is assumed to be 35% according to Ernst and Young (2010).

use a base load factor of 40%. Load factors or electrical down rating (EDR) is important to consider because tidal generation is variable. Including an EDR can minimize the loss of energy from tidal generation. Indeed, "the tidal generation has four peaks and troughs per day representing the tidal current coming in and out twice a day. This fluctuation is particularly apparent during a spring tide[78] when the variations are at their maximum [see figure 5.1]". (Denny, 2007) It is highly unlikely that developers would consider it economically viable to rate the electrical equipment to harness all of the energy available at a spring tide. Therefore, "by feathering the blades during spring tides, it is possible to decrease the rating and cost of the support structure, the drive train, the generator and grid connection. For example, with an IEDR of 40%, only 10% of the available energy is lost [see Fig. 5.2]—this down-rating would probably be cost-effective". (Bryans et al., 2005)

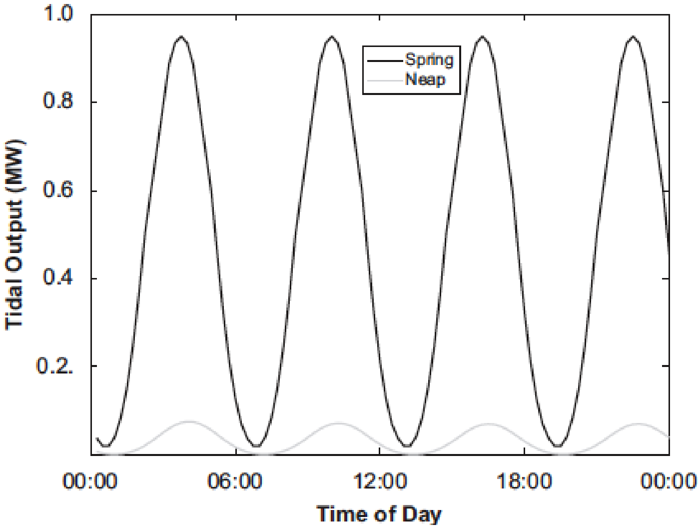

Figure 5.1 The Power Output During a Spring and Neap Tide (Denny, 2009)

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[78] "Twice each month, at the time of the new moon and the full moon, the gravitational influences of the moon and sun reinforce one another and cause the tides to rise to greater heights and fall lower than average tides". (Fisheries and Oceans Canada, 2009) These are called spring tides.

The EDR will be an important factor that will be considered throughout this analysis when valuating both costs and benefits of tidal generation. However, in the valuation of all other costs and benefits except emission benefits, the EDR will be assumed to be 40%.

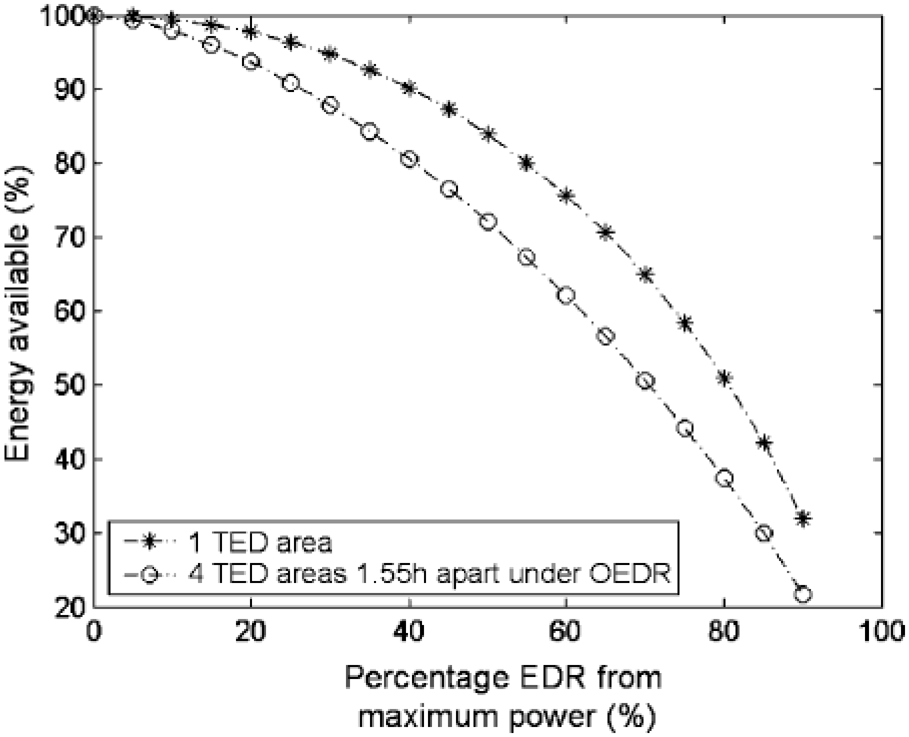

Figure 5.2 Energy Loss Due to EDR Applied as a Cap on Net Tidal Generation Output (Bryans et al., 2005)

In addition, capital costs and O&M costs are assumed to decline with time due to the impact of learning and economies of scale that can be achieved with larger commercial deployment. Therefore, when calculating costs over time, studies have applied a learning rate to renewable energy technologies. The learning rates are often based on the learning rates that can now be observed for other renewable energy technologies, such as wind. Generally, learning rates are between 10% and 15%[79]. The Ernst and Young (2010) study uses learning rates of 13% for the base case scenario, which is the one that is used in this analysis.

5.1.2 Network Upgrade Costs

As the installed capacity of tidal generation increases, it is likely that the transmission and distribution networks will require upgrading. In this case, FORCE chose a transmission line that would meet their immediate needs, i.e., a transmission line for 5MW tidal capacity, but that could be upgraded if needed without significant stranded investment in the future. Therefore, with the installation of a 300MW tidal farm, upgrading the transmission line would become necessary. However, for the purpose of this analysis, no extra costs for interconnection will be added since the Ernst and Young (2010) estimates of capital costs already include them.[80]

It is also important to look at larger upgrades to the provincial grid to transmit and distribute a greater amount of electricity by 2020. In this analysis, it will be assumed that there will be no extra costs associated with an upgrade to the provincial transmission network, as this will already have been achieved as part of the Lower Churchill Project. More precisely, NSPI has committed to build a $1.2 billion Maritime link by 2017, which is a 310 km high-voltage direct current (HVdc) transmission line[81] from Newfoundland to

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[79] Carbon Trust (2006)

[80] "The capital cost estimates in the EY&BV study represent all-in capital costs including construction costs (e.g., overnight capital cost, owner's costs and interest during construction), interconnection costs, and pre-development costs (e.g., pre-licensing, public enquiry and planning, technical development)". (Synapse Energy Economics Inc., 2010)

[81] An HVdc line is a high capacity transmission line, usually used to transmit bulk power over long distances from large generating sites or between system hubs.

Nova Scotia, in exchange for 20% of the power from Muskrat Falls.[82] Therefore, it will be assumed that, as a result of the new transmission line, no additional network upgrades at the provincial level will be required for tidal generation.

