Atlantic Canada's Distributed Generation Future: Renewables, Transportation, and Energy Storage

By

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Abstract

Atlantic Canada's Distributed Generation Future: Renewables, Transportation, and Energy Storage

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Abstract: Nova Scotia and the Federal Government have set low but achievable greenhouse gas targets, aimed at reducing our climate change burden while improving energy security in a globalizing economy. Can we decarbonize our economy and improve our technologic level? To answer this, I assessed our renewable resources and power plants, and in doing so reviewed practicalities of finite and renewable primary energy going forward. I collected data and created Nova Scotia's Energy Map with the objective of improving Energy System Awareness in the region with an interactive online map. I evaluated and compared technology regimes based on: economics; operational risks; quality of environment, human, and animal health; along with social aspects of energy production and consumption. Finally with EnergyPLAN I analyzed and validated a near 100% renewable primary energy scenario to aid the understanding of regional decision makers that decarbonization is achievable and with proper implementation advantageous.

Date: August 31st 2016

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List of Acronyms

ACER	Acadia Centre for Estuarine Research
AEP	Annual Energy Production
ANU	Annual Wind Data
BC	British Columbia
BEV	Battery Electric Vehicles
BOS	Balance of System
CAES	Compressed Air Energy Storage
CAPE	Canadian Association of Physicians for the Environment
CAPEX	Capital Expenditure
CBC	Canadian Broadcasting Corporation
CEPA	Canadian Environmental Protection Act
CESAR	Canada Energy Systems Analysis Research
CFL	Compact Fluorescent Lamp
CHP	Combined Heat and Power
CSS	Cascading Style Sheets
CSV	Comma Separated Value Format
CWA	Canadian Wind Atlas
DECC	Department of Energy and Climate Change
DEM	Discrete Event Model
DG	Distributed Generation
DOE	Department of Energy
DOEnv	Nova Scotia Department of Environment
DSM	Demand Side Management
eCO2	Carbon Dioxide Gas Equivalent
EIA	Energy Information Agency
EIA	Environmental Impact Assessment
ENS	Efficiency Nova Scotia
EPA	Environmental Protection Agency
ES	Energy Storage
ESR	Electricity System Review

EU	European Union
EWEA	European Wind Energy Association
FCEV	Fuel Cell Electric Vehicles
FCHV	Fuel Cell Hydrogen Vehicle
FERN	Fundy Energy Research Network
FFOV	Fossil Fuel On-road Vehicles
FORCE	Fundy Ocean Research Centre for Energy
FST	CWA Proprietary File Format
GDP	Gross Domestic Product
GE	General Electric
GHG	Greenhouse Gases
GIS	Geographic Information System
GMT	Green Metric Tonnes
GOES	Geostationary Operational Environmental Satellite
GUI	General User Interface
HFC	Hydrogen Fuel Cell
HFO	Heavy Fuel Oil
Hg	Mercury
HIA	Health Impact Assessment
HRM	Halifax Regional Municipality
HRO	High Reliability Organization
HVDC	High Voltage Direct Current
ICE	Internal Combustion Engine
IDGPS	Integration of Distributed Generation in the Power System
IEA	International Energy Administration
IEC	International Electrotechnical Commission
INL	Idaho National Laboratory
IPCC	International Panel on Climate Change
IRP	Integrated Review Process
KML	Key-markup language File Format (Google Earth/Maps)
LCA	Lifecycle Cost Assessment

LCOE	Levelized Cost of Electricity
LED	Light Emitting Diode
LFO	Light Fuel Oil
LIDAR	Laser Interferometer Doppler Aperture Radar
LLC	Limited Liability Company
LOC	Lines of Code
MIF/MID	Map Interchange Format
NB	New Brunswick
NEI	National Emissions Inventory
NEMA	National Electrical Manufacturers Association
NFLD	Newfoundland
NL	Newfoundland and Labrador
NOx	Nitrogen Oxides
NPRI	National Pollutant Release Inventory
NRCAN	National Resources Canada
NREL	National Renewable Energy Laboratory
NS	Nova Scotia
NSCC	Nova Scotia Community College
NSDOE	Nova Scotia Department of Energy
NSEM	Nova Scotia Energy Map
NSP	Nova Scotia Power
NSWA	Nova Scotia Wind Atlas
OASIS	Open Access Same-time Information System
OPEX	Operational Expenditure
PEI/PE	Prince Edward Island
PNG	Portable Network Graphics
PV	Photovoltaic Panels
QC	Quebec
QGIS	Quantum GIS Software
RC	Rated Capacity
RE	Renewable Energy
RES	Renewable Energy Strategy
RETScreen	Renewable Energy Technology Screening Software
RPN	Recherche en prévision numérique Format (CWA)
RPS	Renewable Portfolio Standard
SFI	Sustainable Forestry Initiative
SO	System Operator
SOx	Sulphuric Oxides
SSI	Seasonal Selector Indicator
SVG	Scalable Vector Graphic Format
SWOT	Strengths/Weaknesses and Opportunities/Threats
TBD	To Be Determined
UK	United Kingdom
V2G	Vehicle to Grid
VARK	Visual-Audio-Reading-Kinesthetic
WEC	Wind Energy Converter
WF	Wind Farm
WT	Wind Turbine
WWSB	Wind, Water, Solar, and Biomass
WWSE	Wind, Water, Solar, and Energy Storage
XML	Extensible Markup Language Format

List of Units

Units	**Description**	**Equivalent**
tonne	Metric Ton	1000 kg
ton	Imperial Ton	2000 lbs
kT	Kilotonne	1000 tonnes
kg	Kilogram	2.2 lbs
m^2	Meter Squared	$10.76\ ft^2$
GW	Gigawatt	10^9 Watts
PJ	Petajoules	277.78 GWh
BTU	British Thermal Unit	0.293 Wh
mmBTU	Million BTUs	293 kWh
€	Euro (2014)	$1.83 Canadian
GWh	Gigawatt-hours	1000 MWh
MW	Megawatt	1000 kW
MT	Megatonnes	1000 kT

Chapter 1: Introduction

1.0 Introduction

This chapter describes several important concepts that will follow in the rest of the thesis. The stage is set with the understanding how “Choice Awareness” (Lund, 2014) relates directly to “Energy System Awareness”, in that we have a choice in what energy system we will build together as the old one begins to retire. I then complete a quick overview of existing maps, tools, and their limitations. I put forward the idea that we are all in different measures at different times of our life, part-student and part-teacher, and with the right teaching methods – such that the Nova Scotia Energy Map and other tools seek to achieve, we will fundamentally grow from each other’s work.

1.1 Energy System Awareness

The intent of this work is to promote energy system awareness in Atlantic Canada, starting with Nova Scotia as a prime example and moving to include the provinces of New Brunswick, Prince Edward Island, and Newfoundland & Labrador.

The idea for the “Nova Scotia’s Energy Map” website and Flash based interactive map is unique in the region. The energy map started as a hobby in 2007 when working on my undergraduate studies in the applied sciences at Acadia University. The map shows development on a timeline from the 1920s when the first hydropower stations were being built, to include the advent of the thermal generating plants in the 1960s and with rapid expansion of our energy base afterwards. It is important to note that some early hydropower plants, watermills at lumber yards, and coal and oil power plants did not have readily accessible data and have not been included in the energy map to date. Looking from this historical perspective and applying this to present energy developments, such as ongoing construction projects in the renewable energy field; users of the energy map gain a sense of the general push towards electrification, and how it has become a vital part of modern society, encompassing economic drivers and typically altering the environment to support our way of life.

The primary purpose of the map is to provide a general interactive overview of what each major power producing station is capable of – in terms of annual power production, emissions, alongside renewable resource maps, historical data, and relating these system-wide concepts directly to individual energy consumers. The secondary purpose is to allow users to place wind turbines, tidal turbines, solar PV panels, including energy storage technologies such as Hydrogen, CAES and eventually BEV/FCEV connected in V2G configuration on the map to get an estimate of annual power production, and better inform citizens of the realistic capacities of each technology; while also seeing basic economics of each technology based on LCOE ranges commonly found in the literature.

The map design is intended to be fully accessible to the public as all people play intrinsic roles in the energy economy, from production, storage, distribution and use. It should be noted that without everyone's shared expertise and common work ethic the technologies talked about in this map would not exist. In light of that knowledge, the guidance of regulatory mechanisms such as environmental impact assessments and approval processes has provided wisdom to decisions that affect our shared future. For better or worse we all share diffuse responsibility to engage and inspire each other to live 'healthy, wealthy and wise' in our everyday actions.

Climate change (Dawson & Spannagle, 2008) is a factor of vital importance in designing energy systems in modern times, and the promotion of a low carbon future as advocated by the United Nations and IPCC is a mainstay in shaping our common work. With this in mind, energy planning goals set by other leading countries such as Germany and Denmark will be considered and applied to the Nova Scotian context. An EnergyPLAN model for Nova Scotia has been run through several trials, with forecasts of 2030 leading up to near 100% renewable energy scenarios; the main focus being decarbonization, self-sufficiency and export.

On a last note, while working on content for the thesis, the Department of Energy followed through with a mandated Electricity System Review, by consulting experts the summer of 2014 and hosting public meetings that autumn. The quality input they received during this process will shape our provincial energy trajectory for several decades. In tandem the Department of Environment hosted their Greener Economy strategy sessions to hear from the public on how to continue as leaders in this province. Will the collective knowledge we share and skillfully selected paths, chosen together, lead to a prosperous and ethically sound future?

1.2 Existing Maps, Tools, and Limitations

Previous mapping work in the region typically involved basic static maps showing symbols for power plant locations, with little to no detailed information on the map itself. Another rendition style was more artistic in nature and visually interesting but again could only present so much data in the medium used. For the sake of brevity I do not include all the links to these resources.

There was one interactive map that showed some data collected in the province, but neglected to include all power generation stations, as the scope of their work was continental in nature, and could not be expected to get every bit of information on each power plant. My own data collection techniques at the time on the internet usually involved meticulously researched and triple checked news reports, media publications, and whatever else search engines would come up with, which typically meant incomplete or inaccurate datasets. Nova Scotia Power has a Flash based wind only energy map, and includes photos for each wind farm.

Energy maps in other regions have demonstrated capacity to display real-time information, typically how much energy – power plants are producing and energy flows to neighbouring countries. One website used ‘real-time’ alternatively called ‘nowcasted’ wind speeds – meaning they are provided by weather data sourced from satellites and geographically nearby ground stations, but not actual measurements from the wind farm itself; this process gave estimates of how much energy offshore wind farms were producing, but displayed this information in a tabular format, useful definitely, but not visually appealing in any manner.

CanESS (Canada Energy Systems Analysis Research, 2014) is a top down annual statistics-based energy model for every province in Canada regarding primary energy used in each major sector: such as heating, transportation and electricity. They chose to use the sankey diagram visualization that nicely describes energy flows from inputs to useful outputs along with energy losses.

1.3 Overall Objective of Project

The ongoing objective of the project is to use the energy map – as an energy information system – to improve public energy system awareness regarding the history, present state, and direction of our energy systems and how they tie in with local and world energy affairs. The primary methods of achieving this objective combine elements of the existing tools mentioned and blend together a visually interesting, data rich environment.

From a practical standpoint and acknowledging all of the varied expertise locally and around the globe, Canadians are situated in a time of important decision making that will shape all citizens quality of life for decades to come, and either positively or negatively affects all life in some measure. As Einstein once said, “We cannot solve a problem in the same mindset that created it.” In this context of energy system awareness I interpret it to mean we are observing, learning, growing, and changing our methods of achieving goals to be in balance with nature. The aim of this research is to encourage the utilization of best practices and standards, along with current and emerging technologies within evolving world markets. Both policy and utility governance are outside the scope of this work.

1.4 Original Contributions of Thesis

The electricity generation and transmission sector is a well-established industry. There are many textbooks, journals, media, data, and software forecasting tools already available in the public sphere. With countless scientists, engineers, technicians, tradespeople, policy makers and citizens taking part in improving this field – it can be overwhelming at first when deciding where best to make a contribution.

That said I have had an interest in assessing renewable energy projects through my undergraduate degree; so it was natural to extend my passion to include emerging technologies in the renewables industry, and with that – greater accommodation of renewable power generation up to near 100% of provincial energy mix, which has not been seen from a technical perspective in the literature to date for all of the provinces in Atlantic Canada, using Nova Scotia as a case study. Work such as this has been done for other regions around the globe, using modeling software and science to inform our understanding.

Jacobson and Delucchi 2011 and 2015 have completed ground breaking work in the USA, state by state, and also globally for each nation's primary energy optimization. This thesis and the NSEM provide a unique method of engagement by viewing potential energy futures – allowing website users to place potential power plants on the map.

In regards to actually changing the energy systems, this type of work cannot be done alone; so it made the most sense to engage the combined imagination, knowledge and work ethic of the general public and achieve great things together. I figured the best way people learn would be through an interactive energy map, to allow for individual exploration of learning objectives combined with a basic introduction to the topic and example case studies.

The required data to achieve these objectives amounted to a lot of online searching for general power plant data on every installation in the province. This includes some 33 wind farms and 41 smaller ComFIT wind farms, 35 hydropower plants, 5 biomass plants, 3 combustion stations, and 5 coal/natural gas/oil plants. The manual data collection was non-trivial, in that varied quality of data, distributed nature of media reports of wind farms and upgraded thermal plants meant an ongoing dynamic process had to be followed. Utilizing separately maintained data on wind turbine power curves was a good example of the effort required to acquire and organize useful information. Finding top down primary energy distributions by provinces was very helpful, and this partnered with several baseline years from various Nova Scotia Power reports helped greatly. OASIS hourly datasets for the last seven years helped significantly when utilizing energy modeling software and creating realistic future energy scenarios for Nova Scotia.

With these datasets combined, and working knowledge of the general wind energy hub height equation (Figure 104) I created a mostly automated PHP-MySQL computational method to calculate annual power production for all wind farms in the province, based on each farm’s unique turbines’ power curves and automatically matched to Canadian Wind Atlas wind histograms. The initial part that required patience was using QGIS to hand-select the ‘Nova Scotia land area including slightly offshore’ polygons to be a part of the approximately 5200 data points from the initial much larger raw data set. Future plans will be to include nowcasted and forecasted wind speed data with several other weather variables for all wind farms in the province to provide realistic, but not actual, current energy production numbers.

The main contribution is the ongoing design and artistic rendition of the Flash based energy map at my website: www.gonotes.org programmed with ActionScript3, adding up to approximately 5000 lines of code, plus additional modified imported classes from other's work on the internet covered in chapter 6.

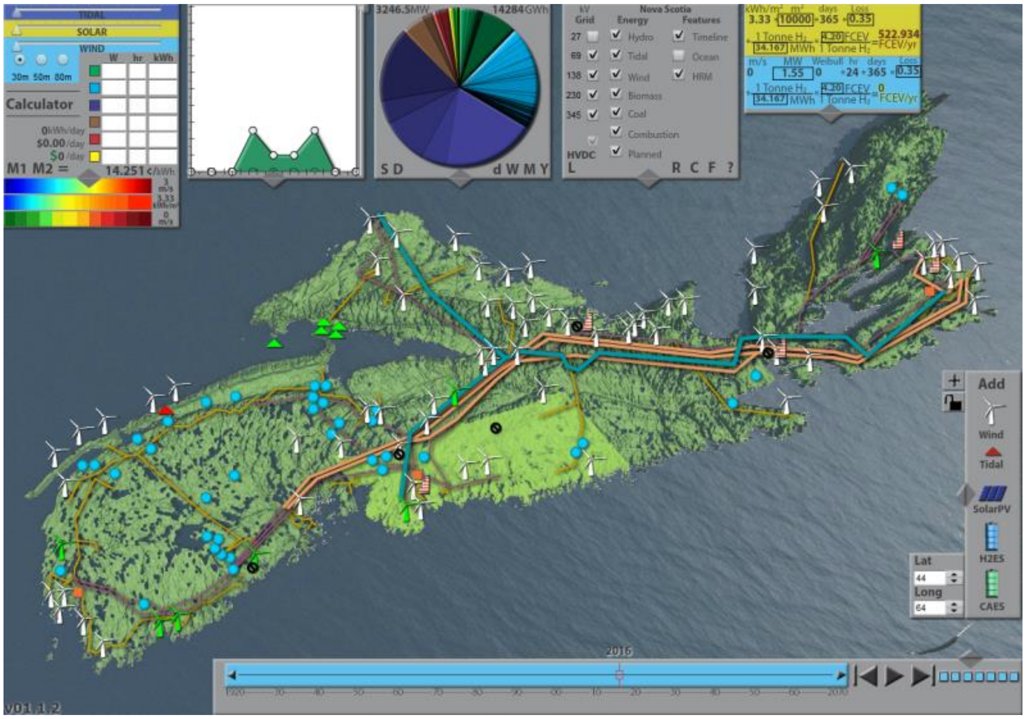


Figure 1: Nova Scotia's Energy Map

1.5 Thesis Organization

Chapter 2 embodies the lessons learned from the early literature review process regarding three main sections: electric grid, energy storage technologies, and local policies in Nova Scotia. Considerable ongoing research has been done, in the form of attending conferences and lectures, along with journals and textbooks read and new lessons learned, which is reflected in following chapters.

Chapter 3 covers energy supply, technology, and storage: broken down into several areas: primary energy supply in Atlantic Canada, finite energy technology, renewable technology, stationary and transportation energy storage. Only with practical knowledge of the components, specifically power plants and demand curves, which were entered in the EnergyPLAN model, may forecasts be constructed with a reasonable degree of quality.

Chapter 4 is a four piece collection of sound economic considerations, operational risks, environmental impact assessments, and health impact assessments. Our energy systems cannot be rationally looked at solely from the framework of energy focused technical details, therefore this section covers topically what government regulatory bodies would focus on before approving any projects.

Chapter 5 describes energy distribution and use, regarding modeling and mapping: first in the form of utilizing the EnergyPLAN software model to assess our energy futures, and taking into consideration GIS mapping techniques, spatial limitations, and best practices for new renewable generation, energy storage and transmission lines.

Chapter 6 includes rationale for the design and implementation of the main features in the energy map, and explains major features written with the ActionScript3 programming language. It also briefly covers earlier stages of the energy map before the pursuit of graduate studies and lays the groundwork of planned features.

Chapter 7 provides a summary and conclusion of the thesis research, what objectives were achieved, and potential future plans.

Appendices include additional valuable information that due to space limitations did not easily fit into the body of the thesis.

Chapter 2: Literature Review

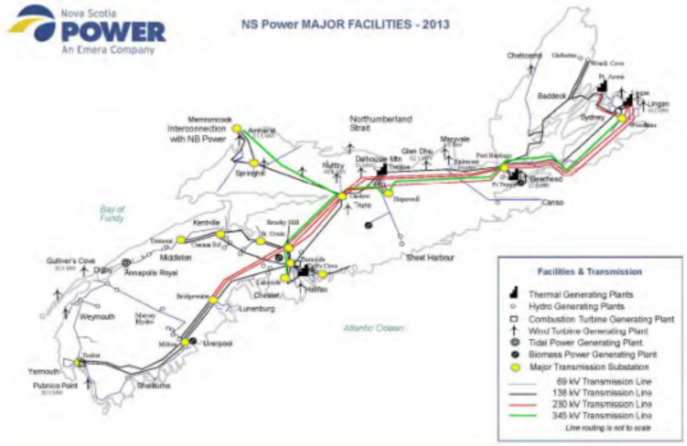


Figure 2: Nova Scotia Power Generating Stations (Nova Scotia Power, 2013)

2.0 Introduction

This literature review sets the stage for a transition away from heavy reliance on fossil fuel in this province, and beyond, to the regional power grid context. It evaluates economic, environmental and social impacts of changing infrastructure. It is highly important that the technologies and construction of systems are built and strengthened in an organized manner to ensure a smooth economic transition. The following historical context will be explored in more detail in the body of the literature review, where many examples are given, such as: US Project Independence, US Hydrogen Initiative, The European Distributed Generation (DG) Example, and Atlantic “Hydrogen Economy” (Theckedath, 1 February 2010) Evaluations (NS and PEI). In the present context examples are given locally and in North America, such as: NS Department of Environment (DOEnv) – Greenhouse Gases and Climate Goals, Department of Energy (DOE) – energy targets, peak oil/carbon pricing, and BC – California Hydrogen Highway Projects.

2.1 Electric Grid

The European example (Bollen & Hassan, 2011) of integrating large scale wind into several national power systems shows what can be done in other countries with good wind resources with the right design strategy. Nova Scotia has a healthy wind resource as seen from the Nova Scotia Energy Map (Thompson, 4 June 2015) and many projects have been built since 2006. There was approximately 316MW of provincial wind power at the start of 2014, with a plan to install more by the end of 2015 up to 560MW not including ComFIT projects, which may cover at least another 100MW. This matches short term goals set out by an advisory energy firm; midrange goals seek to integrate 700-950MW by 2020. Both of these goals were set by Hatch Ltd.'s report (Hatch, 2008) to the DOE in 2008. The literature has plenty of instances of simple modeling of wind, solar, and tidal turbines/farms necessary for system planning. The Canada Wind Atlas (Environment Canada, 21 August 2008) has a top down climate-numerical approach to produce statistical estimates of annual and seasonal wind strength, direction and "Weibull' curve shape factor. This is not necessarily meant to replace meteorological tower measurements on potential sites but provides the first step towards planning on-site measurements. Below, on the right, are statistical data for the Pubnico wind farm.

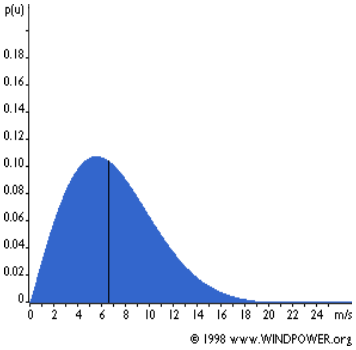


Figure 3: Weibull Model Curve

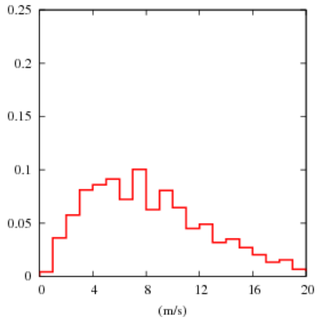


Figure 4: CWA Histogram

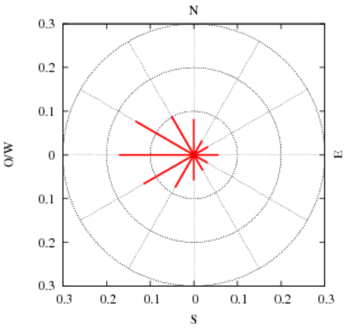


Figure 5: CWA Wind Rose

The DOE plans to provide 40% of Nova Scotia's electricity consumption or Gigawatt hours (GWh) from renewables by 2020 (Nova Scotia Department of Energy, 2010b). Considering both the upcoming plans for wind development by 2020, and also the Muskrat Falls' hydropower (Nova Scotia Department of Energy, 2012) and Maritime Link project is meant to be constructed by approximately end of 2017, citizens see how easily this may be achieved in a practical timeframe. Below is an excerpt from my webpage with an evaluation which draws information from the "Integration of Distributed Generation in the Power System" (Bollen & Hassan, 2011).

> "Nova Scotia's Energy Map is a combination of data to get a sense of what renewable resources consumers are currently using in this province. The general concept of the webpage is to assess and nudge the suggestion of an East Coast Hydrogen Economy into the public fray. The term energy storage covers a number of technologies such as kinetic (fly-wheels), chemical (hydrogen, lithium batteries, lead-acid batteries, flow batteries), or potential (hydropower, regenerative and normal compressed air systems) to name a few options.
>
> One primary issue with variable energy resources is that by definition these sources are harder to accommodate with currently built infrastructure and policy. Overall hydropower output varies each year depending on rain, snowfall and evaporation. Solar varies with cloud cover and temperature but is approximately constant on a clear day, depending on the time of day and of the year. Wind varies with each

passing weather system. Tidal cycles follow the Moon's orbit and position of the Sun to Earth's rotation. Even though these energy resources can be approximately predicted the day before – it is not perfect. With current technology there is always going to be a need to adapt the power generation scheduling plan to fit the weather situation as it happens, which can use up energy reserves. When the margin of error is large, it may affect power quality and use costly fuels if not planned for properly, with the worst implications being blackouts and infrastructure damage. This requires having sufficient power generation that can match any sudden changes for reliable energy delivery.

In Europe a lot has already been implemented in Germany and Denmark with large scale wind farms. Meanwhile in North America, Texas and Quebec have made similar progress. Nova Scotia has made significant strides over the last decade integrating wind into our energy mix. It can be seen in the literature there needs to be infrastructure in place to react and balance quickly (0 to 60 seconds) to ever changing renewable energy variations and customers' changing demands that also occur over longer stretches of time (15 minutes to several hours). Typically pumped hydropower is used in Europe, but it would be smart to locally start making progress on compressed air storage and Hydrogen storage as grid backup supply and peak leveling. The benefit with Hydrogen is it has spin off uses throughout the economy, and can be trucked in a similar manner to fuel oil and other common substances used today.

> The further away power generation is from the end use results in greater line loss, and losses from substations that convert between higher or lower line voltages. One major advantage to solar power when added on appropriate residential, commercial and industrial buildings is that less energy is wasted on the way and can be used in the local distribution grid to lower demand on larger generation plants. At the moment the utility has natural gas to provide quick responses for power fluctuations to a certain extent, and when solar, wind and tidal pitch in the province can stretch out our energy budget." (Thompson, 4 June 2015)

DG generally consists of renewables such as wind, solar, biomass, tidal, and hydropower, but also includes nonrenewable sources such as smaller scale natural gas that are all spread over a geographic area of any power grid. Nova Scotia has primarily and historically used light and heavy fuel oil, coal, and natural gas in a centralized production fashion, with decentralized hydropower maintained from the beginning to present day. Approximately 2000MW is provided by Coal (4 plants), Natural Gas (1 plant) and Light Fuel Oil (3 plants). While approximately 1100MW of rated capacity will be provided by approximately 33 Wind Farms, 35 Hydropower plants, 5 Biomass plants, and 1 Tidal plant at the end of 2015, not including ComFIT projects.

To meet the 700-950MW goal set out by the (Hatch, 2008) report, upgrades to the transmission and distribution systems need to be made to ensure reliability and power quality standards of the system operator (SO). One major project is the Maritime Link which was first conceived in the late 1970s as a source of Hydrogen production and the original design was a Hydrogen pipeline from Labrador to Nova Scotia and then on to

New York (Silverstein, 1981). Currently the Link is designed to be a high voltage direct current (HVDC) transmission cable capable of 500MW. The cost of the Link is $1.2B and will be owned by Emera for 35 years, while the 824MW Muskrat Falls hydropower dam is $2.9B and will be owned by Nalcor, while the Labrador-NFLD transmission system is $2.1B, split between Nalcor and Emera by 71% and 29% respectively. Emera is the parent company of Nova Scotia Power and Nalcor and operates along the North Eastern seaboard (including Maine and New Hampshire).

Transmission line upgrade economics related to power produced in NS will depend on proximity to major lines (69 Kilovolt to 345kV) and capacity for the power grid to absorb variable production. In the Bay of Fundy, FORCE (Fundy Ocean Research Center for Energy, 2015) has planned a tidal current technological test site for different manufacturers to evaluate the unique tidal regime of Nova Scotia's most powerful tides – up to 5 meters per second (Karsten, McMillan, Lickley, & Haynes, 2008). When suitable technologies complete rigorous testing the eventual plan is to construct arrays of these devices to capture tidal energy that fluctuates on a daily and monthly basis. This requires significant adaptation of the current power production in the province.

As said earlier, it is easy to predict the general flow of tidal energy but accommodating it effectively will require grid upgrades and updates to the production planning practices depending on the scale of power capacity undertaken, perhaps 300-2000MW (Nova Scotia Department of Energy, 2015a), as a conservative estimate is written in the literature with up to 5% reduction in tidal amplitude throughout the Minas Basin – (Acadia Tidal Energy Institute, 2015; Karsten et al., 2008). The environmental impacts of lower tides will have a large effect on tidal marshes and general habitat for fisheries; this is being studied by ACER (Acadia Centre for Estuarine Research, 2015) at Acadia University while energy studies are being assessed by FERN (Fundy Energy Research Network, 2015). There have been various sizes of studies researched on the Bay of Fundy region at Saint Mary's University Department of Geography and Environmental Studies by Dr. Danika Van Proosdij.

Solar photovoltaic (PV) has proved that it has significant potential in large populated areas, such as Halifax Regional Municipality with 3.38kWh/meter^2 (GreenPowerLabs, 2009) per day averaged annually due to many roofs being available in a concentrated geography. A recent approval of the 'SolarCity' (Halifax Regional Municipality, June 2015) program encourages citizens by providing rebates and offering purchase plans that enable installations of solar thermal hot water panels. PV panels do not necessarily have to compete with long distance line losses that some wind farms have to deal with. They can be built on suitable roofs or walls with access to sun throughout the day. The solar fluctuations can occasionally be accommodated by the law of large numbers; the premise was demonstrated by a comparable study on provincial distribution of wind power in Nova Scotia by COGS, but the geographic distribution of panels must be considered in respect to typical weather and cloud cover patterns in the region.

A plan by Nova Scotia Power is needed to model the outcomes of large (greater than 1MW) installations with weather data for HRM so that power is reliably and economically provided. A good example might be the installation of PV panels in Burnside industrial park (Appendix A) on potentially 1 in 10 buildings, as a rule, and constructing Hydrogen fuel cell backups and CAES to provide firm power production when the Sun does not shine. Extra Hydrogen fuel could be sold to fuel stations for early adopters of the upcoming Hydrogen Economy – i.e. buses, forklifts (Ballard, 2012) and automobiles. Wind farms could deploy several MW class H_2 Fuel Cells (Ballard, 2013) to provide 'firm wind power' when the wind is calm. This topic will be covered in more detail in Section 2.2 of the literature review.

The full lifecycle cost assessment (LCA) needs to be considered for every practical technology planned for Nova Scotia. This includes capital investments, mining and manufacturing impacts, GHG and particulate pollution, public health, power supply risks and opportunities, energy security, and environmental assessment.

The US has a National Emissions Inventory (NEI) for all point source and dispersed emissions. An article (Colella, Jacobson, & Golden, 2005) covers the transition from fossil fuel primary energy sources and transportation fuels to renewable energy and Hydrogen fuel cell vehicles or battery electric vehicles.

The "Trillion Dollar Formula" in Chapter 3 provides a case study for continental energy markets and their regional assessments. Atlantic Canada would benefit from a generalized economic payback period of Compressed Air Energy Storage (CAES) and Hydrogen Storage (H2ES) integration with the power grid and peak power leveling to provide firm renewable power. There have been high level overviews by (Hughes & Scott, 1992; Silverstein, 1981; Stuart, 2006) but not full scale deployment studies of H_2 and CAES infrastructure by institutions such as the DOE and DOEnv, or independent engineering firms done in similar fashion to the Hatch Ltd., Lavalin Inc. and GE wind reports.

Perhaps the Government of Canada could update their Renewable Energy Technology Screening – RETScreen (Natural Resources Canada, 2014) software (for household and plant level technology) to include municipal and provincial level scaling of economics, GHGs and general energy production including resources. Along those lines "Modeling and Simulation of Discrete Event Systems" (Choi & Kang, 2013), includes computational methods for simulating various complex systems, selection of model types and factors influencing best fit results; which will help in evaluating independent studies and other software modeling tools.

The book "Upcycle" (McDonough & Braungart, April 2013) by the authors of "Cradle to Cradle" (McDonough & Braungart, 2010) looks at improving all technical-nutrient and bio-nutrient system/product cycles so that society operates more effectively from a holistic viewpoint. They advocate being "more-good" not "less-bad" in simple terms. The authors operate their own business supplying technical/chemical datasheets on using nontoxic materials to design human and environmentally safe products and buildings. One factory they improved actually had cleaner water effluent on the way out of the factory than on the way in. These concepts can be applied to the power grid. Providing energy in a manner that improves public health – allows society to flourish – with education, appropriate consumer products, healthy food, clothing and improved lifestyles. It does not mean living in a 'yurt economy' as some economists use the concept, but rather entering the Third Industrial Revolution as Jeremy Rifkin puts it.

2.2 Energy Storage

2.2.1 Hydrogen Economy

The Hydrogen Economy (Kim & Moon, 2008) is not a new concept. From the 1950s onward it has picked up steam sporadically changing each decade as new technologies developed. The Space Shuttle was one prime example of an early effective Hydrogen fuel cell (HFC). The general fuel cell concept is the prime driver of the Hydrogen Economy because of high conversion efficiency (35-50%) compared to gasoline internal combustion engines (ICEs) at 16-30% (Colella et al., 2005). There are many chemical pathway designs for HFCs. Some run at higher temperatures and efficiencies (with longer ramp up and down times) suitable for grid baseload power, while others are more agile at following the desired demand, and cheaper to produce even if they are not as efficient as the former.

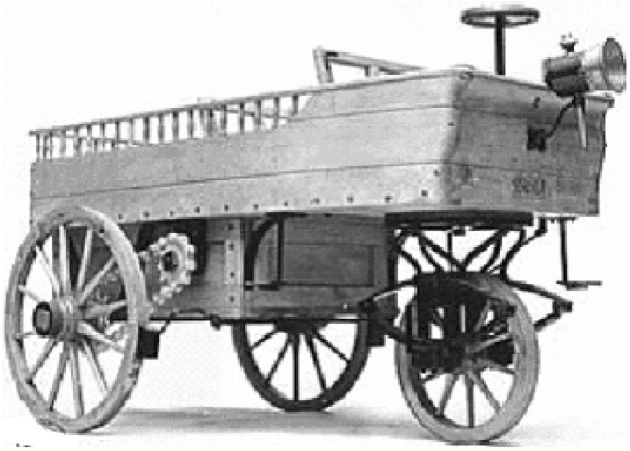


Figure 6: First Hydrogen ICE tested in Paris 1860 - Page 151, (Brunet, 2013)

The production, transportation, distribution and consumption of Hydrogen have been assessed thoroughly throughout the USA (Colella et al., 2005), Europe (Bollen & Hassan, 2011), China (Z. Li, Gao, Chang, Liu, & Pistikopoulos, 2008), and Korea (Kim & Moon,

2008) to name a few. Specific case studies have focused on overall air quality effects of transitioning, to system energy efficiency of "well to wheel" analysis, to different spatial applications of best in class technologies – (Agnolucci & McDowall, 2013; Agnolucci, Akgul, McDowall, & Papageorgiou, 2013), and Greenhouse Gas (GHGs) emissions. The textbook "Wind Power in Power Systems" – (Ackermann, 2012), has a chapter on Hydrogen energy pipeline economics versus transmission lines. The author provides examples of levels of pressurization, converting H_2 to a liquid, using shipping tankers at sea and simple distribution networks to provide transportation fuel and district heating/energy. The practical economics and engineering specifications are laid out for a non-technical reader. Risks are similar to natural gas wells regarding fires and explosions.

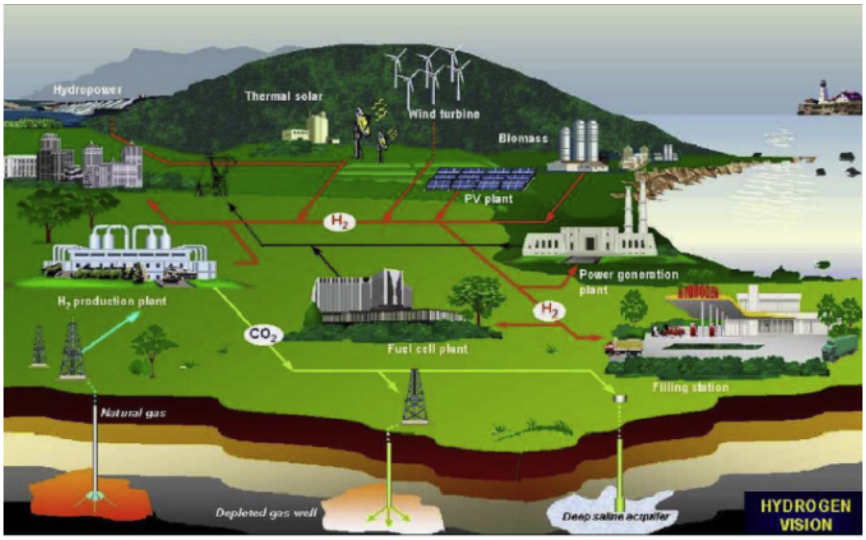


Figure 7: Hydrogen Value Chain (Frischauf et al., 2013)

Canada has partaken in research and development over the decades to support industry uptake, and several prominent manufacturers have been created out of those funding drives. Ballard Inc. (Ballard, 2013) is a prime example of an HFC manufacturer, producing everything from buses, forklifts, automobiles and even backup power for homes, telecommunication installations, and MW class grid power plants. Atlantic

Canada was assessed by (Silverstein, 1981) by using both tidal power in the Bay of Fundy and Muskrat Falls hydropower so that each location could produce Hydrogen and then be moved via pipelines for all of our transportation, heating and electricity needs. More recently (Hughes & Scott, 1992) assessed the positive impact of reducing fossil fuel use on air quality and reliance on foreign imports of energy in 1992. Later, PEI held a Wind-Hydrogen Symposium (PEI Energy Corporation, June 2003) and evaluated the strengths of converting their entire economy to Hydrogen in 2003; as an island economy they wanted to assert independence in energy security, by producing electricity with wind turbines and storing extra energy in H_2. PEI could then power fishing fleets, farm equipment, golf carts and automobiles. There is a business case for hydrogen (Curtin & Gangi, September 2010). UPEI's E. Kathy Stuart (Stuart, 2006) recommended that small island nations adopt Hydrogen economies as they would benefit with both energy independence and economic stability. Small island nations typically suffer from 'mild neglect', being last on the priority list for receiving shipped oil, resulting in higher costs. One researcher gave an example island such as Hawaii whose electricity (Nebraska Energy Office, 16 April 2015) cost sky rocketed (raised approximately 18 cents per kWh) when fossil fuel prices soared over the last decade.

Hydrogen is not without its technical and safety drawbacks. The initial infrastructure using steel pipelines became brittle over time with consistent exposure to Hydrogen gas. Modern manufacturing now employ liners in pipes to separate contact of Hydrogen and steel. There will definitely be significantly less deaths caused by air pollution from fossil fuel combustion relative to Hydrogen fuel cells, but this also requires large percentages of the primary energy system to be renewable powered.

If we consider automobile impacts of FCEVs compared to FFOVs, I am uncertain which is safer. Some FCEVs have built in impact depressurization valves to attempt to reduce explosion risks on impact or rupture of the high pressure Hydrogen gas fuel tank. From an energy standpoint, there is more chemical energy in a standard FFOV tank, but the potential energy of 70MPa is a high risk, similar to the explosion of a scuba tank.

System Efficiencies

System efficiency pathways from well to wheel energy analysis was performed for 39 permutations with the most practical technologies (Bogart, 2002). Project Independence proposed by Nixon nearly 40 years ago, since abandoned, was conceived to reduce the lion's share of imported fossil fuels to US. The US DOE has taken on a new program called the "Hydrogen Fuel Initiative" announced in February 2003 along with the FreedomCAR program launched in 2002. Both are H_2 vehicle focused;

> "The stated presidential objective is 'reduce our demand for oil by over 11 million barrels per day by the year 2040.' " (Bogart, 2002)

In 2002, the quantity of imported oil was 11 M bbl/day or 24.3 Quads (BTU) annually, see https://flowcharts.llnl.gov/archive.html for data. This was two-thirds of the supply for USA's transportation sector. Nuclear, wind and solar were evaluated as the primary energy supplies in the study; Bogart (2002) assessed the economics of each energy supply chain method. He organized these supply chains in order of cost, cheapest being first: hydrocarbon pipelines, hydrogen pipelines, and standard high voltage electrical transmission. Battery-electric vehicles (BEVs), Hydrogen fuel cell vehicles (FCEVs) and Fossil fuel on-road vehicles (FFOVs) were analyzed on the demand side for comparison. The costs of each pathway was assessed and ranged from $1.65 – $22.5 – $128.9 Trillion with nuclear being the cheapest when using the electric transmission and FCEVs pathway. Wind was second cheapest and solar the most expensive based on $20.57/Nuclear-watt, to $28.12/wind-watt, and $161.2/solar-watt (average watts, not peak watts – meaning it requires substantial energy storage if intermittent, they used CAES underground storage, until later stored in Hydrogen gas stations and vehicles). These figures were based off of 2002 prices and efficiencies per each technology. Refer to M. Jacobson and M. Delucchi (2010a, 2010b), for more recent values; also see section 5.2.2 and "The Solutions Project" on page 147. In the US example, 11M bbl of oil is equivalent to 775 GW/day which translates to wheel-shaft work of 80 GW/day in vehicles. In 2015, the installed $per-watt of wind is $1.45 or LCOE $0.07-0.27 kWh and solar PV is $2.49 or LCOE $0.12-0.26 kWh for utility installation sizes (Chapter 4, page 109 for LCOE chart), solar PV is actually half the price for the initial installed cost (from $5 in 2002), and translates over to savings resulting in $124.42 per-watt average or $99.54 Trillion. Wind was $1.88 per-watt in 2002, and would reduce to $26.15 per-watt average or $20.92 Trillion. This only considers solar and wind cost reductions as part of the energy value chain, not ES savings. See Appendix F for $per-watt value and paths.

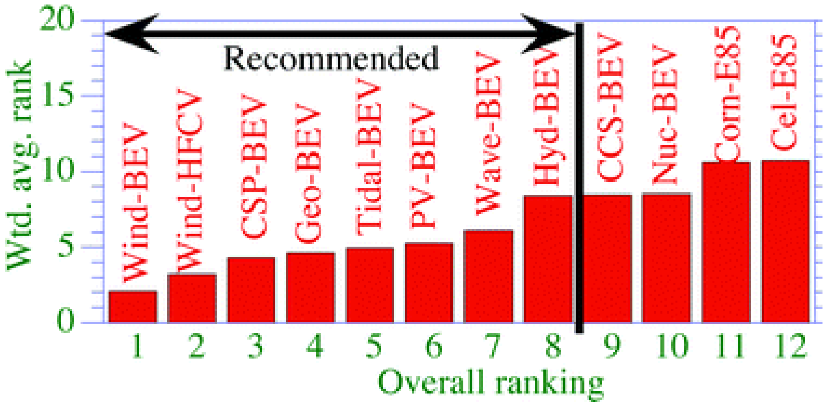


Figure 8: Vehicle-Energy Ranking (Jacobson, 2009)

Storage Timelines/Quantity

The M. Bollen IDGPS textbook (Bollen & Hassan, 2011) postulated that a larger supply of Hydrogen/CAES would reduce the cost effectiveness of each technology. The concept of backup supply to wind, solar and tidal farms is meant more for daily load balancing and based on weather system patterns. When the day ahead forecast calls for i.e. 100 MW of wind, the system operator wants to know with a high level of certainty that it will be a firm forecast with only minor variation that can be adjusted for with quick responding peak unit plants. The best case cost scenarios involve a few days' worth of backup firm renewable power, typical for more frequent low wind periods.

Load Shedding, Peak Shaving, Firm Supply, and Load Spilling

Current practices in Nova Scotia use loads such as street lighting across the province as load shedding 'sinks' so that minor variations in power can be absorbed by variable input sodium street lights. This process acts as a damping effect that benefits grid operation, but is effectively wasted energy. The energy storage concept allows extraneous production on the grid from any DG to be saved and converted into potential energy. There are losses with the conversion from electrical to potential and back again, but since the energy is basically "free" it is wise to capture this resource. The next step once stored is for use as peak shaving power, so that daily peaks in production which waste expensive fuel sources, will effectively lower the operating costs of daily grid demands. Firm supply means when the wind does not blow, the energy storage system can compensate for hourly, daily or potentially weekly gaps in renewable supply. SOs work in what is termed a High Reliability Operation (Szumilas, Swerhun, & Lye, 2011)

(HRO), meaning they are committed to supplying secure energy 99.9% of the time, with exceptions for large wind, and snow storms. Linemen are responsible for preventive, restorative, and maintenance work. Prevention means they will proactively clear potential problem branches away from vital equipment. Restoration means they reconnect downed lines and fix faulty equipment after a storm. Maintenance work ensures equipment is in good working condition and reduces unexpected hardware failure. The phrase “load spilling” originated when there was no need for hydropower from a dam, so SOs would allow water to flow down a spillway effectively letting the potential energy go by without utilization. The same happens when it is windy but there is no current demand for the power, or when tides ebb and flow at times when the grid cannot integrate the supply. Energy storage fulfills an economic and firm power supply niche when properly added to regional power grids.

2.2.2 Compressed Air

Compressed air energy storage has economic benefits (Fertig & Apt, 2011) over hydrogen and it does not require electrolysis but it does require similarly substantial high pressures and large storage volumes (Robb, 2011). Typically H_2 and CAES can use large underground salt caverns to store energy. CAES requires that heat be added when depressurizing the air, which can be done by using fossil fuels, solar thermal, or using captured waste heat which reduces the amount of fossil fuel heat required. One example (Y. Li, Wang, Li, & Ding, 2012) configuration allows 50,000 kWh hours to be stored, and then it requires 10,000 kWh of fossil fuel to access that energy, which nets a 40,000 kWh extractable energy supply. This still involves the release of GHGs but much less than simply burning natural gas.

2.2.3 Pumped Hydropower

A project was cancelled in 2009, called the Lake Uist wind-hydropower farm, in south east Cape Breton on which I completed an Environmental Engineering school project. This project aimed to produce electricity from 100 MW of wind turbines and at night, when demand was low, would pump water uphill to be used as normal hydropower when needed. From an energy standpoint the Lake Uist project was well designed, but was prevented from going forward due to environmental concerns regarding fish populations. Upwards of 1/3 of the lake's volume would have been cycled whenever the upper reservoir was to be filled, which would drastically alter water temperature, Oxygen levels and other factors that would negatively affect fish health. There is the possibility that projects similar to this one will be acceptable under new environmental assessment rules put out by the Department of Fisheries. It should be noted that the residents did not accept the social constraints it would place on their immediate community and way of life, in particular sport fishing and recreation.