5.1.3 Cycling Costs

Cycling costs come from the start up and shut down of conventional generation sources on the system, which are required to meet the fluctuating electricity demand throughout the day and, as a result, the output of these conventional generating stations vary in line with the demand changes. Cycling costs need to be included in the analysis since tidal energy is a variable source and therefore tidal power cannot feed the grid on a continuous basis. A tidal generation station would be considered a peak load unit, meaning that the generating station would operate only at the time of highest demand. This means that during periods of peak demand, baseload and intermediate load units[83] would have to be shut off to use the power from tidal generation and for the rest of the time, when there are no fluctuations in the tides, they will have to be switched on to fill in the tidal power generation gaps. Since tidal power is predictable, unlike wind or solar, scheduling for such backup sources will be made easier, but cycling costs will still have to be incurred. “The magnitude of these variations increase as the installed tidal generation increases, thus, the cycling costs increase as well.” (Denny, 2007)

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[82] Emera Investor Presentation. “Energy Everywhere” (2011).

[83] “Plants used to provide base load operate all year, except for planned maintenance shut-downs. Generating units in these plants can change the amount of electricity they generate based on hourly customer demand. Base load units are fuelled primarily by coal and petroleum coke. Plants needed for intermediate load requirements meet demand during peak business hours of the day and the colder months of the year. Intermediate load units are fuelled by oil and natural gas.” (NSPI, 2012)

5.1.3.1 Plexos Modeling System

In general, utilities and their consultants use third-party optimization models to look at long- and medium-term resource development options. NSPI is no exception. It uses an application called "Strategist" that is owned by ABB Ventyx in order to develop long-term resource development plans and to test projects that have been proposed for utility investment. Furthermore, NSPI's consultant, General Electric, uses "Plexos" (by Energy Exemplar) and "GE-MAPP's" for long-term modeling. Plexos is a recent tool and has yet to be fully populated with data for the Nova Scotia electricity system. Plexos offers a transmission transport model to allow for a better understanding of the impacts of transmission congestion, reactive reserve requirements and sub-hour dispatch requirements, which is particularly useful with the introduction of variable generation.[84] However, being able to master such modeling systems takes years and would be beyond the scope of this thesis. Therefore, this analysis will be borrowing results from a PhD thesis[85] that has used the Plexos modeling system to look at the impact of integrating different levels of installed wind and tidal generation to the generation mix of Ireland. More specifically, this borrowed model will be used to estimate the monetary value of the cycling costs and fuel savings assessed in this analysis.

Denny (2009)'s results for estimated cycling costs for tidal generation are illustrated in figure 5.3. Since the Plexos model in Denny's analysis was populated with specific information for the Irish system, the cycling costs as well as the fuel savings results that will be applied to Nova Scotia will contain an inherent error. Indeed, the

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[84] Information obtained from an interview with Melanie Trudeau, Senor Manger of Sustainability at Emera (2012)

[85] Denny (2007) and Denny (2009)

Plexos model requires that the characteristics of each generator in the system be inputted in the model. Moreover, “the bid price for each generator is obtained by multiplying the appropriate fuel price by the generator’s consumption of energy per MWh.” (Denny, 2007) The model then “runs for each hour for an entire year with increasing [simulated] penetrations of installed tidal generation”. (Denny, 2009) The resulting operating schedules of the generators are then analyzed to determine costs and benefits of tidal generation.

The error in using the model for the Irish system is mainly due to the difference between the Irish and Nova Scotian generation mix. See figure 5.3 for a graphical illustration of the Irish generation mix. Indeed, while most of the baseload supply in Nova Scotia is provided by fossil fuels, it is provided by natural gas in Ireland. Since natural gas generators differ from fossil fuels in terms of consumption of energy per MWh, then the results obtained for the bid price of each generator will be different in both regions. Moreover, cycling costs and fuel savings in this analysis are based on fuel prices in Ireland for 2008. Although fuel prices are similar in the two regions, the National Energy Board of Canada has forecast an increase in the prices of natural gas and crude oil for 2020. On the other hand, “coal prices are assumed to remain approximately constant at levels experienced in 2007”.[86] (National Energy Board, 2009) This means that the fuel prices used in the Plexos model do not reflect what the price in reality might be

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[86] “In the 2009 Reference Case Scenario, the WTI crude oil price is assumed to average roughly US$50/bbl in 2009. The price is assumed to increase with the recovering global economy, reaching US$90/bbl by 2020 (US$2008/bbl). After declining significantly in 2009, the Henry Hub price of natural gas in the 2009 Reference Case Scenario gradually rises from US$6.70/MMBtu in 2011 to US$7.50/MMBtu by 2020. In the period to 2020, coal prices are assumed to remain approximately constant at levels experienced in 2007. Competitive pressures and productivity increases in mining and rail transportation prevent coal prices from increasing with gradually rising oil and gas prices…” (National Energy Board, 2009)

in the future. Ideally, the cycling costs and fuel savings incurred from tidal generation in Nova Scotia should be based on the Plexos model tailored to the Nova Scotia electricity market and forecasted fuel prices for 2020 up until 2040 should be used in order to obtain more accurate results.

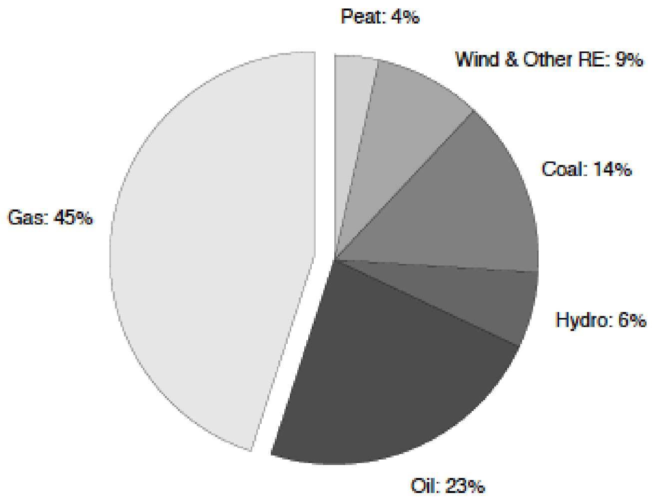

Figure 5.3 Installed Generation Capacity by Fuel Type in Ireland (Denny, 2007)

Furthermore, assumptions that have been made in Denny (2007) need to be understood for the purpose of this analysis as well. “The study represents a near perfectly competitive gross pool electricity market. Thus, the generators are assumed to be profit maximizers and price takers and gaming of the electricity market by individual generators is not taken into account.” (Denny, 2009) This is in line with this analysis, since Denny (2007) also focuses on social welfare maximization, and perfect competition ensures the optimal solution for society in general. The results, therefore, aim at representing the social optimum. Moreover, “electricity system dynamics, although an important technical issue for renewable energy integration" (Denny 2009) have been omitted due to their modeling complexity. Finally, in the analysis, a load factor of 40% for the installed tidal devices is assumed.

5.1.3.2 Valuation of Cycling Costs

"The costs associated with cycling include additional operation and maintenance spending associated with increased overhauls, higher heat rates due to low load and variable operation, auxiliary power, fuel during startup, unit life shortening, increased operator error due to greater hands-on operation, etc. […] The actual cost of cycling is very difficult to estimate and must be conducted on a plant-by-plant basis [as in the Plexos model]." (Denny 2009) According to estimates from Grimsrud and Lefton (1995) the fuel costs of a gas-fired turbine represent 20-30% of total costs associated with cycling while they represent around 10-15% for an intermediate fossil fuel unit. Since Ireland's generation mix relies mainly on natural gas while Nova Scotia's mix relies more greatly on fossil fuels, it is reasonable to say that the cycling costs that will be attributed to the integration of tidal energy in the province based on the Irish Plexos model in this analysis, see figure 5.4, will likely to be overestimated.

Based on Denny (2009)'s analysis, cycling costs for a 300MW commercial tidal farm with an EDR of 40% would be estimated at around $12.5 million annually[87].

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[87] This estimate is derived from figure 5.3 where an installed tidal generation capacity of 300MW is estimated to cost around €8 million annually (real 2008 terms). The exchange rate used to convert this estimate into Canadian dollars is 1.5603, as determined by the 2008 annual average nominal exchange rate from the Bank of Canada.

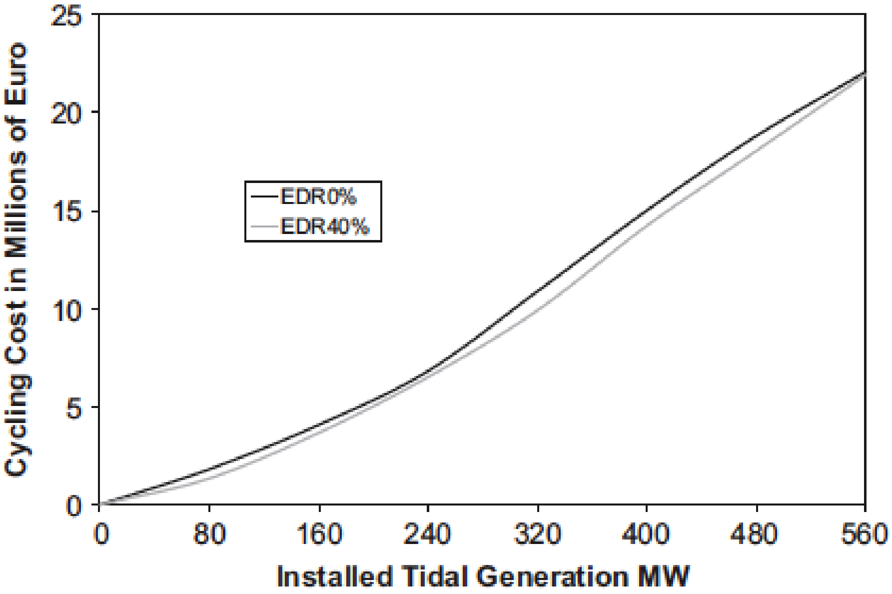

Figure 5.4 Cycling Costs with Increase in Generation (Denny, 2009)

5.1.4 Additional Reserve Requirements

An increase in the capacity of electricity generation of an unpredictable and non-dispatchable resource, such as wind power, increases the uncertainty in the electricity network system. As a result, in such a case, additional costs need to be taken into consideration to provide additional operating reserve. However, since "tidal generation is considered to be perfectly forecastable, no additional reserve is required with increasing capacities of tidal generation". (Denny, 2007) Therefore, no extra costs will be incurred for additional operating reserve requirements with the installation of a 300MW tidal farm in the Minas Passage. Table 5.1 provides a summary of the costs that will be considered in this analysis for the case study.

Table 5.1 Summary of Cost Estimates

Costs	**Estimates**
Capital	$5.25 million/MW (real 2010 terms)
O&M	$246,000/year (real 2010 terms)
Cycling	$12.5 million/ year (real 2008 terms)

5.2 BENEFITS

5.2.1 Emission Benefits

Reducing carbon emissions is one of the main objectives of the government of Nova Scotia. Indeed, the Environmental Goals and Sustainable Prosperity Act "requires that, by 2020, Nova Scotia's GHG emissions be reduced to a point at least 10 per cent below 1990 levels". (Environment Nova Scotia, 2009) The levels that need to be reached to achieve this objective are shown in Figure 5.5.

Increasing the installed capacity of tidal generation means that it will displace conventional generation, which in turn will have an impact on the emissions from the conventional units and will help the province achieve its target. In its 2011 Annual Report, FORCE published estimates of potential annual carbon dioxide (CO2) displacement as a result of tidal generation in the Bay of Fundy, as illustrated in table 5.2. According to the report, a commercial tidal farm with an installed capacity of 300MW would have the potential to displace 1.1 megatons of CO2 annually.

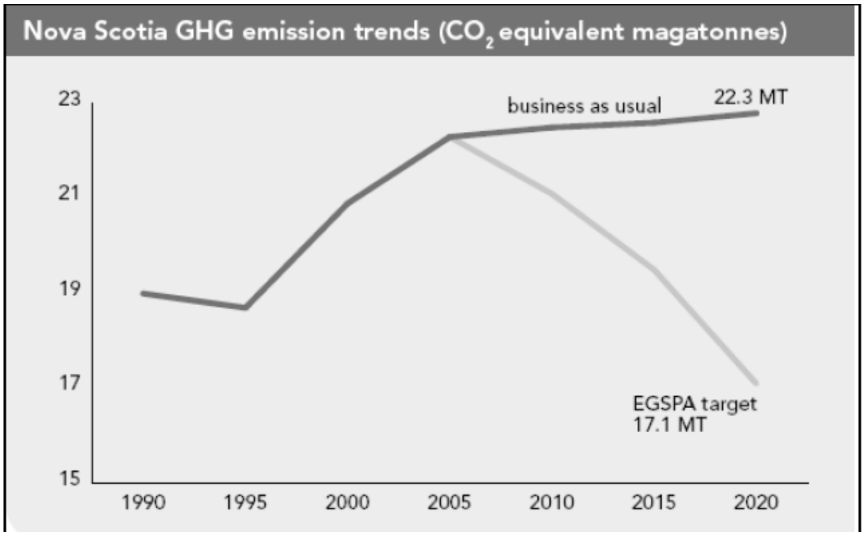

Figure 5.5 Nova Scotia GHG Emissions Trends and Target (NS Environment, 2009b)

The difficulty in this analysis comes from putting a monetary value on the CO2 emissions. Indeed, there is no consensus of the monetary value that should be put on the offsets of CO2 emissions[88]. On the other hand, Tol (2005) reviewed 103 estimates of the marginal damage costs of CO2 emissions from 28 published studies in order to form a probability density function and concluded that "the marginal damage costs of carbon dioxide emissions are unlikely to exceed $50 per ton carbon and probably much smaller". (Tol, 2005) Moreover, the Intergovernmental Panel on Climate Change (IPCC)'s third assessment report, which takes into account induced technological change, the price ranges for carbon emission credits have been identified to be between US$5-65/tCO2 in 2030[89]. In addition, *the Benefits of Reduced Air Pollutants from Greenhouse Gas Mitigation Policies (1997)* by Resources for the Future (RFF), which is one of the most

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[88] Key challenges include our still "incomplete understanding of climate change, knowledge gaps at the level of impact analysis, aggregating impacts requires an understanding of (or assumptions about) the relative importance of impacts in different sectors, in different regions and at different times". (Tol, 2005)
[89] IPCC (2007)

relevant of the US environmental published studies, estimated that the likely monetary benefit of common air contaminant (CAC) reductions associated with GHG reductions would range from \$10 to \$32 per ton of CO2 reduced. According to Canton and Constable (2002), “RFF is generally considered to be a relatively conservative organization in these matters. They have been influential in promoting cost-benefit analysis as an element of regulatory reform in the US and have contributed to peer review panels for the major CBA analyses that have been carried out for US acid rain control policies and the Clean Air Act." (Caton & Constable, 2000)