The largest hydropower installation in the province is Wreck Cove at 230MW, while there are approximately 400MW total for all hydropower systems in the province. These installations can usefully store a little energy in each reservoir when the wind blows; depending on the height of water in each dam, but most of these dams are 'run of river' type, and do not have large reservoirs. This is a form of energy storage, although not the same as pumped hydropower that can convert wind, solar or tidal energy into potential energy in a reservoir by displacing normal hydropower demand. Europe has significant pumped hydropower in the mountainous regions. (Bollen & Hassan, 2011)

2.3 Policy

2.3.1 Hatch2008-Lavalin2009

Hatch released a report (Hatch, 2008) for the DOE working in conjunction with NSP to provide an independently reviewed engineering assessment of what the power grid in Nova Scotia can accommodate. They concluded that the 2010 Renewable Energy Strategy (RES) goal of ~300 MW, the 2015 RES of ~500MW were achievable; while the proposed 2020 RES of ~700 to 950 MW required substantial grid upgrades. These points are important as the DOE (Nova Scotia Department of Energy, 2010b) has mandated that by 2020 NS will achieve the 40% electricity production renewables target; this target will be met with Muskrat Fall online. This is also in line with the DOEnv climate change preventative actions to reduce the quantity of provincial GHG emissions; the DOEnv plans for up to 80% reductions by 2050 (Nova Scotia Department of Environment, 2009).

Lavalin released a similar independent report (Lavalin, 2009) working with the DOE, regarding renewable/wind integration, upgrading infrastructure, and potential system operator restructuring to encourage greater competition of independent power producers i.e. wind farms.

2.3.2 ComFIT-RPS

The “Community Feed in Tariff” or ComFIT is a policy tool used to enable suitable projects by community groups and cooperatives to invest in a local community project (Lipp, February 2008; Lipp, Pattenden, & Tampier, October 2006). Typically this allows local ownership of wind turbines, encourages community support and acceptance.

Most projects of this type are relatively small in power output due to startup costs, but are important pieces of the total solution for provincial green energy targets. The ComFIT process enables smaller projects, typically around a MW, to sell power to NSP; that otherwise might not be economical without the increased cents per kWh rate compared to full scale wind farms. Presently 100MW of ComFIT projects have been initially approved to be built, pending meeting all of the Environmental Assessment requirements, while there were 200MW of capacity based on all of the applications. In a similar earlier attempt, the government of Nova Scotia has gone through several Renewable Portfolio Standard (RPS) processes, requiring NSP to include a certain percentage of energy from renewables. Both of these processes have accelerated provincial acquisition of renewables and will continue to do so over the next decade.

At the time of writing this thesis there has been a lack of government interest in supporting grid intertied PV panels in urban locations where they could offset local production, also known as a SolarFIT. Purchasing options that consider attaching the value of solar hot water panels to property value have been effective, and it would be wise to consider these thrifty investments for provincial prosperity. One energy installer quoted the figure that a household uses ten times the energy to operate, over a hundred year lifetime, as to the energy required to build the household.

2.3.3 Department of Environment

The DOEnv has readily assessed the necessity of adapting to climate change risks (Nova Scotia Department of Environment, 2009). Their proactive approach leads the way in reducing provincial GHG emissions. They have set realistic and achievable targets to follow over the next several decades. It is a matter of ethical, economic, environmental, and societal good faith that positive actions are taken now. Global insurance agencies agree that increased statistical risks of hurricanes, floods and droughts negatively affect the clients they are dutifully protecting. Human and environmental health costs are at the forefront of switching away from fossil fuels in this province. Ground level SOx, NOx, Mercury and other fine particle matter (PM2.5 and PM10 micrometers) has added pressure to respiratory problems in populated areas; which puts strain on our health care system. To quote the old adage: "An ounce of prevention is worth a pound of cure." If the costs of statistical increase in health problems was factored into the price of $/GWh, wind, solar and tidal would be cost competitive compared to coal, heavy fuel oil and other fossil fuels. It is important to mention NSP has done significant work on including expensive scrubbers on their smoke stacks. Also, Tuft's Cove in Dartmouth is now primarily burning natural gas (up to a maximum of about 500MW worth) which has reduced emissions in Dartmouth. Provincially, the SO may have to reassess local coal reserves as an option. Environmental groups and NSP would preferably promote Demand Side Management (DSM), such as electronic shutoff devices on hot water tanks, switching to a heat pump in a well-insulated house (away from inefficient base board heaters), and replacing old incandescent bulbs to either CFL or LED models. Efficiency Nova Scotia (ENS) was created specifically for those reasons, to tackle all DSM related activities, as it saves the province's citizens money, upwards of hundreds of dollars a year, which can be spent elsewhere. For low income households it may mean healthier food, or supporting children in school activities, or other healthier lifestyle choices. NSP is responsible for 46% of NS GHGs. The DOEnv has mandated by 2020: 5 Megatonnes eGHGs/year or 10% below 1990 levels and by 2050: 80% below 2009 levels.

2.3.4 Department of Energy

The DOE has looked at all renewable energy options available to the Maritimes and planned a way forward for political, economic prosperity and energy security reasons (Nova Scotia Department of Energy, 2010b). They have encouraged the setup of the FORCE institute (Fundy Ocean Research Center for Energy, 2015) to test promising in-stream tidal current technologies as the most environmentally benign option compared to a full scale dam. They have assessed not only our local needs, but the needs of our immediate neighbours, i.e. NB, PEI, NL, and New Hampshire along with Maine. They examine possible carbon caps, or carbon pricing in Canada, as ways to stretch out our fossil fuel budget and encourage less wasteful activities.

It can be seen that our economy will be strained if the province stays on a carbon intensive route. There are ample wind, solar and tidal resources in our province, with the possibility of adding pumped hydropower, Hydrogen fuel cell grid capable MW class backup, and CAES in suitable areas to balance daily fluctuations of these renewable technologies. The DOE is convinced the province can increase our renewable production percentage easily to 40%. With Denmark setting the example of pushing to 50% renewable by 2020, therefore it may be possible to do this economically in other jurisdictions (Bollen & Hassan, 2011). In 2011, NS consumed 12,000 GWh of power. The plan for 2015: 3000 GWh, RES 25%. Muskrat Falls – NL coming online ~2017. The plan for 2020: 4800 GWh, RES 40%.

2.4 Literature Review Conclusions

Nova Scotia’s Government and industry have set low but achievable targets for the short and long term. Detailed analysis of wind integration in this province has been completed recently. The US has already assessed economics, environmental impact of full scale Hydrogen fuel cell vehicle implementation. Internationally there is controversy in the literature between sourcing from nuclear and shale-sourced natural gas vs. renewables to create Hydrogen fuel. Only a balanced approach comparing the Strengths/Weaknesses and Opportunities/Threats (SWOT) over the short and long term will logical and ethical choices prevail. The East Coast Hydrogen Economy, as an umbrella concept of the most promising energy storage technologies including V2G, has to be assessed now before the majority of new power infrastructure is planned and built. An educational energy map will help Nova Scotia’s transition to a modern energy economy by increasing energy system awareness. A simple discrete event model will be an effective tool to assess the grid that may be considered for evaluating the threshold of solar, wind and tidal input, based on the Hatch report’s estimate of wind energy integration.

Chapter 3: Energy Supply, Technology, and Storage

3.0 Introduction

Is it technically feasible to decarbonize our primary energy supply? Why should we? Do we have a moral obligation to future generations of all species? This chapter presents the basics of how decarbonization is achievable, while chapter 4 demonstrates why it is necessary in detail.

Here we briefly look at the why; climate change is going to create a whole lot of wasted work for society in maintaining infrastructure, and overall negatively affect crops, agriculture and biodiversity; this in turn affects us at the grocery store and on our plates. Damaged infrastructure might be “good” for GDP, but extreme droughts and flooding are not particularly helpful.

In section 3.1, I begin with a quick overview of primary energy supply in Atlantic Canada broken down by province and look at some general annual fuel cost estimates with worked out examples. I then tackle a Nova Scotia case study as an example of pushing toward a near 100% wind energy only primary energy scenario, with steps to include significant energy storage and then integrate battery and hydrogen vehicles for personal and freight transport. I describe the process of computing the NS annual GWh per power plant from data; with a quick look at larger regional energy issues and solutions. Finally I describe power plant characteristics desirable for energy systems.

In section 3.2, I cover finite energy technologies and use a SWOT analysis to look at the basic merits and weaknesses of the present norm. I then assess the history of oil, coal and natural gas and the end game. Nuclear and GHGs are mentioned in brief, along with carbon emission intensity and the National Emission Inventory (US) plus Canada's National Pollutant Release Inventory.

In section 3.3, I cover in greater depth renewable energy technology fundamentals in terms of the scope of this thesis. I use a SWOT analysis and detail "wind, water, solar, and biomass" resource development. Section 3.4 tackles transportation technologies while Section 3.5 considers energy storage options.

3.1 Primary Energy Supply in Atlantic Canada

3.1.1 Nova Scotia Primary Energy Supply

This section sets out to assess Nova Scotia's primary energy supply in terms of energy totals and costs of various fuel types. I use a case study that illustrates the switch from the present majority of fossil fuel energy to renewables commonly known as "Wind, Water, Solar and Biomass" or WWSB, along with utilizing energy storage (ES) technologies. It is necessary to use ES appropriately to increase each renewable energy plant's capacity factor to match the resource and concurrently lower the Levelized Cost of Electricity (LCOE) which provides limited "baseload renewables" allowing for greater implementation across the province.

Nova Scotia Primary Energy Total Cost Estimates by Major Fuel Sectors:

Using data from the Canada Energy Systems Analysis Research (CESAR) – CanESS Model of the 2010 year, the following data was gathered and displayed in Figure 9 on the next page. The CanESS Model has data from 1978-2010, for all Canadian provinces – as indicated by their working group, some of this data may have been interpolated by the model. I verified CanESS general GWh data and found it to be reasonably accurate when comparing to NSP energy and emissions data, and in doing so acknowledge its usefulness to extrapolate data trends to the decades before 1978 to when the first hydropower plant was built in 1920. GHGs have been approximately accounted for using this time-series of provincial fuel consumption. The fuel quality – i.e. coal with related SOx, NOx, and Hg content is unknown. Similarly the choice to burn coal or heavy fuel oil (HFO) versus light fuel oil (LFO) over the decades has shaped the general emissions profile of the province. For example:

> “HFO is usually composed mostly of Carbon (86% wt.), Hydrogen (11% wt.) and Sulphur (currently averaging around 2% wt.). LFO is usually composed mostly of Carbon (86% wt.), Hydrogen (13% wt.) and Sulphur (0.1 to 0.2% wt.)”
> (CEPA Environmental Registry, April 2013)

Using the CanESS model data extracted from the sankey diagram Figure 13 pg. 55, we see the following economics demonstrated, considering median local fuel costs:

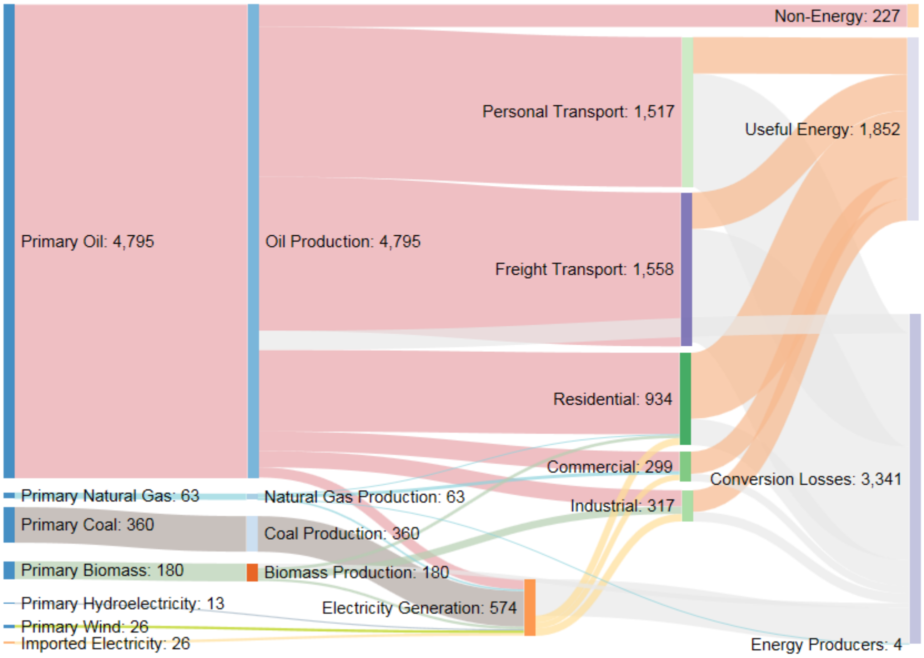


Figure 9: Estimated Annual TPES NS Fuel Costs ($ Millions) 2010 calculated from CanESS

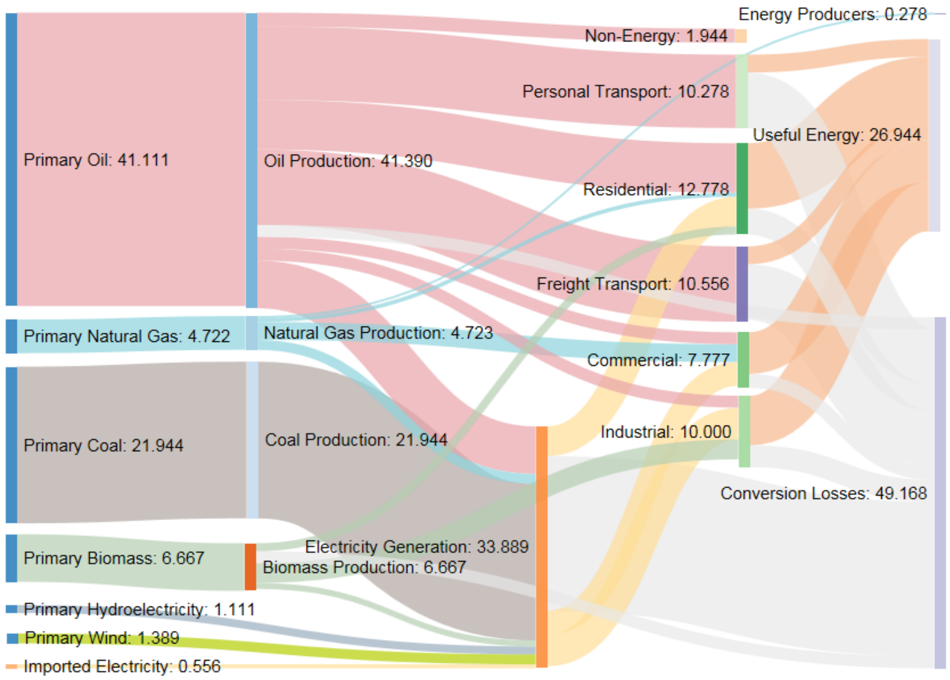


Figure 10: Sankey Energy Flow 2010 (TWh) converted from CanESS (77.4 TWh)

Economics of Supply

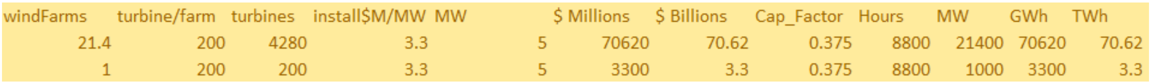
As demonstrated in Figure 9 and 10 above; using medium range market prices for each fuel stock, the cost in $ billions was calculated, converted from Petajoules (PJ) to dollars in Table 1. This brief analysis demonstrates approximate values, which allows us to get a sense of the economics of supply in the province; these prices inherently depend on the fluctuations in $/tonne for coal, $ bbl (per barrel) for oil, $/million BTU for natural gas. Common units for biomass are dry tonnes for woody material in large plants, while landfill gas is usually methane measured in million BTU, or for smaller wood stoves based on the $ per cord. The biomass data details are out of the scope of this example but would be reduced to the two main fuel types, namely wood stoves for space heating, along with pulp and paper plant thermal and power boilers.

Fuel	$CAN/GJ	$ M/TWh	TWh Approx.	$ Million Approx.
Coal	4.56	16.415	21.9	359.510
Oil	32.40	116.635	41.1	4793.7
Natural Gas	3.70	13.306	4.7	62.541
Biomass	7.50	26.999	6.67	180.08
Imported	13.21	47.543	0.56	26.624
Hydro	3.30	11.885	1.11	13.074
Wind	5.28	19.017	1.38	26.243
		Total	**~77.42**	Approx. $5462M
		Total*	**~74.93**	*without Hydro and Wind

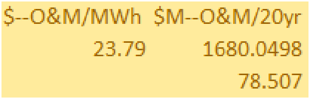
Table 1: NS Fuel Cost Estimate Calculations

In a complete economic sensitivity analysis, the best practice example from the National Energy Research Laboratory (NREL) which is part of the US Department of Energy (DOE) should be followed; they generally give the low, medium and high range of cases to demonstrate the range of possible costs incurred with each unique project. This can be applied to unit prices for primary energy, as well as LCOE assumptions for proper cost risk analysis. For the purposes of the thesis I have not tested a wide range of fuel price variations, but acknowledge the NS DOE Market Trends document data presented in 'Figure 54: Electricity System Review LCOE Estimates' as a suitable starting resource for researchers who want to explore the economics further.

In the following simplified near 100% wind-energy-only scenario in yellow below – without energy storage to start – an unrealistic assumption but important to consider as



windFarms	turbine/farm	turbines	install$M/MW	MW	$ Millions	$ Billions	Cap_Factor	Hours	MW	GWh	TWh
21.4	200	4280	3.3	5	70620	70.62	0.375	8800	21400	70620	70.62
1	200	200	3.3	5	3300	3.3	0.375	8800	1000	3300	3.3



$--O&M/MWh	$M--O&M/20yr
23.79	1680.0498
	78.507

Table 2: NS Wind Farms to power Total Primary Energy Needs (top)

Table 3: Operation and Maintenance Costs over 20 years (left)

a first step in terms of the cost of energy supply itself. Using the average European installation cost gives us a number of $1 Billon per TWh of offshore wind – a total of $70.62B in the Nova Scotia simple case study, it should be noted this is over a twenty year or more time frame that each installation is operating. The annual cost of primary wind energy would be $3.531B assuming no changes in each sectors energy requirements. Operating costs come to about $1.7B over the entire 20 year span. The average installation costs can be seen from the European example below.

	€ 1 = $1.83 Can	**Investment**	**Costs**	**O&M**	**Cap. factor**
	Min/MW	Average/MW	Max/MW	€/MWh	
2006	€1.8M EU	€2.1M	€2.4M	16	37.5
2015	€1.55M EU	€1.81M	€2.06M	13	37.5
2015	$2.8365M CAN	$3.3123M	$3.7698M	$23.79	

Table 4: Offshore Wind Development Costs (Wind Energy The Facts, 2009)

Here are a select number of the most prominent resources, the: US Energy Information Administration (EIA), NREL, International Energy Administration (IEA), European Wind Energy Association (EWEA), NS DOE – for LCOE data and forecasts and will be discussed in Chapter 4.

The second stage of the 100% wind example with 4280 5MW offshore wind turbines requires demand side changes, in this case in the transportation sector. This would assume that a mix of Battery electric vehicles (BEVs) and Hydrogen fuel cell vehicles (FCEVs) would become the status quo for the majority of land transportation modes, see Appendix D for info from CanESS on oil to useful energy in the personal transportation category. Based on ‘fuel in the tank’ using BEVs would improve system efficiency on the whole. Engine efficiency would switch from an average 25% for ICEs to 90% for BEVs. This changes the original balance so that 37.7PJ (10.47 TWh) of primary energy from oil (converted to gasoline) required to power all personal transport in province, would only be 9.42 PJ (2.61 TWh) of delivered electricity (wheel power). At 35% electrical system efficiency loss (including loss of CAES) this would require approximately 3.82 TWh of primary wind based electricity – this would amount to 6.65 TWh less wind energy supply needed, and be a savings of ~ $6.65B wind energy not purchased, lowering the initial cost to $63.97B, or $3.198B annually over 20 years.

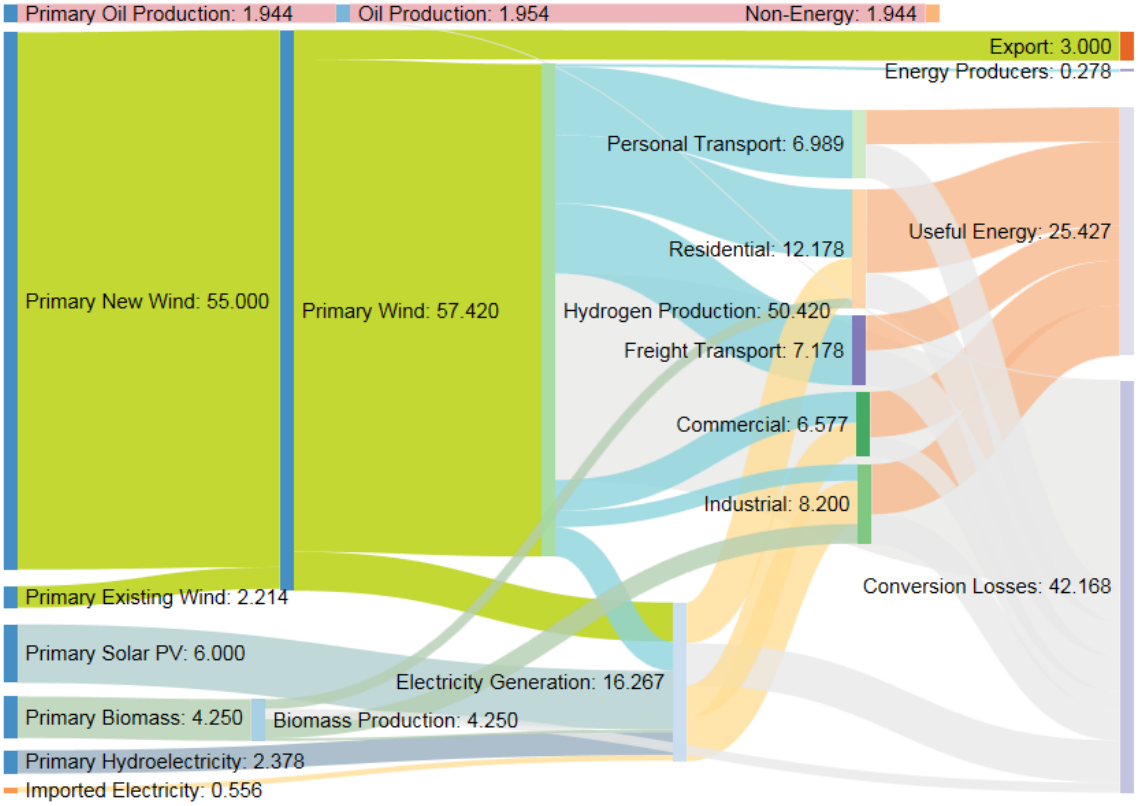


Figure 11: Theoretical Sankey Energy Flow 2030-2050 (72 TWh) (Thompson 2016)

The electricity itself would cost drivers $0.27B annually at $0.145/kWh – assuming 525K personal transport vehicles at 3.5 MWh/vehicle-year for BEVs to drive the NS average of 16,600 km/year, or $508 per vehicle/annually. In contrast, at 7.78

kWh/L of gasoline and 12.333MWh/vehicle-year for FFOVs, or 1580 Liters/year assuming $1.3/L as a multi-year average – it would cost $2060/year-driver, or $1.08B for 525K vehicles; a simple savings of $0.81B provincially, again not including large scale infrastructure upgrades, such as 'super chargers' and other plugs suitable for electric vehicles. Using an FCEV example, it would cost 2.428 times as much energy to provide Hydrogen fuel for the same distance travelled (with present technology, see Appendix F), or 9.27 TWh of primary wind energy supply, this would amount to a 1.2 TWh less of wind energy supply needed, or approximately $1B not spent - $69.42B over 20 years would be $3.47B.