Ultimately, however, the decision for pricing carbon offsets in this analysis is based on already existing carbon market in Alberta[90] and assumes that this monetary value for carbon-offset credits would be applied to an eventual offset system for greenhouse gases in Canada[91], which would in turn apply to Nova Scotia. Although, in the case of Alberta, the market has been established for the selling of agriculture offsets, it is reasonable to assume that the same offset value can be applied to the energy sector[92]. “Since 2007, the selling price of agricultural offsets has increased from \$6 to \$12 / ton of carbon dioxide equivalent (T CO2e) to \$10 to \$14 / T CO2e [in 2010] within the emerging Alberta Carbon Market. (Government of Alberta, Agriculture and Rural

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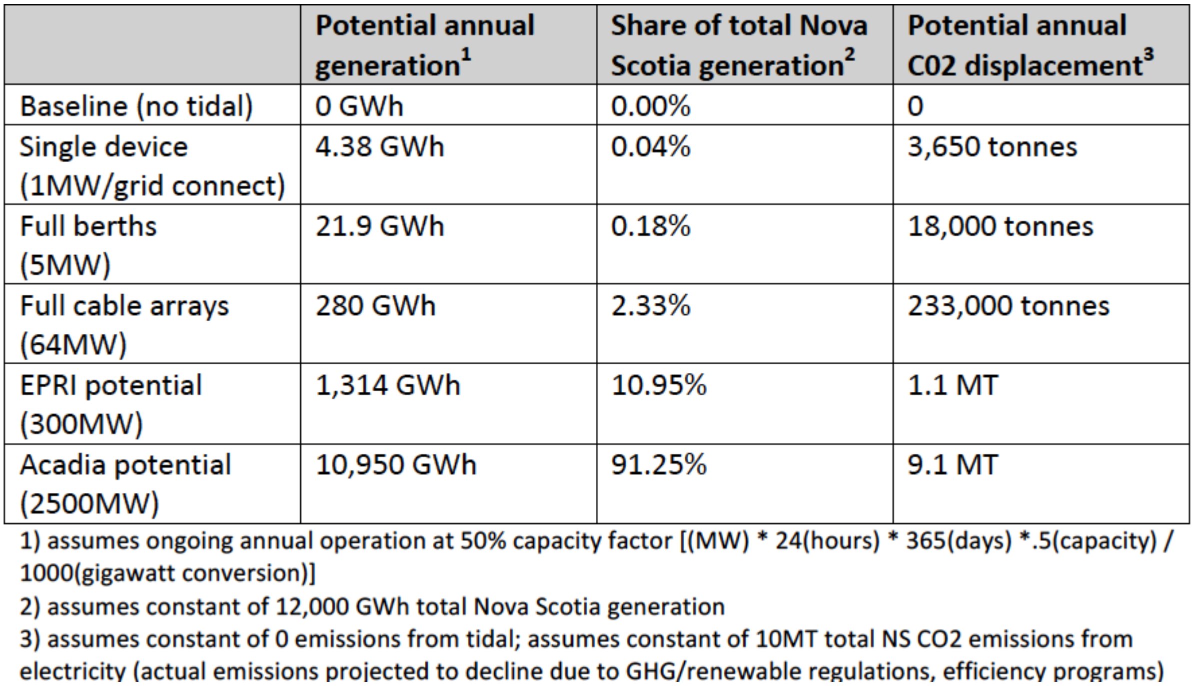
[90] Alberta is the only jurisdiction in North America with legislated requirements for greenhouse gas (GHG) emission reductions. Alberta’s Climate Change Emissions Management Amendment Act (2007) has created a market of carbon trading between regulated emitters and farmers who can reduce or remove GHG emissions through practice changes**.**

[91] Canada Offset System for Greenhouse Gases “is intended to generate real reductions in greenhouse gas emissions by providing Canadian firms and individuals with the opportunity to reduce or remove emissions from activities and sectors that will not be covered by our planned greenhouse gas regulations.
It does so by establishing a price for carbon in Canada - something that has never been done before in this country”. (Government of Canada, 2008) However, it is still not clear when the Canadian offset mechanism will be implemented.

[92] Interview with Tom Goddard, March 5, 2012

Development, 2011) Furthermore, in an interview, Tom Goddard, a senior policy advisor for the Department of Agriculture and Rural Development of Alberta (technology and innovation branch), recommended a minimum pricing of $15/tCO2 for the future as a most conservative prediction and no less. His reasoning is based on the fact that most long-term modeling uses prices in the $25 to $50/tCO2 range if they are looking ahead a few decades or even in the near future. For example, Australia's pricing of the carbon tax/offset system, which was announced in November 2011, starts with an initial price set at $23/tCO2 for 2012. In addition, a provision for the price to increase over time was included due to inflation and price movement expectations[93].

Table 5.2 Potential Annual CO2 Displacement from Tidal Generation



	Potential annual generation[1]	Share of total Nova Scotia generation[2]	Potential annual C02 displacement[3]
Baseline (no tidal)	0 GWh	0.00%	0
Single device (1MW/grid connect)	4.38 GWh	0.04%	3,650 tonnes
Full berths (5MW)	21.9 GWh	0.18%	18,000 tonnes
Full cable arrays (64MW)	280 GWh	2.33%	233,000 tonnes
EPRI potential (300MW)	1,314 GWh	10.95%	1.1 MT
Acadia potential (2500MW)	10,950 GWh	91.25%	9.1 MT

1) assumes ongoing annual operation at 50% capacity factor [(MW) * 24(hours) * 365(days) *.5(capacity) / 1000(gigawatt conversion)]

2) assumes constant of 12,000 GWh total Nova Scotia generation

3) assumes constant of 0 emissions from tidal; assumes constant of 10MT total NS CO2 emissions from electricity (actual emissions projected to decline due to GHG/renewable regulations, efficiency programs)

Source: FORCE Annual Report, 2011

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[93] "The Clean Energy Regulator will issue carbon units. In the first three years of the scheme (1 July 2012 to 1 July 2015, the "fixed charge" years), carbon units will issued at a fixed charge of: $23/tonne in 2012, $24.15/tonne in 2013 and $25.40/tonne in 2014". (Lyster, 2011)

Therefore, in order to keep a conservative but realistic approach for this analysis, the price of the carbon offsets for the energy sector is set at \$23/tCO2. Since the emission savings have been predicted at 1,100,000 tons annually or 1.1 megatonnes (MT), the income generation from carbon offsets for the energy sector in Nova Scotia would amount to \$25.3million/year[94].

5.2.2 Co-Benefits of Air Quality Improvement

Co-benefits from emissions reductions refer to the added benefits that can be derived from better air quality. The two main benefits that can be attributed to such an improvement are environmental impacts and human health effects. Examples of those impacts include: 1) Associated emission reductions of CACs such as reduced smog precursors (avoided health, crop & forest damage), reduced acid rain precursors (avoided ecosystem damage), improved visibility (longer visual range, clearer atmosphere, positive impact on tourism), and 2) reduced human exposure to toxic air contaminants (possibly related to lung cancer)[95].

Unfortunately, in Canada, specific estimates of co-benefits related to GHG reductions are very few and limited in scope. Indeed, “Most Canadian studies have attempted to estimate reductions in fossil fuel related emissions that would occur as a result of implementing various measures to reduce greenhouse gases, with only one recent study (Canton and Constable, 2000) attempting to estimate or value the environmental impacts and human health effects”. (Chiotti, 2002) This analysis will therefore use the estimates calculated in this study, as illustrated in table 5.3, even though

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[94] Since most of the carbon credits have been determined in 2010, the monetary value of emission benefits is given in real 2010 terms.

[95] Canton and Constable (2000)

the authors clearly state that the report is preliminary and that more research needs to be conducted in order to fill in the knowledge gaps associated with co-benefits in Canada.

The study further states that “smaller communities in some provinces (for example, Nova Scotia) would also benefit from reduced emissions impact from fuel switching in electricity generation.” (p.22) Therefore, using the rural damage value for these emissions is recommended. Following the recommendation, the monetary benefits that the province could receive from co-benefits would be $11million/year.[96]

Table 5.3 Co-Benefit Avoided damage Valuation Estimates for CACs Emissions

Value	**Low**	**Mid/Low**	**Mid**	**Mid/High**	**High**
Avoided CAC damage values ($CDN/tonne CO_2)	$5	$10	$18	$25	$32
National average			✓		
Uncertainty limits	✓				✓
Typical rural impacts		✓			
Typical urban impacts				✓	

1) The damage values in Table 5.2 “cover the estimated values of a wide range of public health impacts (shortened lives, respiratory illness and many other health outcomes that are associated with air pollutants) and non-public health-related impacts (acid rain ecosystem damage, visibility impairment, agricultural crop damage, forest damage) for the CACs associated with the GHG reductions”. (Canton and Constable, 2000)
2)”The values integrate across all types of population exposures and environmental impacts in the US and are assumed to apply directly to average exposures and impacts in the southern portion of Canada”. (Canton and Constable, 2000)

Source: Canton and Constable (2000)

5.2.3 Fuel Savings

Fuel savings from tidal generation result from the fact that, as a renewable energy source, it displaces electricity produced from thermal units and therefore the quantity of

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[96] Real 2002 terms

fuel burnt to generate power by those thermal units changes. However, the incremental savings are reduced as the installed tidal generation increases due to low load and cycling costs incurred by conventional units.[97]

In order to calculate the fuel savings in this analysis, the same model (Plexos) was used for calculating the cycling costs as described above. Using the same operating schedules with increasing penetrations of tidal generation, fuel consumption for each generator was calculated by analyzing the gigajoules (GJ) of energy consumed per MWh for each of them. “The largest reductions are seen in gas generation with 560MWof tidal resulting in a 5,000,000 GJ reduction in gas consumption (approx 3%) and a 2,000,000 GJ reduction in oil (approx 19%). Reductions in coal and peat are more modest with less than 0.5% reductions.” The fuel prices used are the same prices used in the dispatch of the generators and are in €2008/ GJ. The monetary value of annual fuel savings with tidal generation as calculated by Denny (2009) based on the Irish system is illustrated in Figure 5.6 below.

Again, it is important to note that the value of fuel savings attributed to 300MW of tidal generation in Nova Scotia will contain a margin of error since the calculation is based on the Irish generation mix. More specifically, the largest reduction should be seen in coal and then gas. However, since coal is devoted to the production of baseload supply and is likely to remain so in 2020, the reduction in fuel is consumed by coal-fired generating plants will likely require a large amount of tidal penetration. Therefore, from this point of view, the fuel savings are likely to be overestimated. On the other hand, as mentioned before, the fuel prices used to put a monetary value on fuel savings are prices

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[97] Denny (2007)

from 2008. If we consider that the price of coal is likely to remain constant at the 2007 level by 2020, then the fuel savings are going to be overestimated since the price of coal per ton in 2007 was lower than in 2008. According to figure 5.5, there could be around $26.5 million[98] of fuel savings from the generation of 300MW of installed tidal capacity in Nova Scotia.

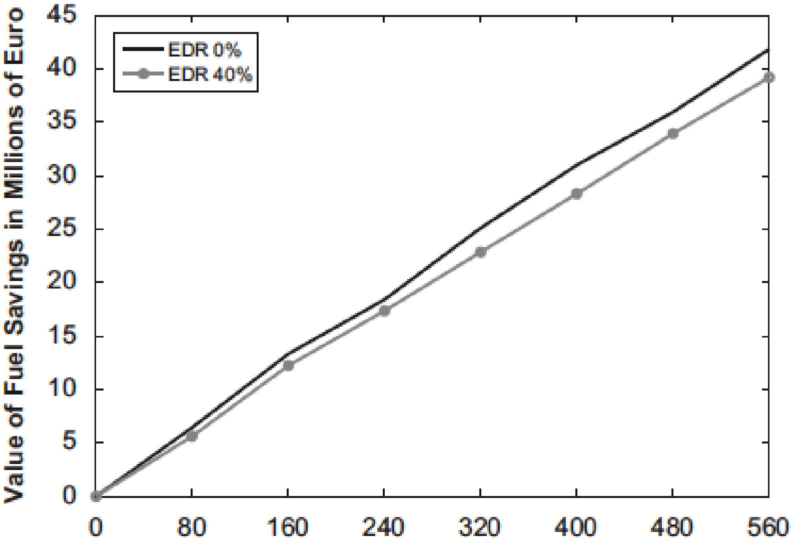

Figure 5.6 Monetary Value of Annual Fuel Savings (Denny, 2009)

5.2.4 Capacity Benefit of Tidal Generation

Another benefit of installing a tidal commercial farm in the Minas Passage is that it will add additional capacity to the Nova Scotia electricity system. This benefit can be calculated in terms of capacity credit, which is the percentage of conventional generation that can be displaced by tidal generation without making the system less reliable. There

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[98] This estimate is derived from figure 5.5 where an installed tidal generation capacity of 300MW is estimated to result in fuel savings of around €17million annually (real 2008 terms). The exchange rate used to convert this estimate into Canadian dollars is 1.5603 as determined by the 2008 annual average nominal exchange rate from the Bank of Canada.

are different methods of calculating the capacity credit for renewable sources but this analysis will be based on the use of a standard Loss of Load Expectation (LOLE)[99] analysis performed with a Monte Carlo simulation technique[100]. Indeed, renewable energy projects, including tidal generation projects, can contribute towards meeting area requirements for LOLE and by comparing the contribution of a new tidal project towards LOLE with the contribution of additional conventional capacity towards LOLE, an effective capacity for tidal generation can be determined. If, for example, the capacity credit is zero, than conventional sources will be needed to meet the electricity need of peak demand. On the other hand, if the capacity credit is greater than zero, then some conventional sources will not be needed to meet peak demand electricity needs and therefore savings will follow from both operational and planning points of view.

Once again, capacity credit has yet to be computed for the installation of tidal energy devices in the Bay of Fundy. However, there has been a study by the New Brunswick System Operator (NBSO, 2005*)* that has used the same method as described above to assign a capacity value to wind projects in the Maritimes. Although it is beyond the scope of this paper, using their analysis to come up with a capacity credit for tidal generation in the Bay of Fundy that would be tailored to the Nova Scotia electricity market would be very useful. Therefore, this paper uses a study done by Bryans et al.

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[99] "Loss of Load Expectation (LOLE) is the probability of disconnecting firm load due to a deficiency of generation resources." (Maritimes Area Wind Integration Study, 2005) It is expressed in days/year.