Years	**20**	**30**
WWSB : B/TWh	70	70
Energy Storage	+13	+20
Billion	83	90
83 Billion/Years	4.15	2.76
90 Billion/Years	4.5	3

Table 5: Estimated Annual Fuel Costs 2030-2050 ($ Millions) (Thompson 2016)

Assumptions: 20 or 30 year life cycle

- $0.26 to $0.40 per kWh of energy storage (high range)
- 50 TWh of energy storage (which is very large in current standards in terms of Hydrogen or CAES), this is not an optimization value.

Air transportation would face other alternative technology changes, assuming a large share of international and domestic flights also made the same fuel switch. Building heating and cooling would adapt from common technology such as heat pumps already being installed and marketed including high amounts of other Demand Side Management (DSM) implementation, such as the Passive House Standard. As mentioned, during this process large scale infrastructure would have to be upgraded and installed in both these transportation cases at additional cost.

This would also require using modern H_2 fuel cell power electric plants or H_2 Combined Heat and Power (CHP) plants; refer to section 4.2.3 and 4.2.4 for risks and potential regulations. Which again like BEV and FCEV technology, with thoughtful system design will reduce required primary energy input – if done with proper planning. Please see Appendix E for an example figure of Hydrogen-CHP systems. The following table represents simple energy storage costs, having an optimized GWh storage size is vital as more storage space increases the cost and concurrently lowers risk of having to use fossil fuels, i.e. storing transportation fuel up over the year:

TWh	GWh	MWh	kWh	$/kWh	$B/NS	$M/20yr	$B/20yr
13	13000	13000000	13000000000	0.142	1.846	36920	36.92
70.62	70620	70620000	70620000000	**$/ES LCOE**			
				0.4	1.4124		28.248
				0.26	0.91806		18.3612
				0.142	0.501402		10.02804

Table 6: NS Terawatt-hours and general cost of energy storage

Presently for NSP, if every customer paid $0.142/kWh, this would provide $1.846B in revenue each year, and would total ~$36B over 20 years; this is the residential rate applied to all electricity sold. Other sectors such as industrial, institutional and commercial, all pay different rates. It is used here as a general starting ballpark number for our purposes. With an adjustment of the number to $1.5B to account for lower rates of other customers we see this gives a number of $30B over 20 years. Using the values for primary energy from the earlier green table, with an annual estimate based on 2010 data (and if we use a straight line average to forecast future energy demand). See Appendix H for ESR detailed demand forecasts. The annual estimated cost of fuel for Nova Scotia is $5.488B or $109.76B over 20 years. Therefore with a median energy storage cost of $0.91B annually, plus $3.531B for all primary wind energy supply annually, with a savings of $2B annually for both transportation (freight and personal) sectors, assuming infrastructure upgrades cost $1.5B annually – we arrive at a figure of $3.941B annually to provide all of our energy needs for the next 20 (to 30 years – which will change the average cost per year, not including equipment replacement); a possible simplified estimated savings of $1.547B annually. This is strictly an example to see there may be possible savings by increasing system efficiency if done in an organized manner by the government and utilities. Many assumptions were made in order to reduce the complexity of the complete Nova Scotia energy system to a highly simplified model that represents the general concept; one main modifier would be the addition of loan interest that would alter the savings achieved. Further details will be covered in later sections, covering more in-depth analysis of several important technological components, LCOE assumptions and resource-geography constraints which would better inform a higher precision model – a complete model that is out of the scope of this thesis. However what we will cover in Chapter 5 discusses the application of the EnergyPLAN model to inform the general supply and availability of wind, solar and tidal in the context of our power plants and system demand, and how the BEV/FCEV transportation sector improves energy system integration.

Other cases that could be assessed include variations on renewable energy supply side, i.e. tidal, hydropower, solar PV, and other mixes of onshore and offshore wind.

Each technology must be combined with energy storage after a certain threshold, or exported out of the province to other larger markets such as Maine, New Hampshire and Montreal that can absorb the variability, and close enough to have reasonable line loss.

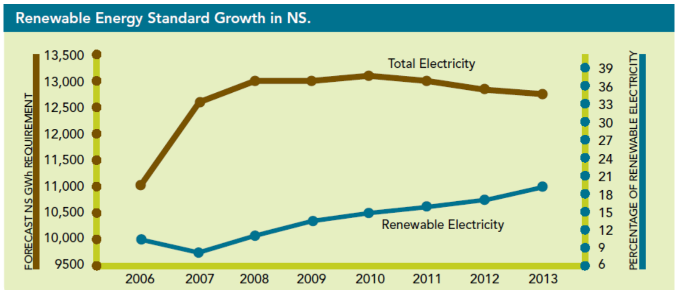


Figure 12: Dual GWh-MW axis of Nova Scotia RE Growth (Nova Scotia Department of Environment, 2009)

The figure above describes the increasing uptake of renewable energy and the fluctuating annual system demand from 2006 to 2013.

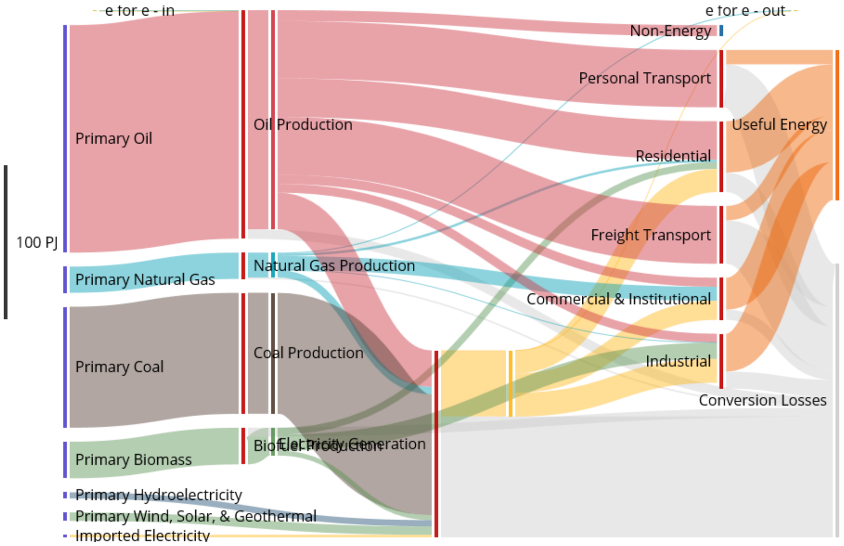


Figure 13: Original NS Primary Energy Supply 2010 (Canada Energy Systems Analysis Research, 2014)

Nova Scotia Annual GWh per Power Plant:

This section focuses on the fundamentals of interpolating and extrapolating overall energy categories (for example oil, coal, and hydropower) using annual GWh primary energy data down to the level of each power plant. The first step used CanESS model primary energy sources from 1978-2010, combined with four baseline years for all

NS power plants/systems, and Canadian Wind Atlas (CWA) wind histograms (representing wind energy). The energy category data has been interpolated using observable operational patterns for each individual power plant on the energy map. This required manual selection from a potential solution curve, so that the margin of error in the multiple column Excel sheet was as small as possible for each energy category and within parameters of each fossil fuel power plant. The second step was to extrapolate power plant data on the timeline from the period of 1978-2010, which extended the trends in the data to 1920 and 2020, using NSP's estimates of mandated GHG reductions.

Data Collection and Interpolation-Extrapolation:

As mentioned at the beginning of this section, the first step uses the annual data provided by the CanESS model as it has all fuel sources divided by sector from 1978-2010. I extrapolated this back based on each power plant's operational date until the nature of power use in the province changed dramatically with the addition of the first thermal power plant in 1965. Prior to that it was a relatively linear curve from 1920 with the first small hydro power plant until the beginning of the 1960s where it reached ~150MW and leveled off, where as the only major hydro plant after that was Wreck Cove in 1978 followed by a few minor hydro power plants in the next two decades. In regards to properly evaluating any model's input variables, of major importance is the level of residential, commercial and industrial electrification over each decade and how that would have shaped the daily and annual power demands. For now simple model assumptions will be used, strictly during the hydropower only decades, that the majority of power generated met existing demands, which was the impetus to build more. Actual data collection regarding these capacity factors from a long term historical perspective is out of the primary scope of this research.

NSP has publically available total hourly power system levels from 2007-2014 on their OASIS online platform. This data is vital to see the general patterns, including minimums and maximums each successive year, as well as other relevant trends in the data. The hourly system data is required for the EnergyPLAN software model; see section 5.1 for more details on how the 2010 year was computed with this and CanESS data.

Lingan	Point Aconi	Trenton	Point Tupper	Tufts Cove	Tusket1	Burnside
3667	1222	1817	1214	2263	10	50
Victoria Junction	Brooklyn	Sackville	Taylor	Northern	Port Hawkesbury	
10	154	9.5	4.5	113	244.5	

Table 7: 2010 Thermal data in GWh. Hydropower/Wind/Tidal not included 39 col

Model Scaling – Using Baseline Years:

This section focuses on the CanESS data extrapolated to GWh per plant. Nova Scotia Power released four baseline years from [2009-2012] for specific power systems in the categories of hydro, tidal, biomass, coal, combustion, separately the map uses ‘climate-wind’ from the CWA – which is the average annual theoretical power output.

This data does not consider if the wind farm power was curtailed or exported, or not, by system operators. The General Electric Wind Integration Report 2013 used a general factor of 2-10% for curtailment and exports in a recent Nova Scotia power grid study; usually a situation where less curtailment occurs requires fast ramping hydropower (such as Wreck Cove) or natural gas to accommodate sudden variability. It should be noted that the Minister of Energy at the Electricity System Review (ESR) mentioned in person that Muskrat Falls-Maritime Link does not have the capacity to store large volumes of energy, but will be used mostly as baseline energy.

Scaling Forward:

Regarding curtailment and going forward, highly reactive short term energy storage technologies such as flywheel, CAES and Hydrogen fuel cell technology variations will be the primary method of integrating more renewables. The province has done studies on other very promising emerging technology options, based on their ESR (NSDOE, 2014) of expert material, from super capacitors to flow batteries and laid frameworks for when the expected in service year(s) may be. Several reports from NS DOE, Integrated Review Process (IRP) and NSP indicate future fuel cost estimates with low, medium and high cost scenarios as well as power grid scenarios using low/baseline/high levels of Demand-side Management (DSM), thermal plants, and further wind integration.

3.1.2 New Brunswick Primary Energy Supply

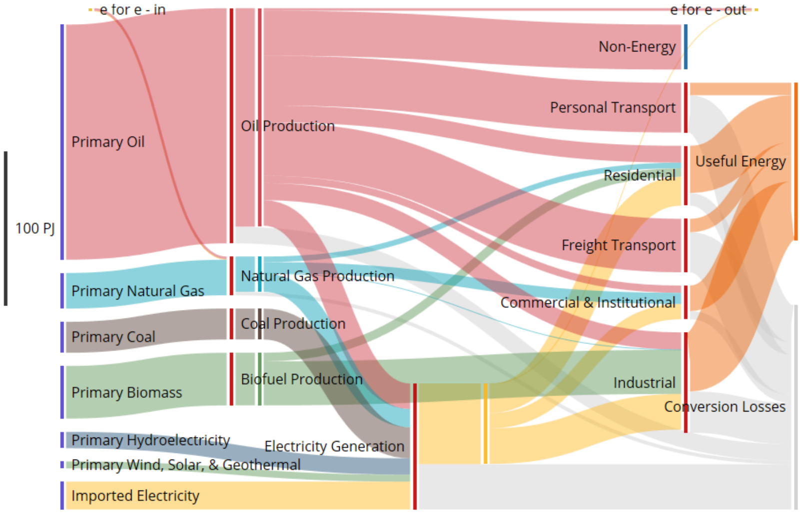


Figure 14: New Brunswick Primary Energy Supply 2010 (Canada Energy Systems Analysis Research, 2014)

Economics

Fuel	**$CAN/GJ ***	**$ M/TWh**	**TWh Approx.**	**$ Million Approx.**
Coal	4.56	16.415	5.55	91.10
Oil	32.4	116.635	42.5	4956.99
Natural Gas	3.7	13.306	6.38	84.89
Biomass	7.5	26.999	9.44	254.87
Imported	13.21	47.543	0.56	26.62
Hydro	3.3	11.885	unk	unk
Wind	5.28	19.017	unk	unk
	*without Hydro & Wind	**Total***	**~64.43**	*Approx. $5414M

Table 8: NB Fuel Cost Estimate Calculations

In 2010 with an annual fuel cost of $5.414B to supply all of NB domestic energy needs.

* Most fuel costs (Electricity System Review Market Trends Report 2014)

Annual GWh per Power Plant

NB basic power plant data has been collected thanks to the help of a group of energy volunteers I organized and worked with over the month of November 2014. The numbers of power plants per category in NB are: 1 biomass, 2 coal, 3 diesel, 3 fuel oil, 10 hydro, 2 natural gas, 1 nuclear and 2 wind. NB has a total rated capacity of approximately 4654MW. I currently have rated capacity for each plant. Presently I have names, some dates built, general location with hydropower plant latitude and longitudes, owner, and type; thanks to the energy volunteers.

3.1.3 Prince Edward Island Primary Energy Supply

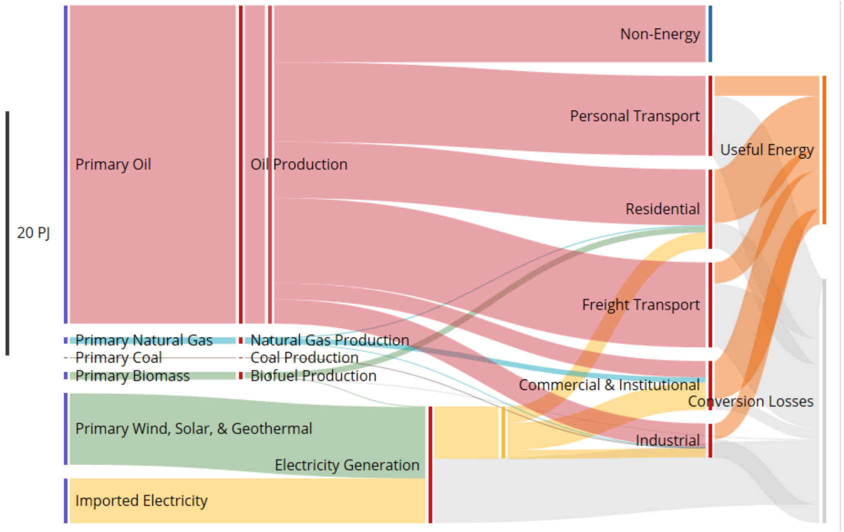


Figure 15: PEI Primary Energy Supply 2010 (Canada Energy Systems Analysis Research, 2014)

Economics

Fuel	$CAN/GJ	$ M/TWh	TWh Approx.	$ Million Approx.
Coal	4.56	16.415	0	0.00
Oil	32.4	116.635	7.22	842.10
Natural Gas	3.7	13.306	0.278	3.70
Biomass	7.5	26.999	0.278	7.51
Imported	13.21	47.543	1.11	52.77
Hydro	3.3	11.885	unk	unk
Wind	5.28	19.017	2.2	41.84
	*without Hydro	**Total***	**~11.09**	Approx. $948M

Table 9: PEI Fuel Cost Estimate Calculations

In 2010 with an annual fuel cost of $0.948B supplies all of PE domestic energy needs.

They import 4PJ (1.11 TWh) annually of electricity from NB (12% of total).

Annual GWh per Power Plant

The numbers of power plants per category in PE are: 2 diesel, 1 fuel oil, and 5 wind. PE has a total rated capacity of approximately 260MW. I currently have rated capacity for each plant.

3.1.4 Newfoundland & Labrador Primary Energy Supply

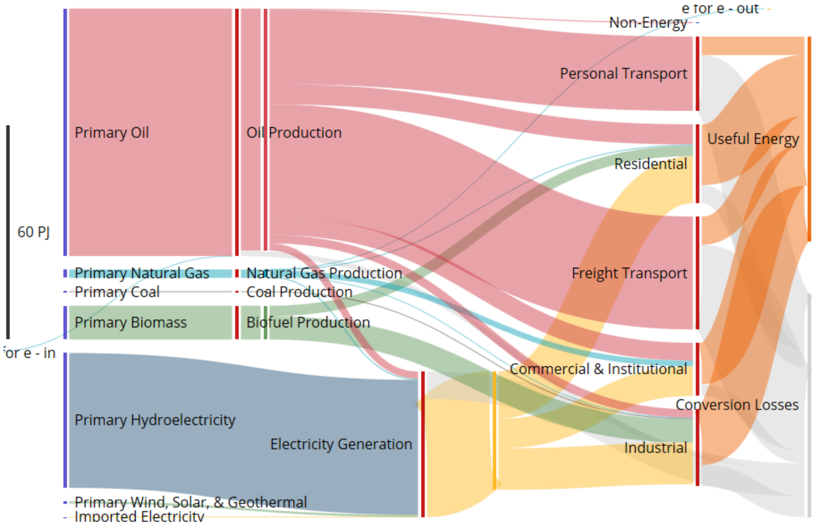


Figure 16: Newfoundland Primary Energy Supply 2010 (Canada Energy Systems Analysis Research, 2014)

Economics

Fuel	**$CAN/GJ**	**$ M/TWh**	**TWh Approx.**	**$ Million Approx.**
Coal	4.56	16.415	0	0.00
Oil	32.4	116.635	19.17	2235.89
Natural Gas	3.7	13.306	0.56	7.45
Biomass	7.5	26.999	2.5	67.50
Imported	13.21	47.543	0.56	26.62
Hydro	3.3	11.885	10	118.85
Wind	5.28	19.017	unk	unk
	*without Wind	**Total***	**~32.79**	Approx. $2456

Table 10: NL Fuel Cost Estimate Calculations

In 2010 with an annual fuel cost of $2.456B supplies all of NL domestic energy needs.

Annual GWh per Power Plant

The numbers of power plants per category in NL are: 1 biomass, 2 diesel, 1 fuel oil, 40 hydro, and 3 wind. NL has a total rated capacity of approximately 1524MW and 6952MW including Churchill Falls (usually included in QC totals). I currently have Rated Capacity for each plant.

3.1.5 Regionalization Benefits and Drawbacks

There are energy balancing and economic synergies of working together with our neighbouring provinces and nearby states. Some interest groups are avidly studying the ways we can best serve each other; looking at technical capacity to generate and transmit electricity among the regions. Groups such as the “Atlantic Energy Gateway” have been assessing the regionalization potential of Atlantic Canada and opening up our markets to import and export energy with our neighbours. Having the option of purchasing competitively priced market rates for electricity may be helpful from a simple standpoint as long as those market rates are less than what the utility can provide through other energy sources.

Drawbacks include increased grid complexity and with it higher chances for power outages. With proven technologies complexity does not always reduce reliability; the focus here is on human fallibility. On the economic side, purchasing utilities may not be provided with fair market rates, as other utilities may sell energy to the highest bidder based on need.

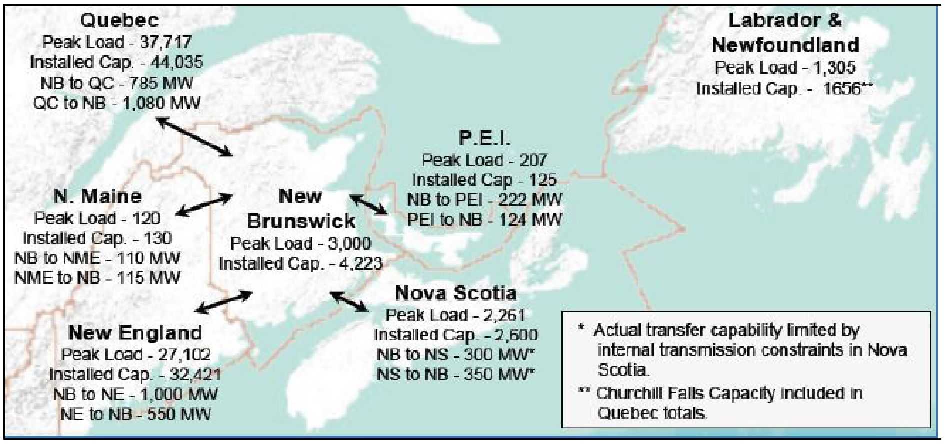


Figure 17: Transmission Interconnections vs. Peak Load and Generation Capacity (Dalton, 2012)

Markets beyond Atlantic Canada

Nova Scotia is practically an energy island; in reality it is a peninsula with a very minor connection to New Brunswick. The primary reason consumers did not lose our power in the province during a major North American blackout throughout the upper US and Ontario, is because the system disconnected the unstable energy in a manner of seconds. The province fully has the capacity to operate without incoming electricity, but that truly only works as long as our primary energy reserves hold out, presently that being coal, oil and natural gas.

Increasing our revenue from exports is a primary tenet in nation building, and is the foundation of the fossil fuel industry. So if the province continues to assess our capacity to sell electricity, technology, skills & knowledge, or perhaps Hydrogen fuel to other regions we may place our workforce in a robust position going forward.

3.1.6 Power Plant Characteristics

This section highlights the common technical specifications in an overview manner, to see how technologies shape what is possible in a grid analysis.

Base Load and Peak Load Units

Hydropower, coal, oil, and nuclear are the generation facilities that come to mind when thinking of the advent of the industrial revolution. These have been the technologies with modern society the longest and claim the ‘best position’ of base load energy generation. They are the most predictable in terms of energy supply for a properly designed power plant. Operation and maintenance are scheduled based on statistical likelihood of failure and many standards have come into being over the last six decades for best handling these types of stations.

Only in recent years in Nova Scotia has natural gas been looked to in providing base load electricity generation. Supply has become more common, and because it has favourable environmental health characteristics compared to other fossil fuels when combusted in urban areas, it is the go to of choice for modernizing thermal plants.

Common peak load units are able to burn LFO and HFO, while others like Tufts Cove used mostly natural gas in recent years; meanwhile Wreck Cove is the largest hydropower installation. They are all faster to adjust to customer demands for electricity and cheaper to throttle constantly over the average day.

Ramp Rates and Energy Conversion Efficiency

Coal power plants typically take hours to ramp up, as they produce more energy over time. Nuclear is also slow to ramp up, involving complicated procedures and is better left to base load duties. Thermal plants are limited by thermodynamic efficiencies when converting potential energy into electricity on the power grid. Centralized stations have much higher energy conversion efficiency than consumer-level generators, due to best technologic practices and energy recovery units, along with a host of other factors unique to each technology.

Power plants and fuel types should not be assessed only on one power plant's capabilities, but also in the scope of how yearly operational trends play out, and the balancing between all power plants on the grid in relation to consumer demands. The overall system efficiency is the sum of its working power plants and power grid. The optimization of any system can make or break a province's energy and economic future.

3.2 Finite Energy Technology

3.2.1 Thermal Plants SWOT Analysis Oil, Gas, Coal, and Nuclear:

Strengths: Plants produce reliable base load power; known fuel reserves; proven technologies; relatively cheap up front fuel costs; centralized generation equates to less transportation costs associated with maintenance, and with an analogy: less "moving parts" in a complex system.

Weaknesses: Planning and building large facilities requires considerable resources; once built utilities tend to keep them operational for long timeframe; need to keep feeding the power plant more fuel which takes time and energy in itself; Resource extraction such as mining, drilling, fracking for resources involved in environmental degradation; water usage; health concerns brought up by doctors around the world regarding fine particulate matter, which is defined as pollution less than PM2.5 and PM10 microns associated with coal, oil and gas combustion technologies; GHG emissions financial disincentives by 2020 strongly proposed for world markets; the Nova Scotia Finance Department is considering revenue neutral “Pollution Tax” in near term to help with provincial debt as has worked in British Columbia; centralized generation equates to possibly greater transmission line losses.

Opportunities: Improved air pollution control upgrades to existing plants; higher efficiency per volume of fuel used with new technologies; nuclear may potentially be a lower emission source of energy compared to fossil fuels, depending on the specifics of each plant and fuel handling processes; safer power plant designs that consider all local environmental hazards with proper planning and operating procedures to lower primary dangers to the public.

Threats: Rising market costs due to available supply and globalization demands; environmental threats of fuel spills on route to power plants; carbon storage in the form of ash cenospheres can spill from above ground storage reservoirs; long term radioactive fuel waste storage problems; dramatic meltdown of improperly designed or operated power plants.

3.2.2 Oil Historical Context

Nova Scotia ran into trouble by relying too much on oil in the 1970s. When the world oil crisis hit, consumers ended up paying double the rates, and then approximately double again over a short period of time. This reasonably caused panic amongst Nova Scotians and generated much local discussion on better energy security. After that the utility switched to burning locally sourced coal to offset our reliance on a single imported fuel source.

3.2.3 Coal Historical Context

History describes that coal was burned in a large scale fashion at the start of the industrial revolution in Europe, after they chopped too many trees down, forcing the workers to find alternative fuel sources beyond conventional wood burning. In Nova Scotia the locally sourced coal burning period continued for quite some time, until cheaper and cleaner burning coal could be sourced out of province. NSP (Annual Capital Expenditure Plan 2014) indicates they still burn coal in several of our primary thermal power plants throughout the winter months when heating and electricity demands are at their annual highest levels, but during the summer months several units are actually shut off or idled, which has been reducing our GHG profile provincially as part of the provincial plan (DOEnv 2009).

3.2.4 Natural Gas Solutions and Limitations

Natural gas has low emissions when combusted. This is only one way to assess the resource though, and like any extracted energy it has effects on the environment. In the case of conventional drilling, on land or off shore, the impacts are removed from most people's backyards and instead exploration and extraction activities only affect the local wildlife.

The interesting present dilemma of integrating high levels of renewable energy in the province is that it sets the stage for the utility to encourage more natural gas exploration and combustion, due to the technological advantages of present peak units and reduced air pollution in high density urban areas. This will change when CAES peak units become commonplace; specifically I am referring to the promising thermal energy recovery technology created and going through research and development by the LightSail company working in Nova Scotia.

3.2.5 Nuclear –Past, Present and Future Developments

Nuclear, when used correctly and properly planned and executed has large energy implications. Many developed nations and international bodies have seen the major benefits of stable predictable energy supply such as this source. According to the "Thorium: An Energy Solution" (2011) documentary, Uranium was not intended to be the primary fission based technological variation. The original Manhattan project scientists had advocated and considered Thorium to be a much better fuel, in that the reactors were safer, produced significantly less radioactive waste, and could be reused through several cycles before being permanently stored in geological vaults until the radioactive emissions were no longer dangerous to organisms.

Thorium and Uranium risks many be few and far between, but looking at major accidents like Chernobyl, Fukishima, and reading about near misses around the world, such as Three Mile Island. I think we are not taking nuclear energy resources seriously as a society in general, and whether it be the contractors/engineers installing, or not, safety equipment, or cutting corners to save costs, or testing procedures leading mistakenly to a meltdown and dire consequences; we may not be ready as a society for this resource.

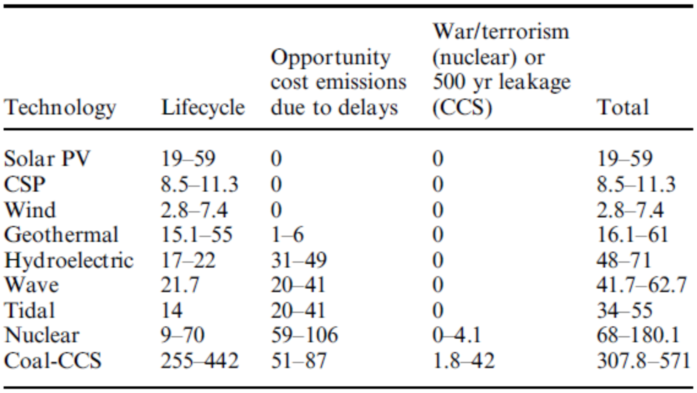
Fusion ultimately is the long term energy solution for advanced civilization. The required understanding to achieve a large net production of energy and material and computer development is still decades off according to most scientists. Two promising variations are the confinement version that requires large structures to operate and actually produce more energy than it takes to initiate the nuclear fusion reactions. The second is the targeted-confinement category being researched in BC, where massive pressures are reached in a non-chain based reaction, once the fuel used is consumed the reaction stops and there is never an opportunity for user or mechanical error to cause a conventional meltdown; but high pressure based explosions are possible.

3.2.6 Greenhouse Gases

Carbon Emission Intensity

All technology, in the very nature of its creation causes some amount of Carbon release. This can be as little as the breath of a person who shaped a stick into a spear, or as massive as combustion of fossil fuel in the scale of 31734 mega-tonnes annually to provide modern conveniences to the populace globally. The highest is fossil fuels since they are Carbon based, but other contenders are surprising at first glance, such as hydropower plants, typically because one thinks of the dam, rather than the water itself. Large hydropower involves massive land use changes by flooding large tracts of land; Carbon is released from the decomposing biological matter at the bottom of the reservoir, along with a host of other chemicals that leach out of the soil in the process. In order to construct a large dam, conventional concrete production is required and is another reason Hydropower has a carbon footprint. Run-of-river dams do not have the same level of carbon intensity as large reservoir dams.

Nuclear is touted as emission free energy, but the focus is on the fuel itself, and not including all the embodied energy and requisite emissions inherent in the concrete, metal and electronic control devices, along with the mining, refining, disposal and transportation of appropriate fuel.



Technology	Lifecycle	Opportunity cost emissions due to delays	War/terrorism (nuclear) or 500 yr leakage (CCS)	Total
Solar PV	19–59	0	0	19–59
CSP	8.5–11.3	0	0	8.5–11.3
Wind	2.8–7.4	0	0	2.8–7.4
Geothermal	15.1–55	1–6	0	16.1–61
Hydroelectric	17–22	31–49	0	48–71
Wave	21.7	20–41	0	41.7–62.7
Tidal	14	20–41	0	34–55
Nuclear	9–70	59–106	0–4.1	68–180.1
Coal-CCS	255–442	51–87	1.8–42	307.8–571

Figure 18: Equivalent Carbon Dioxide Lifecycle (g CO2e kWh-1) (Jacobson, 2009)

Figure 18 describes the carbon intensity per kWh of various technologies, covering their entire fuel and supply chain lifecycle cost assessment (from mining, building, transporting, burning, operating, disposal and security). Opportunity costs of emission due to long construction periods are included to contrast short cycle technologies with longer periods of planning and construction. War and terrorism is included for nuclear to include the risk and security measures to prevent such risk. 500 year leakage for CCS technologies take in to consideration that geological deposits can shift, and thus release carbon into the atmosphere.

National Emission Inventory

Some countries, such as the US, have compiled National Emissions Inventories (NEI) since the early 1990s when global warming first became a lukewarm topic in national media. Canada had a “Volunteer Emissions Inventory” program in which many commercial and industrial organizations and local governments participated. This formed the basis for data driven decision making which would take place later. The National Pollutant Release Inventory (NPRI) is the Canadian equivalent to the NEI with data from 1993-2014.

The understanding that not all sectors of the economy have equal measure in the Carbon emission arena can be taxing for politicians and citizens without a background in science and any decision about the right thing to do can weigh heavily on officials. Health care, education, along with goods and services all require some form of energy. Progress as it is understood was based on fossil powered technologies, so any way of maintaining that way of life was sought out, and then finally sustainability became the mantra at the end of the 20th century.

Informed decisions and national energy plans that take into consideration ongoing low carbon global actions – this type of progress is the only way to stabilize the thermal-chemical balance of the planet we share with all life at this juncture. Inaction and disbelief will only fuel species loss, up to at least 30% of which will be on a path to extinction on the order of a 3 degree Celsius rise in global average temperature (Dawson & Spannagle, 2008). Simply put, present plant-life and agricultural crops on the whole cannot adapt fast enough to raise their heat tolerance, and along with droughts and floods, pest migration and disease, it does not present a pretty picture for people to flourish with the same quality of life by modern standards.

3.3 Renewable Technology

3.3.1 Wind/Water/Solar/Biomass SWOT Analysis:

Strengths: Huge predictable reduction in GHG emissions; sustainable; distributed generation equates to possibly less transmission line losses, especially if connected on distribution lines and homes – as there are less substation and transformer losses from converting voltages; Little Mercury/SOx/NOx/ PM2.5/PM10 emissions during generation of electricity.

Weaknesses: Variable energy sources; wind – hours before reliable estimates, day before is much more difficult. Supply is on its own schedule; LIDAR 15 minute forecasts are highly accurate; solar – climate/regional cloudiness percentages can be estimated, but local variations for each solar installation are nearly impossible to predict. When sun is shining supply always matches up during peak demand; tidal – most predictable of the mix, tides and other weather factors, such as precipitation, evaporation, and air pressure modulate the daily cycles. Main issue is with constantly moving high tide times mean the energy will not always match up with demand; hydropower – reservoir size with potential to store energy until needed up to certain MWh level until energy must 'spill-over', weakness of dams is that they flood large tracts of otherwise usable land; catalysts and other vital components may be made of rare (expensive and uncommon) earth metals, along with typical mining-resource extraction environmental degradation.

Opportunities: Ongoing technological improvements such as increased energy efficiency; reduced material use; longer lasting designs and longer life materials. Cradle to cradle design philosophy, sorting technical nutrients and biological nutrients indefinitely, and rather than only down-cycling (the typical form of recycling today), to upcycle materials into high quality, healthy, and environmentally sound products.

Threats: Energy extraction, especially with any type of turbine technology endangers the lives of animals passing by (can be mitigated by shutting down briefly at certain periods during the day or season). This may negatively impact ecosystems and population genetics when scaled up to provide all of humanities energy needs and wants in the modern era.

3.3.2 Wind – Maps, Energy Potential, Power and Production Curves

Canadian Wind Atlas

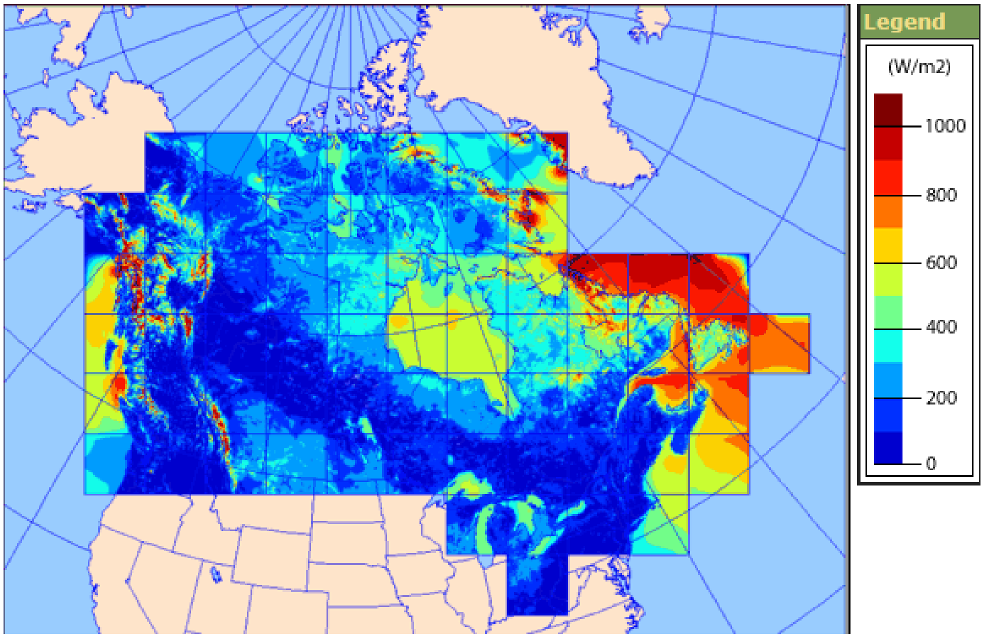


Figure 19: Canadian Wind Atlas (Environment Canada, 21 August 2008)

As covered briefly in the Chapter 2 Literature Review and in more detail regarding wind histogram and wind rose data, the CWA resource sets the stage for each province to proceed with finer resolution maps based on this climate data and local topography using software based numerical methods.

Data is publically available in downloadable formats of ~30MB zip files using MIF/MID file types (Map Interchange Format) (Environment Canada, 21 August 2008). Higher density data is available in raw zip files of ~55MB in their proprietary FST file format. Each block covers part of a province, Nova Scotia land area covers about four large overlapping blocks each containing one of the 15 unique layers mentioned in the wind histograms section.

NS, PE, NB, NL – Wind Atlas in Atlantic Canada

Nova Scotia, New Brunswick and Prince Edward Island have all created public provincial wind energy maps to encourage developers and energy companies to consider building wind farms and providing electricity to their populace. Newfoundland and Labrador do not appear to have taken this step of creating a modern provincial map yet due to present consumer demand for electricity and interest, but it is a logical next step after developing Muskrat Falls and Lower Churchill Falls hydropower developments from an energy and economic standpoint. One study used an older method with basic contour lines to develop a wind map for NL, but it is not as detailed as the figures below.

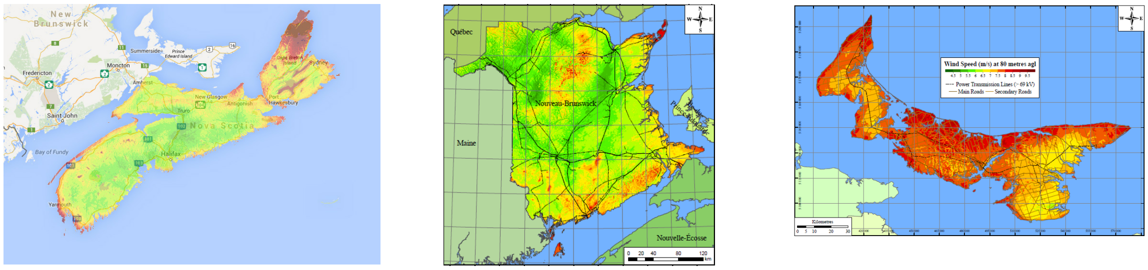


Figure 20: NS, NB, and PE Wind Atlas

Software typically used to downscale from the 5 km resolution provided by the Canada Wind Atlas has been either the WAsP 8.2 Model, or alternatively, WindMAP in common practice. Ontario has also created a provincial wind atlas but is out of the scope of this thesis. It would be helpful if another researcher used a WAsP Model to create a NL wind map, as once the Maritime Link comes online any extra wind power production they have may be sold to Nova Scotia or other markets. The following is an excerpt about who produced the Nova Scotia Wind Atlas:

> “The Nova Scotia Wind Atlas is a project of the Nova Scotia Department of Energy developed in a partnership with the K.C. Irving Chair in

> Sustainable Development at the Université de Moncton and the Applied Geomatics Research Group at the Nova Scotia Community College." (Nova Scotia Department of Energy, 2010a)

An excerpt from how they created the PEI wind atlas.

> "Using the Canadian Wind Energy Atlas as input meteorological data and integrating information for topography and land use, the WAsP model was used to obtain wind resource maps (30 m, 50 m, 80 m) at a resolution of 200 m for the province of Prince Edward Island. Validation of the results from the model was made using the met tower data of the PEI Wind Assessment Project and with a control group composed of persons with an extensive knowledge of the environment of PEI. This research work was done by a research group of the Environment Program at the Université de Moncton, namely Nicolas Gasset, Yves Gagnon and Gérard J. Poitras, who wish to acknowledge the contributions of Carl Brothers of Frontier Power Systems, PEI." (Gasset, Gagnon, Poitras, & Brothers, October 2005)

Energy Potential and the FCEV Calculation

The NSEM uses the wind speed pixel colour embedded in the Nova Scotia Wind Atlas (NSWA) each of which represents mean wind speed. This wind speed allows the NSEM FCEV Equation to estimate the number of vehicles fueled annually. See Figure 21 for two example wind Weibull curves.

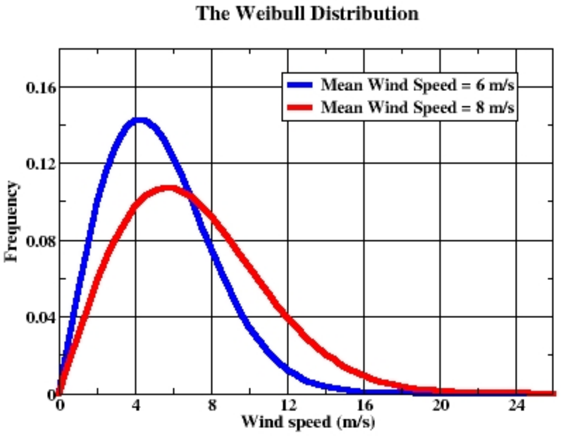


Figure 21: CWA Weibull Distribution at two mean wind speeds (Environment Canada, 21 August 2008)

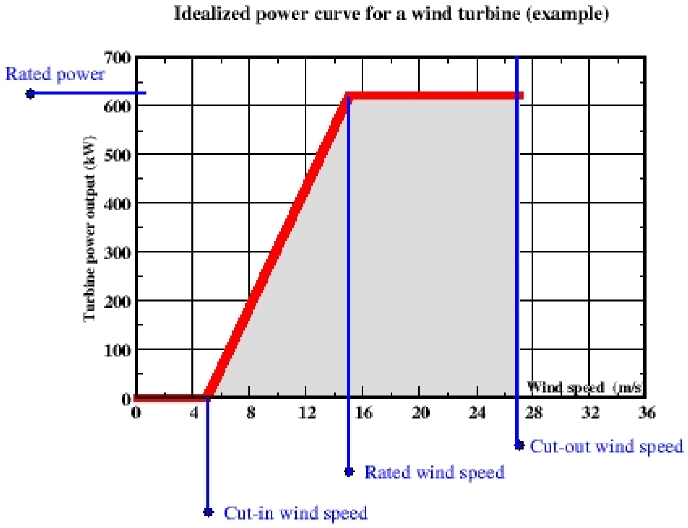


Figure 22: CWA Idealized Wind Turbine Power Curve (Environment Canada, 21 August 2008)

The second component of computing yearly energy output is to use an ideal turbine in conjunction with a wind histogram from the CWA, the figure above demonstrates that with data on the cut-in wind speed, rated wind speed (maximum power), and the cut-out wind speed we can simplify and normalize a straight power curve of a typical wind turbine.

The other method to compute the FCEV calculation employs the actual power curve of a specific turbine. I have cataloged the makes & models in Nova Scotia of each wind turbine (typically there are only 1 or 2 types for each farm), to get exact production curves for already constructed wind farms based on the manufacturers' power ratings.

Turbine Power Curves:

NS wind turbine specifics, such as how many of each type, and if turbines were added a particular year after the initial construction are relevant data. The RETScreen database has been utilized from the publicly available RETScreen software. The Idaho National Laboratory (INL) database has 44 manufacturers of wind turbines as individual Excel spreadsheets; I manually processed these files to merge all of the data in the master list of 270 turbines.

All of the turbine power curve datasets were compiled in a master list. The duplicates were accounted for and removed and any incomplete data has been excluded in the short term. Minor missing data was accounted for using manufacturer specific common hub heights or rotor diameters. Some of these data were not specified but it is known that manufacturers may have multiple configurations they can market. Some of this information is vital for wind histogram selection (i.e. hub height) that computes the production curve. Interpolated hub heights that are common to wind turbines of that MW class were used, thus providing reasonable approximations.

Wind Histograms:

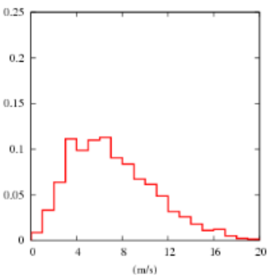


Figure 23: CWA Wind Histogram

The CWA provides a database with histogram and wind rose info for total annual along with all four seasons, at specific elevations from 30, 50, and 80 meters; this means there are 15 datasets of polygon layers. Figure 23 has a y-axis range that represents the overall wind distributions of Canada.

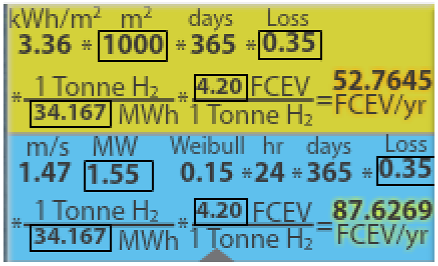
The 5km by 5km polygon raw data for one layer is quite large for a standard workstation to process in QGIS software. For example NS has approximately 5200 polygons (ANU_80m) spread at varying latitudes and longitudes over the landmass and extending tens of kilometers offshore. These polygons had to be selected and compiled from three larger overlapping rectangles of 178X178 polygons, whereas the Wind Atlas recommends removing at least 13 and up to 34 polygons from each side of the rectangles as they may include boundary conditions that were required for creation in the original model but are not accurate to what the climate model creates closer to the centre of the rectangle.

The NS data has been pre-processed from its lengthy ~330 columns and ~5200 rows in the MySQL database to readily accessible wind rose and histogram datasets. These have been combined into a row with 27 columns created for the histograms and then another table with 12 columns for the wind rose. This data reflects the 80 meter elevation wind speeds and wind directions, basically only 1 of the 15 original datasets. The information that was lost in this data transformation is the histogram for each direction of the wind rose, which relates to climate but is unnecessary for our purposes of creating general wind power production curves for specific wind turbines, unless a non-standard design was considered that could not pivot to face the direction of the wind.

In a finer precision calculation knowing directional histograms would help with wind turbulence and flow modeling, and it would equally require high resolution topography and obstacle mapping to be effective.

Production Curve:

The FCEV wind calculations (blue) are logically paired with the minimum and maximum wind speeds on the map. When the wind speed is at a maximum of 9.5m/s on the NS map, the number provides a linear relationship to estimate capacity factor and calculate the conversion to Hydrogen energy and then FCEVs fuelled annually.



$$\overset{kWh/m^2}{3.36} * \overset{m^2}{\boxed{1000}} * \overset{days}{365} * \overset{Loss}{\boxed{0.35}} * \frac{1\ Tonne\ H_2}{\boxed{34.167}\ MWh} * \frac{\boxed{4.20}\ FCEV}{1\ Tonne\ H_2} = \frac{52.7645}{FCEV/yr}$$

$$\overset{m/s}{1.47}\ \overset{MW}{\boxed{1.55}}\ \overset{Weibull}{0.15} * \overset{hr}{24} * \overset{days}{365} * \overset{Loss}{\boxed{0.35}} * \frac{1\ Tonne\ H_2}{\boxed{34.167}\ MWh} * \frac{\boxed{4.20}\ FCEV}{1\ Tonne\ H_2} = \frac{87.6269}{FCEV/yr}$$

Figure 24: FCEV Solar and Wind Calculations from NSEM

An example of this equation put to use is that one 1.5 MW turbine can produce anywhere of enough Hydrogen Fuel to power 100-500 FCEVs in NS, or 250-1250 BEVs annually.