[100] LOLE can be determined through a Monte Carlo random number probabilistic simulation of each generator's availability for each hour of the year. This process considered that the probability of a generator being unavailable for any hour is described by its Forced Outage Rate (FOR). FOR's are provided for each generator based upon operating experience, and are typically in the range of 1-10%. Random numbers between 0 and 1 produced each hour for each generator simulate that a generator is unavailable if the random number for that generator is less than its FOR, otherwise it is available. Planned maintenance is also factored into each generator's simulated availability by forcing generators to be unavailable during planned maintenance hours. (Maritimes Area Wind Integration Study, 2005)

(2005) in which the capacity credit is assessed based on the Irish grid system and is also based on a LOLE analysis performed with a Monte Carlo simulation technique. The criterion for Loss of Load Hours[101] (LOLH) used in the Bryans et al. study is the current LOLH standard of 8 hrs/year. The criterion NSPI uses is different than the standard one and follows the guidelines set out by the Northeast Power Coordinating Council (NPCC) with a LOLH criterion of 2.4 hrs/year [equivalent to a LOLE of 0.1day/year]. The criterion for NSPI is stricter than for Ireland and if the LOLH obtained for the province is greater than 2.4 hrs then the system fails to meet the adequacy requirement and more capacity is required. Basically, it only means that what is considered to be adequate in Ireland may be less reliable in Nova Scotia just because Ireland has a different criterion. In 2005, when the data were used by Bryant et al, the province was assessed to have a LOLE of .015days/year, which meets the NPCC LOLE criterion while Ireland's LOLH was forecasted to be 2.7hrs/year, which is slightly above the NCPP criterion but below the standard 8hrs/year criteria.[102]

Bryans et al. (2005) found that with an EDR of 50%, an average additional demand of 19.3% could be supported with tidal generation. In order to keep this analysis consistent, we will use the capacity credit for an EDR of 40%, which is has been assessed by Denny (2007) based on the results from Bryans et al. (2005), as illustrated in figure 5.7. Therefore, the capacity credit for an installed tidal generation of 300MW with an EDR of 40% would be around 17%.

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[101] LOLE is expressed in days/year but can also be expressed using LOLH in hours/year.

[102] The Nova Scotia LOLE assessment is taken from NPCC (2005) Maritimes Area Triennial Review of Resource Adequacy Report. The Ireland's LOLH forecast is taken from the Transmission System Operator Ireland (2003) Generation Adequacy Report 2004-2010.

The monetary value of capacity credit of tidal generation can be calculated as the capital and O&M costs that can be saved from the displaced conventional generation[103]. In line with the Nova Scotia Renewable plan, this analysis will assumed that new conventional generation built in the province will be natural gas generating station. Thus, installing a 300MW tidal farm in the Minas Passage with a capacity benefit of 17% would save the costs of building and maintaining a 60MW conventional plan with an availability of 88% (60MW X .85=51MW). Assuming that the capital and O&M costs for a new gas fired plant are $811,000/MW and $75,450/MW per year respectively[104], the cost savings when the capital cost is converted to an annuity with a term of 20 years and a discount rate of 8%, amount to $7.15 million[105] over the plant life.

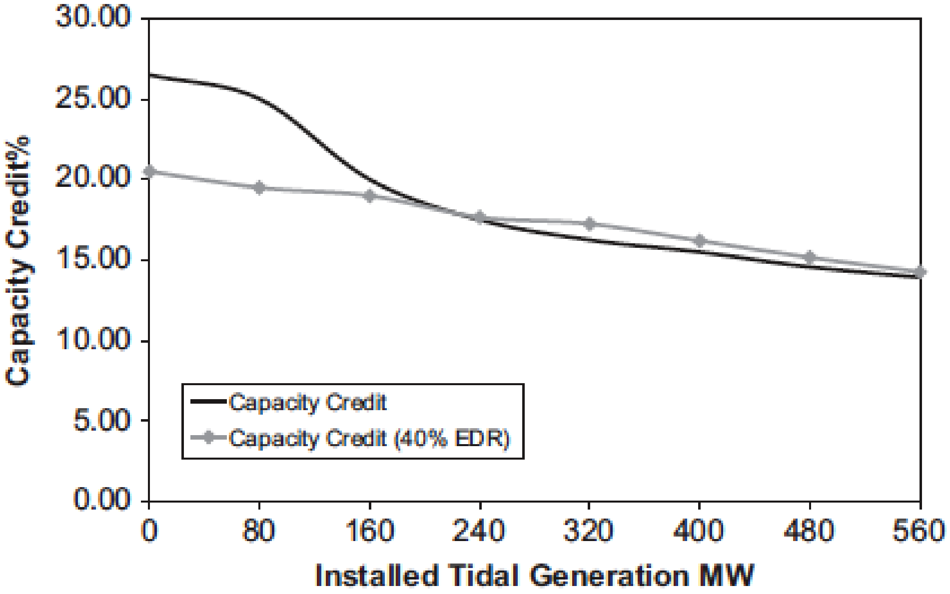

Figure 5.7 Capacity Credit of Tidal Generation
(Denny (2007) adapted from Bryans et al., 2005)

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[103] Denny, 2007

[104] The costs are based on Doherty et al. (2005) and represent the cost achievable for a Combined Cycle Gas Turbine (CCGT) plant in 2020 in Ireland. The costs are in real 2005 terms and were converted from euro to dollar using the 2005 annual nominal exchange rate of 1.5090 as given by the Bank of Canada.

[105] Real 2005 terms

5.2.5 Energy Security

Aside from emission reductions, security benefits can result from threat reductions to the province/nation's energy infrastructure and reductions in disruptions in the province's energy supply. Again, the same issue of attributing a monetary value to an increase in energy security arises: "associations among changes in energy efficiency, energy supply, energy prices, and security impacts involve many assumptions, with highly uncertain causal relationships." (Ruegg & Jordan, 2010) In the recently developed cost benefit analysis approach by the Energy Efficiency and Renewable Energy (EERE) research and technology development programs of the US, it is recommended "to avoid monetary estimates of security benefits, and, to the extent feasible, to use an estimate of the reduction in physical units of barrels of oil equivalent deriving from the use of renewable energy..."(Ruegg & Jordan, 2010) Since most of conventional generation in Nova Scotia comes from coal imports, this analysis will make an attempt at estimating the reduction in physical tons of imported coal as a result of tidal energy generation.

By generating electricity from tidal energy, the need for coal imports is reduced and therefore greater energy security can be achieved. In 2008, 3 MT of imported coal was consumed in Nova Scotia. "Almost all of this consumption was used in coal-fired electric power generation, which provided about 56% of the province's electricity" (Stone, 2009); this represents about 75% of total fuel fossil generation in Nova Scotia. According to the renewable electricity plan, the total generation from fossil fuels should be down to 40% in 2020 and, assuming that imported coal will represent 30% of the mix, then about 900,000t of coal should be imported annually. This represents a reduction of

2.1MT of imported coal per year and considering that according to table 5.1, 11% of that reduction in imported coal will have been as a result of tidal energy generation, then that tidal generation would result in a reduction of 210,000t of imported coal annually until 2020. Since the price of imported coal is forecast to remain constant at the 2007 level until 2020[106] and it is estimated that the global thermal-coal price[107] was around $60 per tonne in 2007[108], then a monetary value of $12.6million/year[109] can be placed on greater energy security from tidal generation. Table 5.4 summarizes the benefit estimates.

Table 5.4 Summary of Benefit Estimates

Benefits	**Estimates**
Emission benefits	$25.3 million/year (real 2010 terms)
Co-benefits from air quality improvement	$11 million/year (real 2002 terms)
Fuel savings	$26.5 million (real 2008 terms)
Capacity benefits	$7.15 million (real 2005 terms)
Energy security benefits	$12.6 million/year (real 2007 terms)

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[106] National Energy Board (2009)

[107] There are two typed of imported coal, coking and thermal coal. Nova Scotia mainly imports thermal coal. (Stone, 2008) And, "prices of coal imported to Nova Scotia, New Brunswick and Ontario reflect the competitive international market" (National Energy Board, 2009)

[108] Natural Resources Canada (2012)

[109] Expressed in real 2007 terms.