In regards to CWA data, other factors such as weather/climate variables (humidity, temperature, air pressure) as it relates to wind power density will be left out as the data is not available for annual calculations related to the production curve.

Geographic Coordinates for Dynamic Power Plant Population

I have divided data from existing AS3 functions and arrays and created a useable format and loaded this into the database which in concept was straight-forward, but to read the data format by the energy map required some trial and error to get fully functional. Data is given in several types, using the wind farm example first, from how many wind turbines at one location, to unique make and models of turbines, owner of wind farm and more given in Appendix C. Other power plant types share some traits of data structure, with unique characteristics specific to each category.

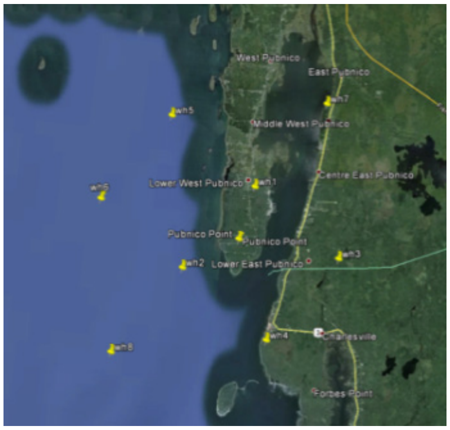


Figure 25: Pubnico Wind Farm with CWA 5km^2 polygon coordinates (Google Earth)

Wind Farm Coordinates:

Lat/Long coordinates were meticulously collected on all wind farms in Nova Scotia. Previous data had been used earlier in the 2014 but were only precise to the 1 kilometer level – simply to the second decimal place when measuring coordinates in decimal degrees. After reassessing the original data, and verifying using Google Earth, whether wind turbines could be visually identified at the locations given (uploaded using KML format), the precision was updated to an appropriately sized three decimal places. This means the location data is now confident down to 111 meters, which is suited for industrial scale wind farms. Most of the wind turbines/farms were identified on satellite images (if up-to-date images were available). Anywhere from half a kilometer to 8 kilometers elevation in Google Earth was adequate for noticing most wind turbines shadows – depending on time of day and the white-balance of the satellite imagery. Some of the wind turbines were so far afield from the initial estimates that it literally took hours to locate, corroborating with search engine results of the company/owner names, some of which changed hands several times since 2002, construction reports from subcontractors, news releases in the media on estimated locations and construction dates, and other available data.

Matching Lat/Long with Climate Wind Data:

Greatest circle method – employed to match CWA wind histograms with combined power curve data per wind farm. This PHP method was adapted to fit my database structure, and in doing so enabled the inclusion of the nearest N number of coordinates based on distance as the crow flies.

Turbine Power Curves Recap

In recap, a master list of 270 unique wind turbines was collected, organized and verified from multiple online sources and data types, and is now being used to provide power curve information to inform the energy map regarding how many annual GWh would be produced at each wind farm; visible as GWh values in each power plant popup, and accessible to the "add plant" feature.

Wind Farm Production Curves

This process is mostly automated via PHP; the selection of unique wind turbines is fed from the database for each wind farm. Presently when there are multiple turbine manufacturers used at one wind farm, I utilized PHP to produce a nested array within each wind farm in the province, this is output to the browser, and then was edited by hand in Excel and combined and exported back to the database. The "add plant" feature in the energy map combines these in one step, allowing for complete coordinate-turbine(s) to annual GWh calculation.

Wind Farm Offshore Water Depth:

Seen on the left is the variable water depth in the near coast environment, ranging from 0m (sea level) in deep red colour, to yellow which is approximately 100-200m depth.

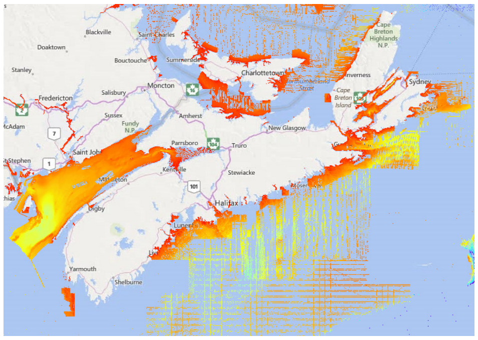


Figure 26: NS Ocean Floor Depths Close to Shore (Geoportal as part of the Government of Canada, 2015)

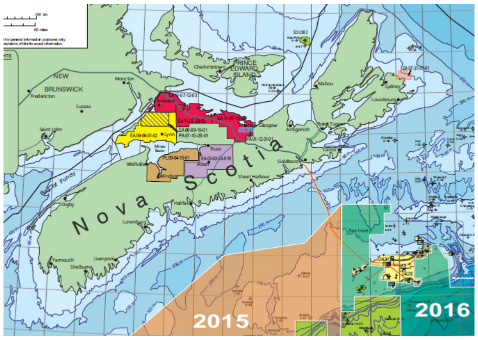


Figure 27: Off Shore Ocean Depth and Oil Exploration Map (Nova Scotia Department of Energy, 2015c)

The above right map from the DOE shows the general ocean floor topography, the first two shades near the shore are 50m and 100m depth. The European example below has demonstrated most offshore wind farms are developed on average in 20 m depths, with the deepest approaching 40 m; costs tend to go up based on more foundation structure being required as the water gets deeper.

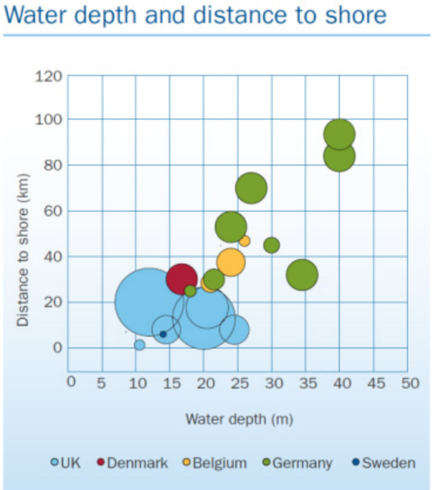


Figure 28: Water Depth, Distance to shore and Size of offshore wind farms under construction during 2013 in Europe (Corbetta, Pineda, & Moccia, January 2014)

“The weighted average water depth of offshore wind farms where work was carried out in 2013 was 20 m, slightly lower than in 2012 (22 m). The average distance to shore for those same projects was 30 km, almost the same as in 2012 (29 km)”

3.3.3 Water – Maps, Tidal, Wave, Barrage Dams and Hydropower

This section briefly covers what technology is planned to be installed in the FORCE berths, and general resource map data. Other reports and publications cover this subject in greater detail. It should be noted that the NS DOE is strongly encouraging tidal research and development, and concurrently the Nova Scotia Legislature released the Marine Renewable Energy Act on April 29th 2015 to regulate construction approval.

> "…Govern the development of marine renewable energy resources—including waves, tidal range, in-stream tidal, ocean currents, and offshore wind–in designated areas of the Nova Scotia offshore. Establish two 'Areas of Marine Renewable Energy Priority' for Nova Scotia–within a part of the Bay of Fundy and Cape Breton Island's Bras d'Or Lakes, with the authority to identify additional areas through regulation." (Nova Scotia Department of Energy, 2015b)

Tidal Current – Large Provincial Capacity

Figure 29: Proposed Tidal Turbines in Bay of Fundy FORCE berths

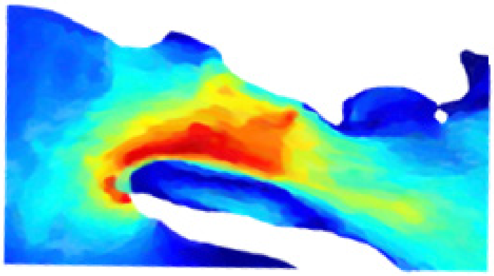


Figure 30: Tidal Power in the Minas Passage (0–5 m/s) Edited from the original image (Karsten et al., 2010; Karsten, Greenberg, & Tarbotton, November 2011)

I compiled and entered a small database of 23 tidal turbine power curves that are used by the "add plant" feature in the NSEM. A different list on the following page includes tidal turbine types that are planned to be installed in the FORCE berths.

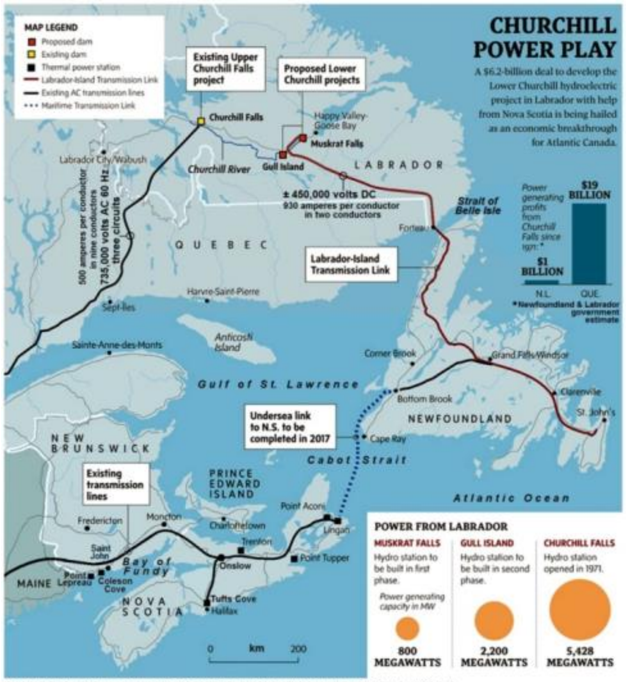
units	Capacity	model	makeN	Tech Type	output	Area Name	Built	company	Lat	Long
1	19.4			Barrage	19.4	Annapolis Valley	1984	NSP	44.752	65.511
1	2.5	Schottel	Triton S36	Current	2.5	Minas Passage	2015	Black Rock Tidal Power	45.364	64.422
1	2	Marine Current	SeaGen F 16m	Current	2	Minas Passage	2016	Minas Energy	45.368	64.429
2	2	Open Hydro	OpenCentre 16m	Current	4	Minas Passage	2015	NSP	45.367	64.425
1	1.5	Atlantis	AR1500 18m	Current	1.5	Minas Passage	2016	Lockheed Martin/Irving Shipbuilding	45.367	64.437
0	0	TBD	TBD	Current	0	Minas Channel	TBD	TBD	TBD	TBD

Table 11: The current and planned Tidal Energy installations in the Bay of Fundy as of 2015/2016

See Appendix G: Map of Potential Tidal Current Energy (Tarbotton & Larson, 2006)

Local Hydropower and the Maritime Link

Nearly all of the medium and large hydropower resources in the province of Nova Scotia have been developed. Only one recent project was proposed at Lake Uist in 2009, for a combined 100MW wind farm in conjunction with 100MW pumped hydropower, the developers were denied their EIA approval with regard to impacting fish populations and negative community objections. Alternatively, experts claim that if used appropriately, pumped hydropower can also aerate portions of large bodies of water, and actually be a net benefit to water that "…has a low biological productivity, like specific parts of the Bras d'Or Lake System" – Bruce Hatcher. Since the province lacks any significant hydropower resources locally, the focus has been in developing Muskrat Falls and the 500MW Maritime Link import project with the idea that Lower Churchill Falls Phase II (Gull Island) would be a good second construction project.



JOHN SOPINSKI/THE GLOBE AND MAIL ■ SOURCES: GOVERNMENT OF NEWFOUNDLAND AND LABRADOR; NALCOR ENERGY; EMERA INC.; HYDROQUEBEC
(with six small improvements by I.C. Smith)

Figure 31: Muskrat Falls, Gull Island, and Churchill Falls Hydropower Projects
(Government of Newfoundland and Labrador, Nalcor Energy, Emera, & HydroQuebec, November 2010)

Wave Power

I attended the 2014 International Ocean Energy Conference which was held in November in Halifax, to learn about new tidal energy devices and how technologies may affect future energy regimes in the Bay of Fundy. ICOE2014 demonstrated that many products are being manufactured and deployed around the world. Wave power is promising, but at this point more interest in NS is focused on ocean current, sometimes also referred to as in-stream, because of our uniquely strong tidal current regime. Engineering companies are interested in the tidal mega-project in Figure 32.

Coastal ‘non-blocking’ Barrage Dams in the Bay of Fundy

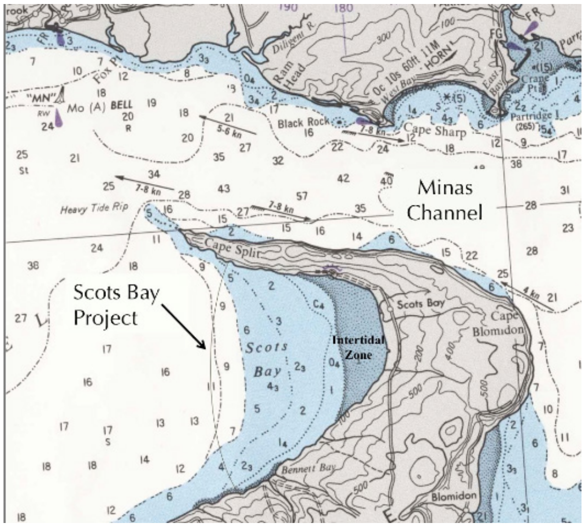


Figure 32: 1100MW Halcyon Proposed Project at Scots Bay (Halcyon Tidal Power LLC., 2014)

The Scots Bay Halcyon project has a long lifetime, very low LCOE values, has a huge energy storage potential whenever the tide is low enough to produce power and could allow for the sale of export energy to the Northern US market, as planned by project proponents.

3.3.4 Solar Photovoltaics – Maps, Applications, ComFIT, Data

GreenPowerLabs has produced a high resolution solar insolation map specifically for Nova Scotia. They have also worked with Halifax and produced an assessment based on LIDAR measurements of rooftop angles, sun exposure potential and annual energy production, called Solar City. (Halifax Regional Municipality, June 2015). Google is releasing a solar mapping tool in the US, Project Sunroof, and may begin to allow other countries access later on. Mapdwell www.mapdwell.com and NREL’s Prospector maps.nrel.gov/prospector have similar projects.

Residential, Commercial, Industrial Applications

The NS Department of Energy has assessed LCOE figures for distributed solar PV along with centralized solar PV power plants; they quote numbers from a document produced for NREL (Black, 2012). As is the nature of forecasting market prices and technology, based on other evidence, the LCOE numbers should be lower than what is being used as a guide in the Electricity System Review process. The SunShot report, focused on solar PV, put out by NREL has this statement in the executive summary:

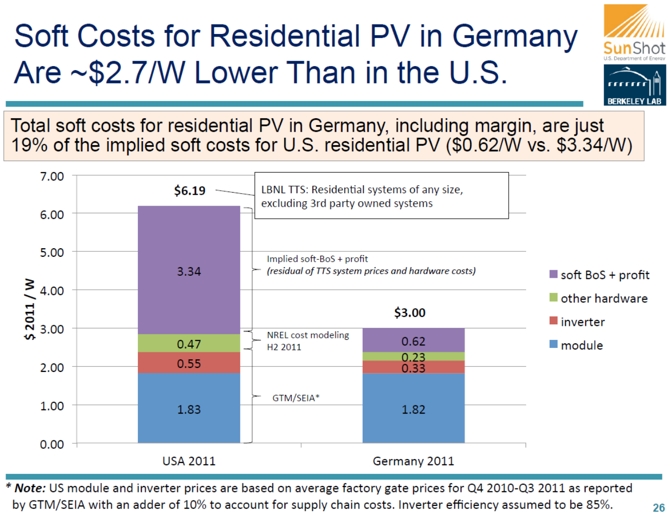
> "The installed capacity of global and U.S. photovoltaic (PV) systems has soared in recent years, driven by declining PV prices and government incentives. The U.S. Department of Energy's (DOE) SunShot Initiative aims to make PV cost competitive without incentives by reducing the cost of PV-generated electricity by about 75% between 2010 and 2020." (Feldman et al., 1 November 2012)

In the conclusion of the same document:

> "This summary report provides an overview of historical, recent, and projected near-term PV pricing trends in the United States—focusing on the installed price of PV systems. Reported price data from an extensive sample of more than 150,000 installed PV systems show substantial system price reductions over time, and variability in prices depending on system size, configuration, and location. Installed prices of U.S. residential and commercial PV systems declined 5%–7% per year, on average, during 1998–2011, and preliminary data suggest that even steeper price reductions, as witnessed during 2009–2011, will continue in 2012.

> In 2011, the median reported installed price of residential and commercial PV systems was $6.13/W for systems of 10 kW or smaller, $5.62/W for systems of 10–100 kW, and $4.87/W for systems larger than 100 kW. The capacity-weighted average reported installed price of utility-scale PV systems (ground-mounted systems at least 2 MW in size) declined from $6.21/W during 2004–2008 to $3.42/W in 2011. The drop in installed system prices has resulted from module and non-module cost reductions, but module costs have declined more quickly, thus heightening the PV industry's recent emphasis on reducing non-module costs." (Feldman et al., 1 November 2012)

Of importance to note in Figure 33, the Balance of System (BOS) costs vary greatly by region, typically involve differences in how much profit installers earn and transportation costs involved in delivering and installing panels.



Soft Costs for Residential PV in Germany Are ~$2.7/W Lower Than in the U.S.

Total soft costs for residential PV in Germany, including margin, are just 19% of the implied soft costs for U.S. residential PV ($0.62/W vs. $3.34/W)

* ***Note:*** US module and inverter prices are based on average factory gate prices for Q4 2010-Q3 2011 as reported by GTM/SEIA with an adder of 10% to account for supply chain costs. Inverter efficiency assumed to be 85%.

Figure 33: Germany and USA Solar Installation Costs (Seel, Barbose, & Wiser, 2013)

ComFIT and Local Solar Farm Potential

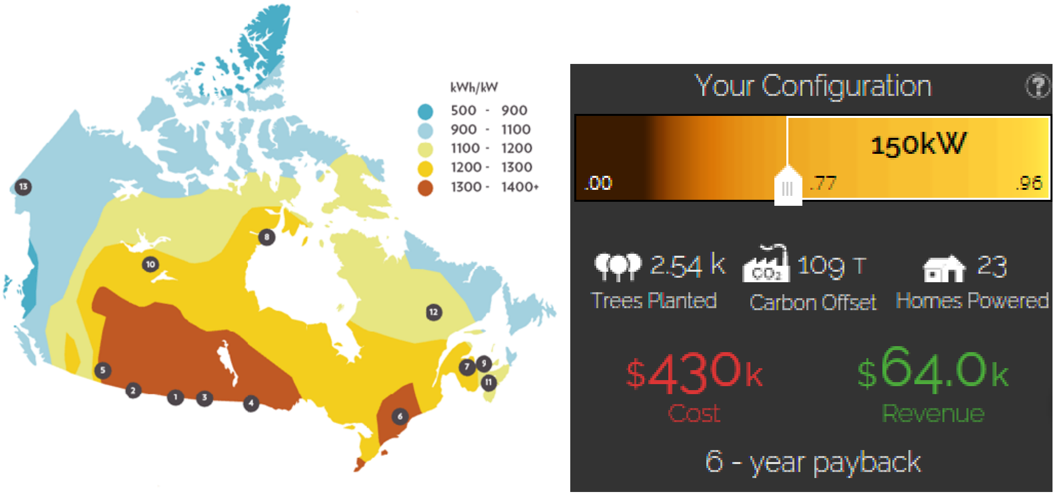
SolarFIT was once proposed several years ago, and was deemed a higher cost option when those market prices were assessed. Canada has a reasonable solar PV resource, as colder temperatures and snow reflection improve panel performance. The difference between kWh per kW installed between January and July is nearly 50%, so the same square meter gets almost half the energy in the winter months, mainly because the panels have less daylight hours to work with. Of importance to note is whether the panels are stationary or tracking (generally on 1 or 2 axes) as this radically alters performance characteristics based on direct sunlight access and other surface reflections from the area surrounding the panels. If Halifax, Dartmouth, and Burnside ComFIT capacity potential were fully used, the power grid could add 78MW of Solar PV. The local details such as size of installation, perhaps 50kW could be the baseline; would mean 840 installations could be built in Halifax, 460 installations in Dartmouth, and 260 installations in Burnside. This type of project would require energy storage to go along with each location and should be considered as a pilot project for Advanced Metering Infrastructure, Nova Scotia Power may want to assess on this scale of project.

	78	MW installed		NS 11 TWh
Month	GWh min	GWh max	$/kWh	Avoided Power Cost
Jan	4.68	6.24	0.145	$904,800
Feb	4.68	6.24	0.145	$904,800
Mar	7.8	9.36	0.145	$1,357,200
Apr	6.24	7.8	0.145	$1,131,000
May	7.8	9.36	0.145	$1,357,200
Jun	7.8	9.36	0.145	$1,357,200
Jul	7.8	9.36	0.145	$1,357,200
Aug	7.8	9.36	0.145	$1,357,200
Sep	7.8	9.36	0.145	$1,357,200
Oct	6.24	7.8	0.145	$1,131,000
Nov	3.12	4.68	0.145	$678,600
Dec	3.12	4.68	0.145	$678,600
Total	72	89	0.145	$13,572,000
% PV	0.65%	0.81%		

Table 12: 78MW – NRCAN Solar PV typical monthly power production

National and Provincial Maps

NSCC COGS performed a solar study and used GOES cloud cover data for Nova Scotia. http://agrg.cogs.nscc.ca/Solar-Resource-Maps in this link each monthly map is comprised of hundreds of, 1 km resolution, statistically analyzed satellite images to show general ground solar radiation. The same can be done for NB, PE, NL using their method; either by COGS, another post-secondary institute, or department can take on the project to improve local energy system awareness. The publically availably NASA GOES data: http://www.goes.noaa.gov/goes-e.html



Your Configuration

150kW

.00 .77 .96

2.54 k Trees Planted

109 T Carbon Offset

23 Homes Powered

$430k Cost

$64.0k Revenue

6 - year payback

Figure 34: Solar PV kWh Annual Production per installed kW (left); Mapdwell Cost Estimate (right)

Data Coarseness

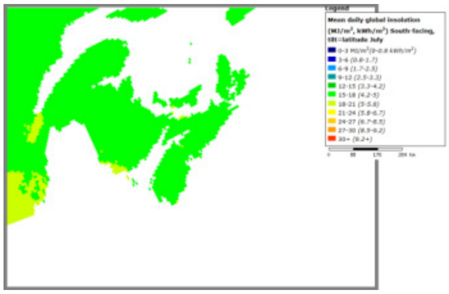


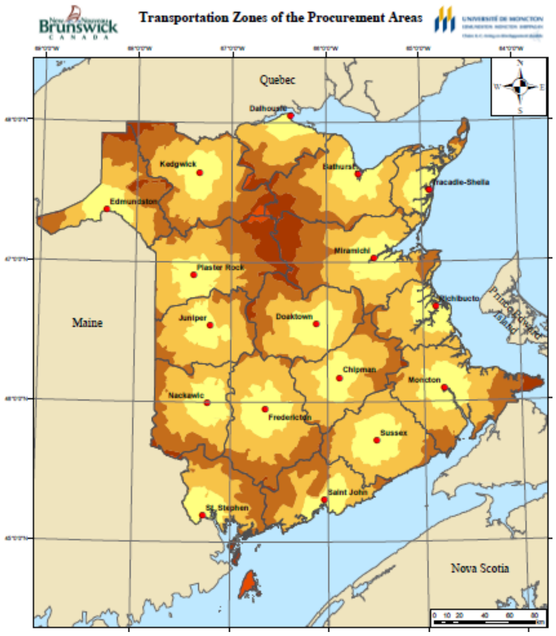
Figure 35: NRCan Solar July

To the left is an example of monthly solar insolation maps by NRCAN for July. http://pv.nrcan.gc.ca/pvmapper.php

Data is very coarse, with nearly 20km wide blocks-pixels, but demonstrates monthly trends across the province that other annual maps do not.

3.3.5 Biomass – Maps, Annual Yield, Sustainability, Value Added Sector

NB has mapped biomass harvesting potential and created possible Combined Heat & Power (CHP) plants where they theoretically would produce the most power with the least transport energy losses for fuel stock. NS, PE and NL could be viewed with a similar approach. Data was not readily available on these other provinces.



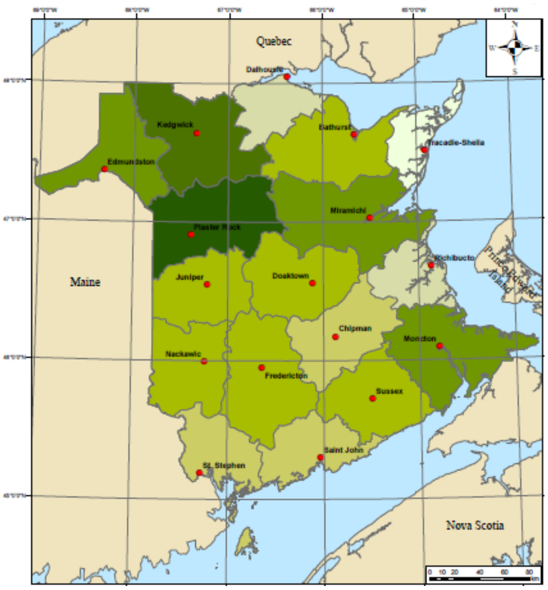
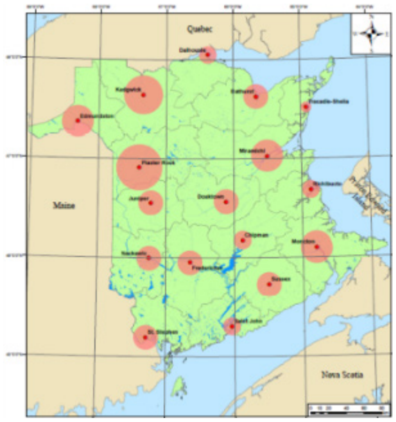


Figure 36: NB Transportation Distances to CHP Biomass from 1-25km to 101-125km (left)*
Figure 37: NB Green Metric Tonnes (GMT) from 0-100 k GMT to 600k-700k GMT (right)*



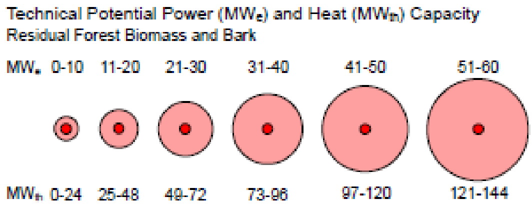


Figure 38: NB MW electric, and MW thermal from 0-10MWe to 51-60MWe (top)*

Figure 39: NB Potential CHP Biomass Locations (left)*
*(Bouchard, Landry, & Gagnon, 2012)

With approximately 21 potential CHP Biomass plants, it is estimated from Figure 39 that nearly 500MW electric capacity is present. If we stated that the average GMT needed to produce that amount of electricity from the largest CHP capacity and efficiency, of on average 132MW thermal from average 650,000 GMT annually, which works out to 55MW electric. We can see it is reasonable to estimate that nearly 500MWe would require 5,900,000 GMT annually. We are fortunate to live in a country with companies that regulate and stand by the Sustainable Forestry Initiative (SFI), but there are longer term gains in solid wood products, habitat protection and biodiversity, using selective silviculture, besides for our immediate needs and that we should aim for harvesting only the necessary needs with paper products.

It is vital to consider a second option besides renewable energy as a solution to mitigating climate change. The following Figure 40 displays the extent of forest area in each country. Global forest area was 3,999,134 kha in 2015 from the FRA 2015.

Figure 40: World Forest Area (kha) FRA 2015

The following Figure 41 displays net deforestation extent in hectares by country.

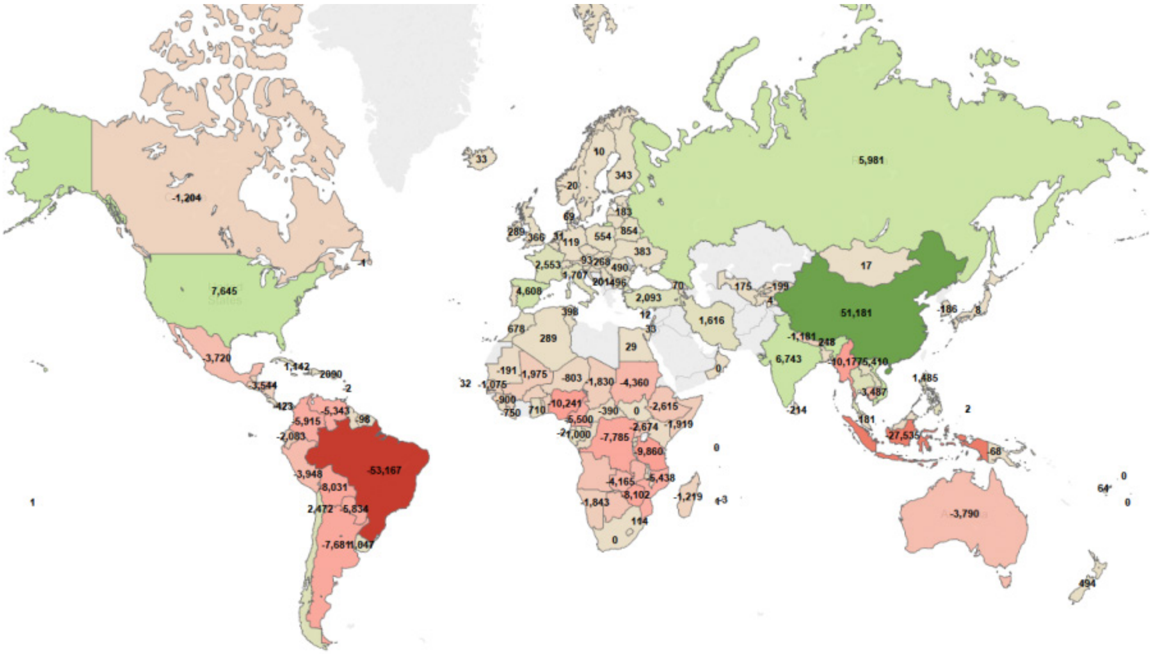


Figure 41: Counting Net Deforestation 1990-2015 kha (3.13%) FRA 2015

What about over the previous 50-100 years? What would be involved in a true atmospheric LCA? According to FRA2015 data, 125,429,000 ha have been deforested since 1990 and not replanted. The following is a tree graph of the same data from above.

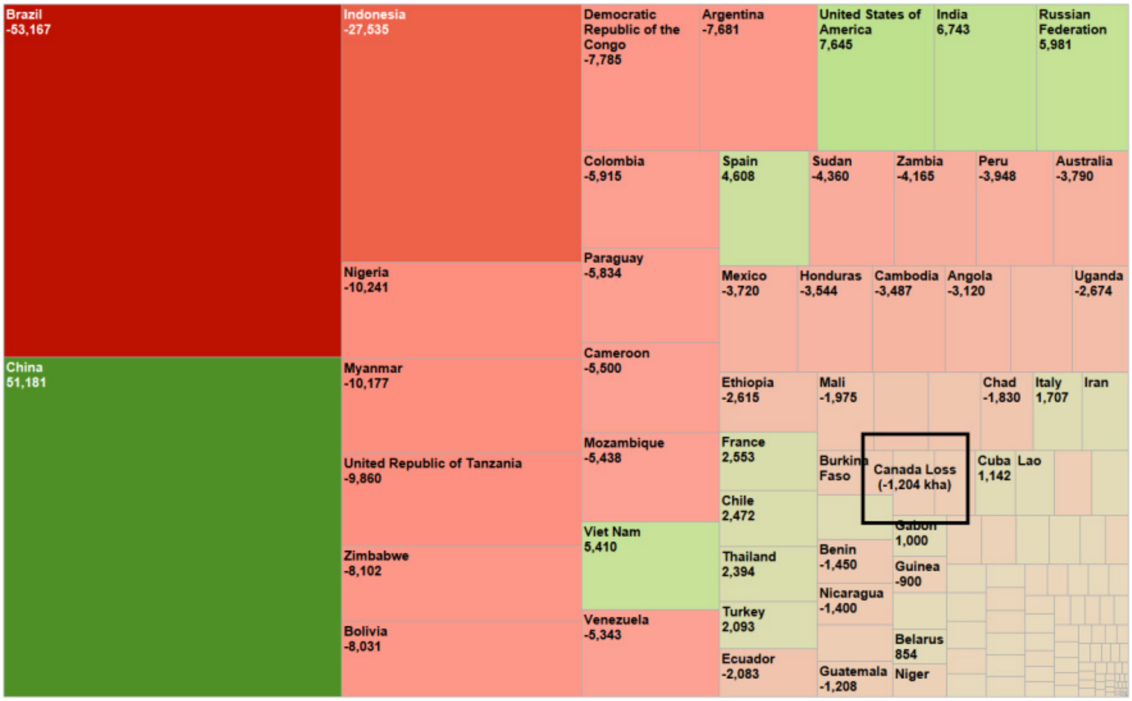


Figure 42: Counting Net Deforestation 1990-2015 kha (3.13%) Tree-graph FRA 2015

What if 25% or greater of non-essential cropland were reforested? (Goodland 2009)

- 25% of ~2,000,000 kha equals ~500,000 kha
- This is a 12.5% increase in World forest area!
- 7,400 Mt/annually of "cheap carbon capture" (In boreal or temperate forest ecosystems).

The FAO estimated deforestation connected to eCO2 of:

- 7328 Mt/annually of lost sequestration potential from tropical deforestation.
- 5496 Mt/annually not being used for minimum global afforestation/reforestation.

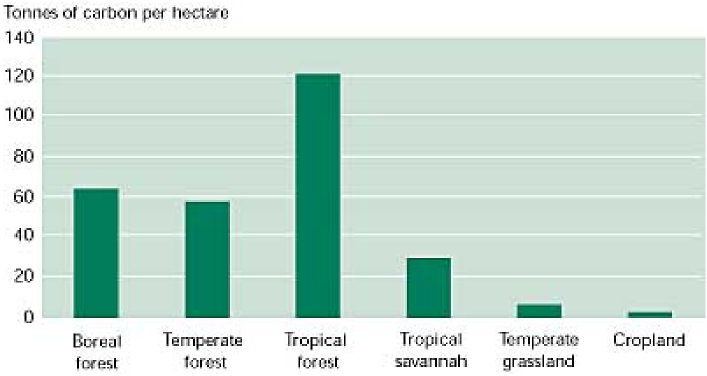


Figure 43: Above Ground Carbon Density for Selected Vegetation Types (FAO 2002)

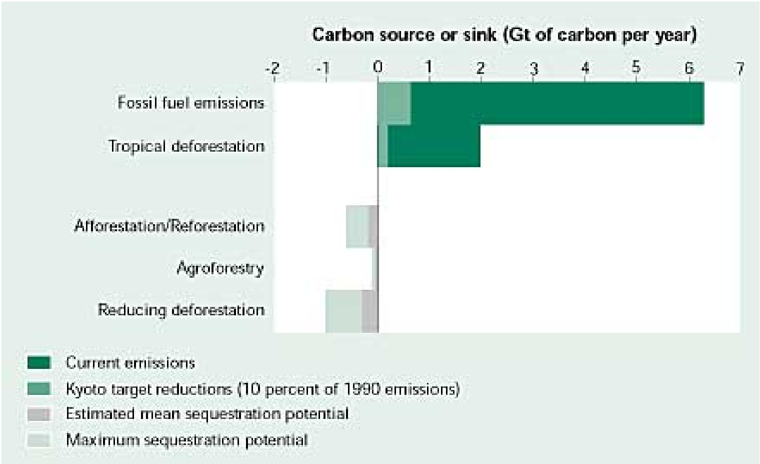
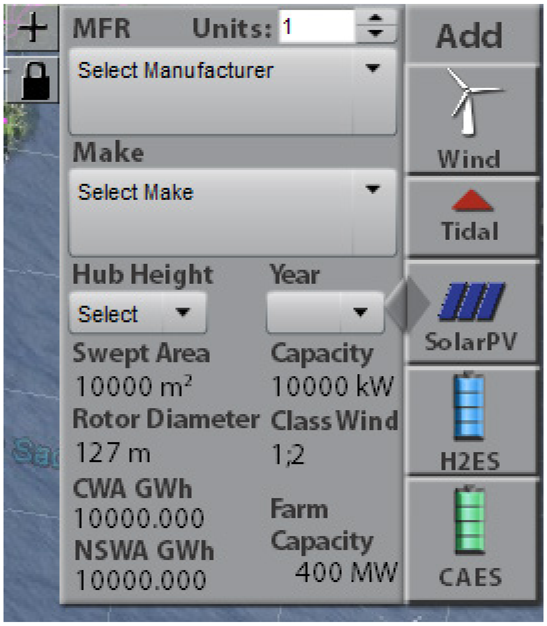


Figure 44: Carbon Source or sink Gt of Carbon annually (FAO 2002)

3.4 Stationary Energy Storage

Energy Storage Technologies:

Basic ES increases available capacity factor if near power plants on a limited connection power line; also they can be located near demand to reduce demand on grid capacity at peak times. See image of the "add plant" feature below:



MFR Units: 1

Select Manufacturer

Make

Select Make

Hub Height

Select

Year

Swept Area

10000 m²

Capacity

10000 kW

Rotor Diameter

127 m

Class Wind

1;2

CWA GWh

10000.000

NSWA GWh

10000.000

Farm Capacity

400 MW

Figure 45: Add Power Plant Feature

The "add plant" feature of the energy map allows users to build wind, water and solar power plants, and then place CAES or H2ES to provide a level of firm renewable energy.

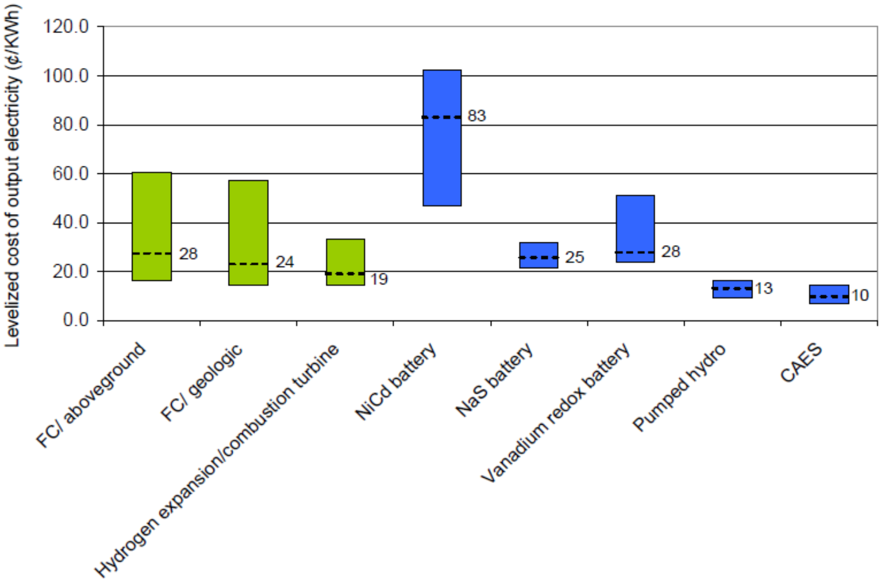


Figure 46: NREL LCOE boxplots of Energy Storage Technologies (Nova Scotia Department of Energy, May 30 2014)

Energy Storage Technologies – Important Considerations: reservoir sizes in GWh. hydro/CAES/H2 reservoirs can scale independently of 'generator' or fuel cell. Peak output MW. See image below regarding time to ramp up/ramp down in seconds/minutes/hours, and how that looks on the electricity grid.

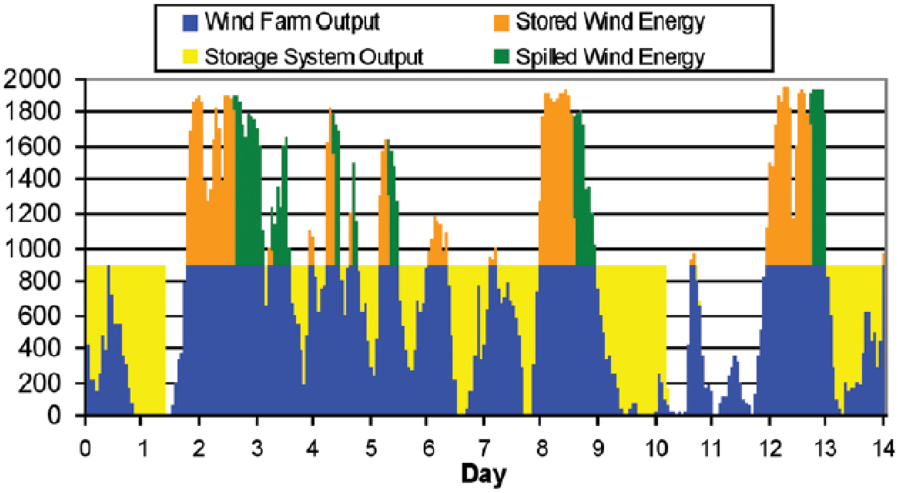


Figure 47: Shows 'renewable base load' effect of adding Energy Storage to grid (NREL 2010)

On this page the image below represents how electricity can be stored over different lengths of time, and what that may mean for a power grid using significant amounts of solar or wind power. A significant portion of energy could be stored during the windy winter months and then distributed when needed, i.e. acting as peaking units until summer and then excess solar could be stored in a similar fashion.

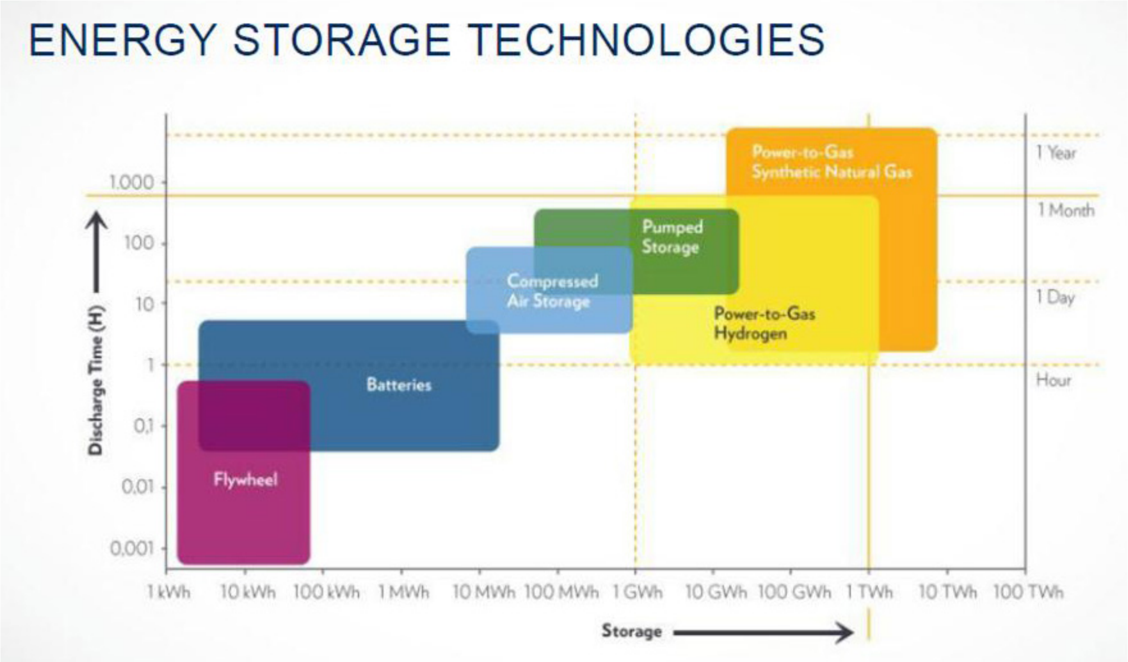


Figure 48: Energy Storage Sizes and Discharge Times (Goggin 2015)

One promising hydrogen pathway, of the variety of chemical and process based variations, includes using liquid methanol trucked to standard gas stations, and outfitted with Hydrogen gas fuel pumps that convert methanol on demand at high pressure without a “normal” gas compressor component. Kraus Global is presently selling these pumps. - http://krausglobal.com/products/hydrogen/dispensers/introduction/

3.5 Transportation Sector Integration

3.5.1 Fuel Cell Electric Vehicles and H2-Internal Combustion Engines

This section sets out to objectively assess the benefits and drawbacks of each major transportation technology. Use of one does not preclude the other but each may have different user types, such as typical distance travelled, operational temperature(s) and charge times, which will be looked into in this section.

Common Infrastructure:

Infrastructure needs to be put in place for both, while BEVs already have a power grid in place, the greater percentage of uptake will put strain on distribution systems and introduce a new growing variable for power system operators to account. Both technologies will have a cost on general electricity rates, as it stands fossil fuel infrastructure in terms of gasoline needs to be either replaced with newer gasoline distribution as mechanical components and pipelines age, or replaced with BEV and FCEV charging/fueling stations.

Fuel cell vehicles in contrast to BEVs can be fueled in about 3 minutes, similar to a gasoline vehicle and the range is much greater than BEVs. Hyundai ix35 has an average range of 593km. Toyota FCEV Mirai Sedan has a range of 650km. Nissan Terra's theoretical range is estimated around 600km.

Figure 49: Toyota Mirai on left, Nissan Terra on the right

3.5.2 Battery Electric Vehicles and BEV-Hybrids

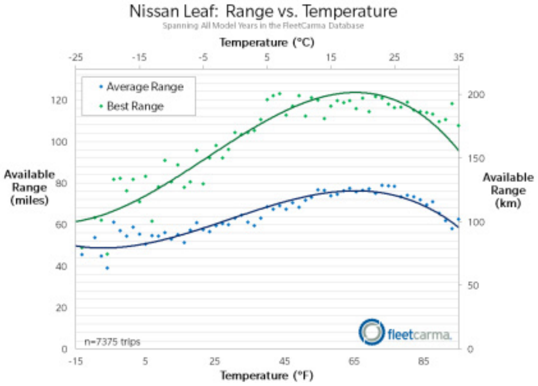
Both main types of alternate energy vehicles need primary energy to be converted and stored in either a Battery vehicle or Hydrogen vehicle, there are well known system efficiencies for the overall conversion of this energy. This conversion process has a large impact on reduction in greenhouse gas production relative to fossil fuel power vehicles, with battery technology being the clear winner in this metric. Environmental costs are not only measured with one parameter though, so other things like mining for materials needed in the production and operation and maintenance and eventual disposal and recovery of materials must also be considered in the Lifecycle Cost Assessment (LCA) of each technology.