CHAPTER 6 NET BENEFITS

Now that the costs and benefits of tidal generation for this specific project have been set out, section 6.1 takes those estimates and brings them together to determine the net benefits of tidal generation using the NPV evaluation method. Section 6.2 presents a sensitivity analysis by changing some of the assumptions that have the largest impacts on the net benefits.

6.1 NET BENEFITS OF TIDAL GENERATION

The first step in determining the net benefits is to have all the costs and benefits expressed in real 2010 terms so that they can be compared.[110]. Since three amounts (emission benefits, construction costs and O&M costs) are already expressed in real 2010 terms, the rest of the terms have been converted into this same currency base. Those calculations are shown in Appendix A. Moreover, many assumptions have been made throughout this study and Table 6.1 summarizes the ones that are needed to calculate the NPV.

As mentioned in chapter 4, the NPV can now be calculated using the following formula:

$$\sum_{t=1}^{n} \frac{TB - TC}{(1+r)^{t}} \qquad (6.3)$$

It is assumed that the construction period will last for three years and will start in 2017, so that in 2020, the project will be ready to generate electricity. Therefore, the project life of 20 years starts with the completion of the construction phase and the period

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[110] Used the historical Consumer Price Index for Canada (Statistics Canada, 2012)

is set at n=23 in the NPV calculation. In order to be able to build the farm, it is assumed that the developers will receive a loan of $1,575 million ($5.25 million/MW x 300MW) at an 8% interest rate[111] for a period of 20 years. During the first three years of the project, only the costs of capital ($1,575million/3 for each year), as well as the cost of debt are being incurred. During the 4th year, or the first year of operation, and until year 20, all the annual costs are deducted from the annual benefits. The annual costs incurred include O&M costs, cycling costs and the cost of debt while the annual benefits include emission benefits, co-benefits from air quality improvement, fuel savings, capacity benefits and energy security benefits. For the rest of the project life (year 21 until 23), the same annual benefits are being reaped but only the O&M costs and cycling costs are being incurred as loan has been fully paid and, therefore, no more cost of debt is incurred. The specific formula used for this scenario is given in Appendix B.

From the base case scenario, a negative NPV of approximately $1212.3 million is obtained. As indicated in chapter 4, a negative NPV indicates that the estimated total costs exceed the estimated total benefits and, therefore, it means that the society would be made worse off with the project. However, given the many assumptions required in this study, in section 6.2, two of the main assumptions are altered in order to investigate the impact of the changes on the NPV.

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[111] A debt service cost of 8% was chosen to finance the capital cost according to current market condition and project financing data after an interview with Natasha V. Lymburner, Account Manager of Business Banking at HSBC Bank Canada in Halifax, Nova Scotia. (2012)

Table 6.1 Assumptions in the Calculation of Net Benefits for the Base Case Scenario

Assumptions	**Base Case Scenario**
Load Factor	35% for Capital and O&M costs 50% for emission benefits 40% for all other costs and benefits
Capacity MW	300
Debt Service Cost	8%
Loan Life	20 years
Discount Rate	9%
Construction Period	3 years
Project life	20 years
Capital Cost	$5.25million/MW
O&M Cost	$246,500/year
Cycling Cost	$12.8 million/year
Emission Benefit	$25.3 million/year
Co benefit from Air Quality Improvement	$12.8 million/year
Fuel Saving	$1.3 million/year
Capacity Benefit	$389,000/year
Energy Security Benefit	$13.2million/year
Discount rate	9%

6.2 SENSITIVITY ANALYSIS

As mentioned in chapter four, the choice of discount rate is crucial to the CBA, as a lower discount rate compared to higher discount rate might change the value obtained in the net present value calculation of a project and make it more favorable for approval. This is especially true in the case of a project affecting climate change as the benefits are received over longer periods of time, while the major costs are incurred early on in the project. Therefore, the same base case scenario will be repeated in calculating the NPV but with a higher discount rate of 15% and a lower one of 1%. This choice of the higher discount rate is motivated by the Carbon Trust (2006) study, in which a rate of 15% is used for initial projects as they are considered to be higher risk projects. Recalculating the NPV with a discount rate of 15% using formula (6.4) gives us a negative NPV of approximately $1072.3 million. On the other hand, the decision to use an extremely low discount rate of 1% was made to test whether there would be any discount rate that could potentially yield a positive NPV at the average Capex as calculated for the base case scenario. The result that is obtained with the 1% discount rate is a negative NPV of $940.2 million. This is to show that, due to the large capital costs that need to be incurred in the first three years of the projects, an extremely large negative NPV is obtained and as a result the choice of a discount rate has no influence on the conclusions reached for this analysis, i.e. the project is not economically viable at the average estimated capital cost.

The second important assumption that will be altered is the capital cost, which is the main reason given against the potential for tidal generation. As mentioned previously, the capital cost used in the base case is an average of the more optimistic and pessimistic cases. In order to investigate the impact of a lower capital cost, a cost of $4.2 million/MW as estimated by Ernst & Young in their optimistic case, has been used in the NPV calculation. The NPV formula with the lower capital cost was first applied with the base case discount rate of 9% and secondly with the higher discount rate of 15%. The first result gives a negative NPV of $778.3 million and the second one a negative NPV of $797.3 million. Those two values, even though an improvement from the base case scenario, still do not support the approval of the project. Under the base case scenario, producing a small positive net benefit for tidal energy would require the capital cost to be less than approximately $949,000 per MW installed. Under the scenario with a 15%

discount rate, the capital cost would have to be even less at $594,700 per MW installed or less. Both of those figures are considered to be unrealistic level of capital costs; thus, it is concluded that tidal generation will not be a feasible option, or at least not on that scale, by 2020.

CHAPTER 7 CONCLUSION AND DISCUSSION

This thesis presented a cost-benefit analysis for tidal generation with specific reference to the installation of a 300MW tidal farm in the Minas Passage, in Nova Scotia, in 2020, as a case study. Different costs and benefits were included requiring a large number of assumptions due the early stage of the in-stream tidal technology and uncertainties about the valuation of environmental impacts. Finally, the NPV was computed with the assumptions for the base case scenario and the assumptions identified as the most important were tested to investigate their effects on the results.

Section 7.1 presents a discussion on a number of issues faced in this analysis as well as elements that could have been included but were not, as they are considered beyond the scope of this study. Some areas for future research are briefly outlined. Section 7.2 reviews the main conclusions of the work presented throughout this thesis.

7.1 DISCUSSION

The main issue with conducting a cost-benefit analysis for environmental projects is that money is used as the unit for comparison and economically valuing environmental effects is extremely difficult. The reason for this is that the environment is considered common property and thus, the resource ownership is not clearly defined. There is therefore an absence of fair and effective property rights attributed to it. Indeed, if resource ownership of air, for example, was be well-defined, then it would be backed up by a litigation process on which resource owners could rely to manage their property even if only to maintain its basic value.[112] However, since it is not the case, whoever

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[112] Abelson (1979)

wishes to pollute the air today or improve its quality, is confronted with no penalties or given no reward. As mentioned in chapter 5, markets for carbon emissions are starting to appear in some regions but we are far from reaching a global agreement, as the failure of Kyoto protocol to be ratified by many developing nation demonstrates. Therefore, there is no fixed rate that has been established at which carbon emissions should be taxed or at which their reduction should be credited. As a result, the range of economic values that are argued should be attributed to carbon credits in the literature is extremely wide. In order to conduct this analysis, an estimate based on both theoretical and practical valuations was chosen. However, whether it will reflect the carbon credit value that will be chosen for Canada or the world in the future, no one can say. Other difficulties arise when trying to determine the amount of CO2 emissions that will be reduced from a specific project. In this case, the reductions have been estimated by FORCE but even that estimate seems to be controversial amongst the different individuals that have been involved in helping throughout the development of this analysis. Although FORCE has been requested to explain its methodology in computing the potential annual CO2 displacement, no response was received from any of its members and so the estimate was taken as given. Finally, the same can be said with the valuation of co-benefits. The valuation of co-benefits is best when performed on a regional basis, as the difference in demographics such as population density and population by age as well as the type of health care system, might make significant contributions to the values obtained. Even then, however, identifying all the co-benefits related to air quality improvement and their impacts on society is almost an impossible task. As mentioned before, there have been very few Canadian studies that have attempted to estimate reductions in fossil fuel-related emissions from measures implemented to reduce GHG emissions and their impacts. Indeed, this analysis used the only recent study attempting to estimate or value the environmental impacts and human health effects of reductions in GHG emissions. Moreover, not only do the authors emphasize the fact that it is only preliminary research, but it was published in 2002 and the data that they used then are likely to have changed since.

Furthermore, determining the economic value of greater energy security is also of great difficulty since there is no direct relationship between the development of renewable resources and the impact this may have on the reduction of imports in fossil fuels. This analysis attempted to put a monetary value on the reduction of imported coal by using a direct relationship between the increase in tidal generation and the decrease in coal imports, which is likely to be skewed. In addition, rather than looking at the reduction in fossil fuels imports, some of the literature on energy security looks at the variations of new generation technology in their availability, affordability, and acceptability and uses them "as indicators of existing and potential changes to the overall energy security system". (Hughes, 2012) In the case of tidal generation, availability (expressed as a percentage) is greater than conventional sources that need to be imported and of which supply depends on global situations, acceptability (represented in terms of emission benefits) is also greater than with the conventional sources, but affordability (expressed in annual costs), on the other hand, would reduce the energy security benefits even if the increase in the prices of conventional sources is taken into consideration. For future research, it would be interested to calculate the energy security benefits using this methodology, as it might result in a very different estimate.

Another issue that was discussed in chapter 5 is the use of a modeling system used to calculate cycling costs and fuel savings that is based on the Irish electricity market. Since the generation mix for Ireland is different from the one in Nova Scotia, there is an inherent error in calculating those estimates. By using a model based on the Nova Scotia electricity market, one might find that the error is minimal, but this study cannot draw any of those conclusions. However, according to Denny (2007) from which the modeling system has been borrowed, "The results shown in this thesis were given for a case study on the Irish system. In general, the costs and benefits of wind generation will be highly dependent on the underlying plant mix, however, the methodology described in this thesis could easily be applied to other systems and other forms of renewable generation". (Denny, 2007) This means that this type analysis for tidal generation could therefore be applied to the Nova Scotia modeling system. Moreover, a more general framework for different levels of installed capacity rather than for a specific case study could be used to determine the optimal tidal penetration at the most efficient cost.

Finally, this thesis did not investigate support mechanisms for renewables offered by the government as incentives for their development. As discussed in chapter 3, the government of Nova Scotia is working on setting a feed-in-tariff for large-scale tidal projects developed in the future. As the net benefit results indicate in the case of this specific case study, it seems unlikely that the government could come up with a level of FIT that would be large enough to support large-scale tidal generation projects in the near future. Indeed, 300MW of tidal generation by 2020 doesn't appear to be the optimal level of tidal penetration at least cost. Therefore, an interesting area for research in the future would be to determine what the optimal tidal penetration would be in a given timeframe in order to set a FIT based on an optimal case study. It will be interesting to see what will be the FIT the government of Nova Scotia sets for large-scale tidal energy projects in the future, what parameters are used to calculate it and whether it will be sufficient or not to encourage the level of development they are seeking.

7.2 CONCLUSION

After conducting a cost-benefit analysis of tidal generation in Nova Scotia, the conclusion is reached that the development of a tidal farm of 300MW in the Minas Passage by 2020 is not the optimal level of penetration for tidal energy as the costs greatly outweigh the benefits. As a result of the project, the province would be made worse off and investments in other renewable energy sources that can yield a positive net present value should be considered. It was also concluded that in order to be beneficial for the project, the capital cost of developing a project should be no more than $$949,000 per MW, which is not a feasible level of costs that can be achieved in the near future according to current cost estimates. However, this does not mean that all large-scale tidal projects should be considered not economically feasible; it means that the timeframe and scale of future projects have to be analyzed in order to come up with the optimal entry point for those projects. Finally, if no developments of large-scale tidal projects is deemed to be efficient for the near future, it would be interesting to consider tidal projects for other purposes than electricity generation, such as energy storage and transportation.

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APPENDIX A Consumer Price Indexes

In order to convert all the costs and benefits into real 2010 terms, the following formula was used:

$$\left(\frac{PRICEyearX}{CPIyearX}\right) \cdot CPI2010$$

The following tables indicate the CPI index used in each case:

Benefits	Estimates	Year X	CPI Index Year X	Results 2010 real terms (CPI 2010=116.5)
Emission Benefits	$25.3m/year	2010	116.5	$25.3m
Co-benefits from air quality improvement	$11m/year	2002	100.00	$12.8m/year
Fuel savings	$26.5m	2008	114.1	$26m/year
Capacity benefits	$7.15m	2005	107.0	$7.78m
Energy security benefits	$12.6m	2007	111.5	$13.2m

Costs	Estimates	Year X	CPI Index Year X	Results 2010 real terms (CPI 2010=116.5)
Capital	$5.25m/MW	2010	116.5	$5.25m/MW
O&M	$246,000/year	2010	116.5	$246,000/year
Cycling	$12.5m/year	2008	114.1	$12.8m/year

APPENDIX B NPV Formula

The following NPV formula has been applied to this specific case:

$$\left[\begin{array}{l}\left(\frac{-(CC+CD)}{(1+r)^{1}}\right)+\dots+\left(\frac{-(CC+CD)}{(1+r)^{3}}\right)+\left(\frac{\begin{array}{l}(ES+EB+AQ+FS+CB)\\-(OM+CY+CD)\end{array}}{(1+r)^{4}}\right)+\dots+\left(\frac{\begin{array}{l}(ES+EB+AQ+FS+CB)\\-(OM+CY+CD)\end{array}}{(1+r)^{20}}\right)\\+\left(\frac{\begin{array}{l}(ES+EB+AQ+FS+CB)\\-(OM+CY)\end{array}}{(1+r)^{21}}\right)+\dots+\left(\frac{\begin{array}{l}(ES+EB+AQ+FS+CB)\\-(OM+CY)\end{array}}{(1+r)^{23}}\right)\end{array}\right]$$

Where CC denotes the cost of capital, CD the cost of debt, CY the cycling costs and OM the O&M costs. While the benefits are denoted by ES, the annual energy security benefit, EB, the annual emission benefits, AQ, the annual air quality improvement benefit, FS, the annual fuel savings, and CB, the annual capacity benefit.