On average BEVs have lower initial capital costs to date, must have their batteries swapped at some point in their lifespan, have long charge times – anywhere from 30 minutes to ten hours and have lower ranges than the average North American gasoline car but are improving with new technological advances. Cold weather negatively affects driving range so may not be useful in the colder parts of Canada and the US. Several vehicles to mention are the Nissan Leaf (average 100km range), Chevy Volt (a gas-electric hybrid; average 40km electric range – 380km total) and the Tesla Model S (average 370-480 km range stated by retailer – BEV energy storage of 60 kWh to 85 kWh) which has the longest electric range. The major forcing factor for reduced range in colder climates is heating the interior of the vehicle, whereas with FFOVs and FCEVs they mostly use waste heat, unless it is exceptionally cold (below minus 15°C).

As an example of the best class of technology, we take a quick look at the charge time for the Tesla Model S, from the charger section: "8km per hour up to 100km per hour charging" (Wikipedia, 2015). Lifespan and cost to replace for Tesla Model S, from the battery section: "The battery is guaranteed for eight years or 125,000 mi (201,000 km) for the base model with the 60 kWh battery pack" (Wikipedia, 2015). With both the charging and lifespan of the batteries in mind, we have to ask if BEVs truly are both more convenient and greener than FFOVs or the alternative of FCEVs.

The following two figures demonstrate the electric range versus temperature of the Nissan Leaf, and also the Chevrolet Volt, both are on different temperature scales because the Volt is a gas-electric hybrid and the motor kicks in when it gets below -5°C.

Figure 50: Nissan Leaf Range vs. Temperature (Allen, August 2014) Left



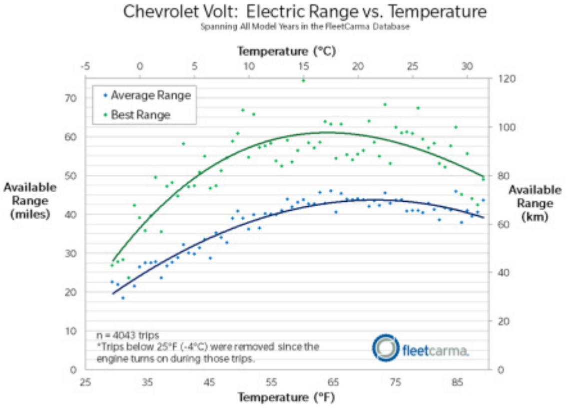


Figure 51: Chevrolet Volt Range vs. Temperature (Allen, August 2014) Right

If an individual is simply commuting to work and back in an urban environment and does not need to drive very far and can charge both at home and at work, we can see how BEVs with lower ranges are attractive economic and functional investments.

Arguably it makes more sense based on average annual distance travelled in Nova Scotia to use vehicles with both a reliable (year round) and longer range, such as gas-electric hybrids as transitional fuel vehicles, and eventually full scale longer distance BEV and FCEV taking up half the personal transportation market each, as worked out in the Chapter 5 example of the near 100% energy example. See Figure 52 for the average annual distance travelled in Nova Scotia in 2008.

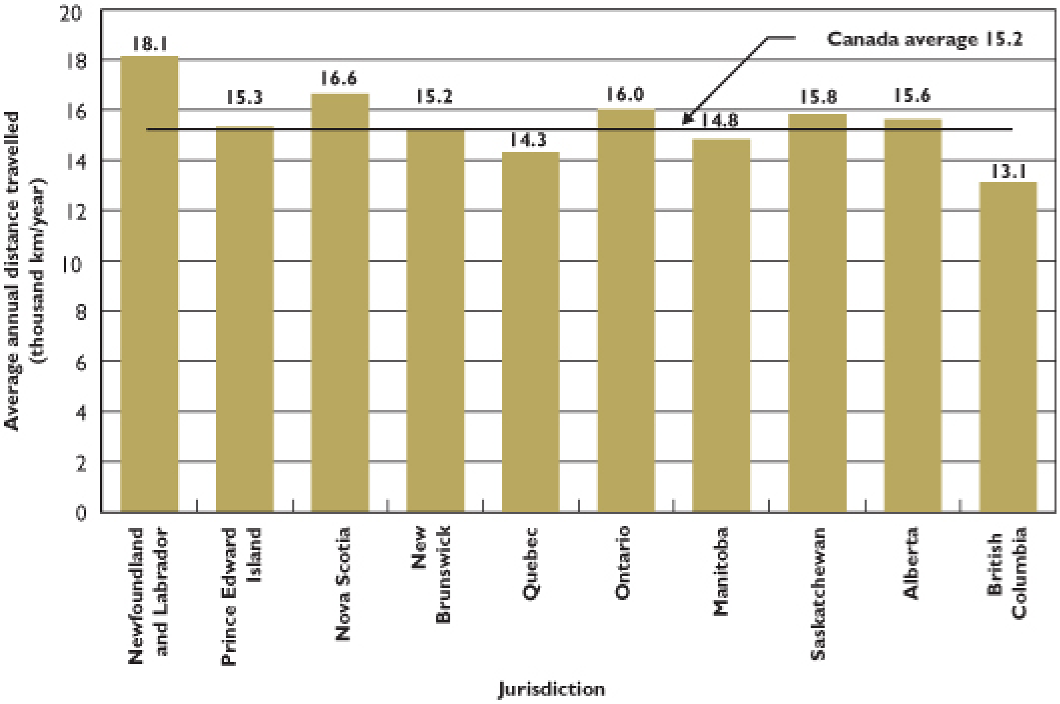


Figure 52: Average annual distance travelled by light vehicles by jurisdiction 2008 (Natural Resources Canada, 2010)

How much energy is required to travel annually? What would that cost?

BEV → 3654 kWh @ $0.142/kWh = $519	Battery kWh / (Efficiency kWh/km) → Range Annual Distance*Efficiency*Electricity Cost → Cost 16600km*0.198kWh/km*$0.142/kWh = $467
FCEV → 8740 kWh of H2 @ $4/kg H2 @ $8/kg	Tank kg / (Efficiency kg/100km) → Range Annual Distance*Efficiency*Hydrogen Cost → Cost 16600km*0.7692 kg/100km*$4/kg = $510 16600km*0.7692 kg/100km*$8/kg = $1020
FFOV → 12782 kWh @ 7.78kWh/L and $1.3/L = $2136	Tank Liters/ (Efficiency L/100 km) → Range Annual Distance*Efficiency*Gasoline Cost → Cost 16600km*9.9 L/ 100 km*$1.3/L = $2136

Please see Appendix I, for the highlights from the micro-teaching example assignment I created regarding BEVs, FCEVs, and FFOVs, as it describes fuel-tank/battery size, liters equivalent/mpg, and fuel costs to drive the Nova Scotian average distance with a variety of vehicle examples. FFOVs in NS in 2008 had an average fuel consumption rate of 9.9L/100km. (Natural Resources Canada, 2010)

3.6 Original Contributions of Chapter 3

In summary in Chapter 3, my original contributions in this thesis were towards:

- The economic analysis of NS fuel prices,
- Provincial data extraction for NS from CanESS model,
- Data extrapolation for GWh for all NS power plants,
- Near 100% wind primary power example, with energy storage and transportation basic conceptual costs,
- Power plant data collection in Atlantic Canada (energy volunteers assisted with NB, PE, NF),
- Wind resource maps discussion,
- Analysis of NSWA and using ideal turbines to create BEV/FCEV calculations to estimated vehicles fuelled annually,
- Turbine power curves data collection, sorting and formatting,
- CWA QGIS data selection procedures,
- Wind farm coordinates data and PHP to match them using greatest circle method,
- Introduced the concept of offshore ocean floor depths to allow users to add wind farms up to a maximum depth with respect to EU common practice,

- Tidal turbine berth technology research and compilation of tidal turbine database,
- Maritime link addition to energy map,
- Comparison of promising technologies and basic energy resource maps for WWSB,
- ComFIT example for HRM 78MW using NRCAN data and connection capacity,
- Energy storage and WWS add plant feature introduced, including concept of eventually adding economic range to estimate cost of projects,
- And finally, BEV/FCEV fundamental overview comparison of practical every day uses (range, cost to fuel for a year, operational considerations) which includes microteaching example activity.

Chapter 4: Economics, Risks, EIAs and HIAs

4.0 Introduction

Chapter 4 first encompasses broad strokes from reading widely of best practices in economic measures and applied philosophy in the form of the Triple Bottom Line approach. Second, I tackle a few of the major risks that require awareness and mitigation strategies. Third, from reading and skimming the majority of Nova Scotia's provincial EIAs produced for all 33 wind farm proposals and a select few from Canada, the US, and the UK, I provide a synopsis of the most important and reoccurring themes considering, human and animal, along with general environmental health. Finally I detail the necessity of green technologies based on the imperative for healthy individuals and provide a brief but thoughtful assessment on external mining impacts of any primary energy option.

In section 4.1, I begin with economic measures such as the definition of LCOE, along with common assumptions in models that form the components necessary to make an adaptable, precise and reliably accurate LCOE value that can be applied to a region such as a state or province. I introduce the general idea of the Triple Bottom Line approach for unfamiliar readers and provide a simple analogy using monoculture versus permaculture and labourers. I walk the reader through a simple application of the principles using the above example and then finally apply the environmental lens to WWSB and suggest solar in the context of operational least harm done. A short section on externalized costs and market failures describes a related and necessary idea of the FoodPrint as it ties in the social side of decisions that affect our provincial and global GHG emissions, which are unnecessary with simple changes in behaviour.

In Section 4.2, I state basic operational risks with several of the technology options, from fire hazards, hurricane damage potential, explosion risks and mitigation, standards and regulations for fuel/energy use, and finally this section wraps up with high reliability organizations and terrorist threats.

Section 4.3 is equally important covering the micro and macro environmental impacts from radar reflections, infra-sound, and animal kills for wind turbines to defining the basics of resource extraction to manufacture enough wind or solar to power all our primary energy needs. I compare and contrast the material intensities required, from using Steel, Aluminium, Copper and Lead, and including some less common elements. In this section I work out the general details of rolling out enough solar PV on a majority share of residential and commercial rooftops, and hectares of solar PV power plants. I work out the details of the best and worst efficiencies of common solar PV and how much area would be required to power our primary energy needs, and then convert that into material requirements, we can see that solar PV may have harsher environmental impacts in the mining sector and adversely affect animals in the material acquisition.

Section 4.4 completes an important and succinct health impact assessment based on the Fundamentals of Air Pollution (Vallero, 2014) textbook regarding point and stationary pollution applied in the Nova Scotia primary energy context. First I calculate the transportation sectors impact. Next I include the published data on electricity sector emissions from 2005-2014, and then I extend a forecast to match their GWh and eCO2 emission forecast, so that now we can estimate Mercury, NOx, and SOx, per power plant from their provincially required system caps. Finally I finish with a short section to wrap up the HIA section with Ambient Soil, Water, and Air Quality.

4.1 Economics

4.1.1Levelized Cost of Electricity

The economic view presented here is structured to compare common assumptions that create the quantified value for Levelized Cost of Electricity (LCOE). This vital indicator hinges on an array of complex project considerations, and is generally normalized over a large region with similar project constraints. Both the NREL and EWEA have published figures demonstrating current and forecasted future LCOEs. They have assessed energy storage technologies and renewable energy contrasted with nuclear, gas and coal respectively. Risk sensitivity uses low, medium and high ranges with deviations spread higher and lower based on certain aspects of each project; Boxplots are a useful visual aid as seen from the NREL Figure 46 on page 96. Purchase pricing of electricity for energy storage technology LCOEs is a typical forcing factor, with each technology varying uniquely.

Levelized Cost of Electricity Definition:

The LCOE is the method of reducing project lifetime costs to a single number commonly written in the literature as either the $ per kWh, $ per MWh, or in terms of Hydrogen fuel as $ per kg. Simply stated, this is cost per energy unit, or cost per mass.

Using the figures from medium wind energy regimes, the offshore energy potential is huge within 30km of the coast of Nova Scotia, and up to 20-40 meters depth of water as is being done in Europe. With higher winds the LCOE number is actually less than this chart, which in strict economic terms is a good thing. The benefits of switching to wind from coal or oil where appropriate is already cost competitive in many cases, especially from a GHG perspective. Offshore wind costs more than onshore wind to develop and maintain, but the wind blows on average 10-12% more in terms of capacity factor. On land the capacity factor for a typical site may be assumed to be 25-32%, but offshore is usually assumed to be 35-37%, depending on local climate wind regimes and geography. The following LCOE information came from the forecast tool at EWEA:

http://www.ewea.org/policy-issues/economics/

Levelized Cost of Electricity (LCOE) from EWEA $/kWh	2010	2020	2030
Onshore Wind	0.094666	0.083819	0.080577
Offshore Wind	0.130845	0.107748	0.092433
Gas	0.080636	0.097178	0.115223
Coal	0.098652	0.117238	0.140321
Nuclear	0.145693	0.146453	0.146672

Table 13: LCOE of Primary Power Supply Choices

Figure 53 below visualizes the data from Table 13.

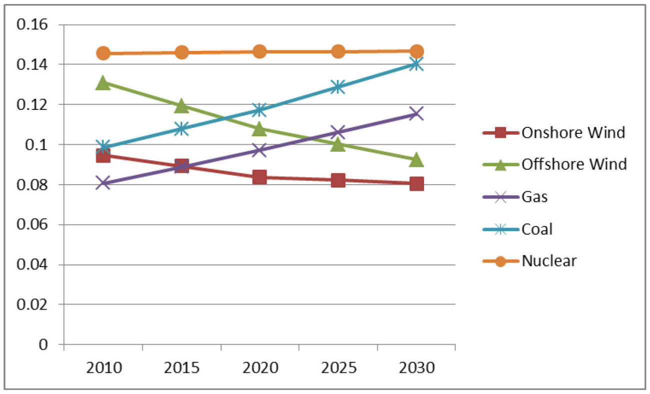


Figure 53: Demonstrates the changing economic environment for onshore and offshore wind over next 20 years

Common assumptions that shape Power Plant LCOE calculation:
*depends on energy type

- $M/MW installed capacity
- Operation and Maintenance (O&M)
- Balance of Plant (BoP)
- Capacity factor
- Labour costs
- Commodity costs to build plant
- Distance from shore and/or major transmission lines
- Water depth (0-40m) Average EU installation approx. 20m
- Distributed or centralized?
- Local grid capacity to absorb unpredictable MW level variations?
    - i.e. Cloudy forecast is not good enough, scattered clouds would create large scale power fluctuations without energy storage leveling the power quality/supply
- Small/medium/large power installations
- Carbon credits or pollution tax by end of 2015 or 2020?
- Lifespan/parts replacement
- Decommissioning
- Recyclability of technical nutrients

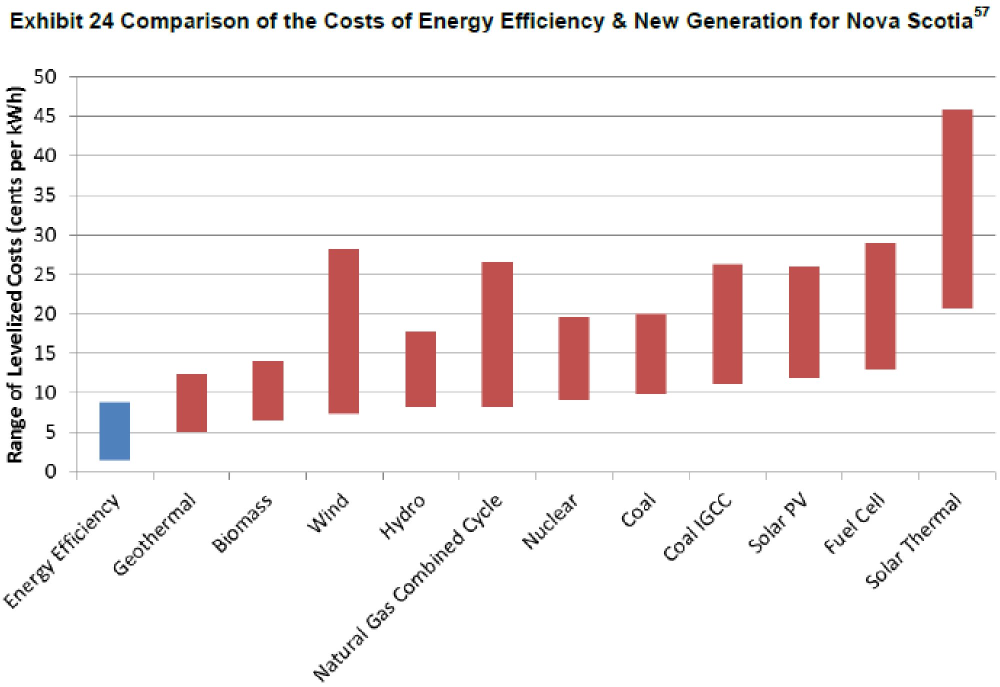


Figure 54: Electricity System Review LCOE Estimates (Nova Scotia Department of Energy, May 30 2014)

The NS Department of Energy produced a number of referenced technology and market trend reports. Using Figure 54 above as an example, we see with the generalization of average technology economic performance that wind, water, solar, biomass and energy storage options are viable options with known performance points. That said, each research and development process that creates new opportunities and develops everything from production processes, to chemical energy pathways, to recyclability and less reliance on rare earth metals, improves the chances the technology can be utilized on a global scale to name a few. When the appropriate smart grid technologies are proven and ready, it is certain that overall technology regimes will change and lifestyles will adapt to fit new energy niches.

4.1.2 CAPEX, OPEX, and AEP

Below is a short list of several important economic definitions for power plants.

Acronym	Definition
CAPEX	Capital expenditure
OPEX	Operational expenditure
AEP	Annual energy production

Table 14: Economic Definitions

Figure 55 demonstrates a breakdown of CAPEX into components of: development, turbine, support structure, array electrical, and construction (all per MW). Next is OPEX with components of: operations and planned maintenance, and unplanned service and other OPEX (all per MW/year). Finally is AEP with components of: gross AEP (MWh/year/MW), losses (%), net AEP (MWh/year/MW), and net capacity factor (%). The thousand dollar value in Figure 55 is measured in Euros.

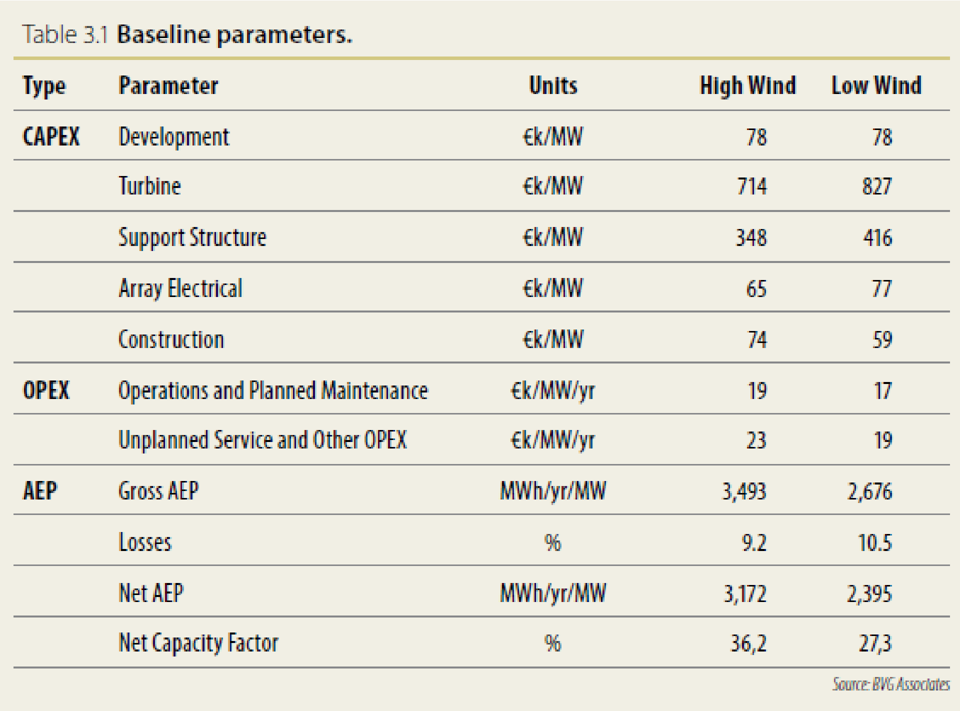


Table 3.1 **Baseline parameters.**

Type	Parameter	Units	High Wind	Low Wind
CAPEX	Development	€k/MW	78	78
	Turbine	€k/MW	714	827
	Support Structure	€k/MW	348	416
	Array Electrical	€k/MW	65	77
	Construction	€k/MW	74	59
OPEX	Operations and Planned Maintenance	€k/MW/yr	19	17
	Unplanned Service and Other OPEX	€k/MW/yr	23	19
AEP	Gross AEP	MWh/yr/MW	3,493	2,676
	Losses	%	9.2	10.5
	Net AEP	MWh/yr/MW	3,172	2,395
	Net Capacity Factor	%	36,2	27,3

Source: BVG Associates

Figure 55: Parameters of CAPEX, OPEX, and AEP for Wind Turbine installation (Valpy & English, 2014)

4.1.3 Triple Bottom Line Approach

Figure 56: Triple Bottom Line (Berg, 2014)

Companies, governments, institutions, and individuals may apply Triple Bottom Line (TBL) methodology to develop creative new solutions when they are faced with difficult challenges. The most challenging part is to be as unbiased as possible when generating questions, and then to go through afterwards and mature each idea.

For example: from an environmental lens with present mono-agricultural practices, we know that this tends to make it extremely easy for insect pests to flourish without competition from other predator species. Permaculture practices have known this for thousands of years, but more recent efficiency practices would rather reduce efforts in the harvesting side to make food cheaper for all in the short term, which is okay at face value, but if the chemical development, soil retention and fertility, economic and nutritional losses are factored in, it may not seem as well suited to the complexity of the Earth's biosphere.

It seems that there has been a systemic loss of common sense when faced with what seems like infinite unhealthy food and activity choices. It comes down to public institutions relearning and vigilantly promoting what is healthy based on the science, tastes great, and other basic foundational knowledge, fads aside, that can easily fix some impulsively dangerous societal behaviors.

Social responsibility requires community education which includes all lifelong learners' capacity to remember, understand, and apply – while growing an individual's ability to analyze, evaluate and create possible solutions to any issue (Bloom's Taxonomy).

Figure 57: Business Ethics and Social Responsibility (SocialWorkJobs.com, 2014)

Applying the TBL environmental concept to the thesis example of wind, water and solar primary energy supply, we see that any turbine will harm wildlife in some measure at an individual level, for example there are approximately 9880 species of birds globally (Withgott, 2015) of which ~3200 of them are on a current path to extinction if GHG continue to be emitted at present rates at 3°C rise (Dawson & Spannagle 2008).

Perhaps based on 20 kills/turbine per year and providing double humanity's TPES, "only" 8-17 species annually would be eliminated if 1500 GW of wind was installed annually after 35 years, while possible saving many other species from climate change losses over the next hundred years and beyond. If all things were equal in the mining, manufacturing, shipping, construction, and decommissioning phases in terms of materials, energy and toxins released then the only difference would be in operation, and fundamentally – stationary rather than mechanically – sourced primary energy would cause less harm. Noting that the location of wind or tidal plays a dramatic role in how it affects the populations of species and their health is important to consider.

4.1.4 Externalized Costs and Market Failures

We look at the cheap cost of luxury products in the present day, but do not see how many kWh, GHG, and how much habitat was destroyed and toxins spread into the world that went into making the product. Although with the advent of smart phones, there is almost always "an app for that" in that you can go into a store and scan barcodes, or do a search and get a report on the company's environmental practices, if they test on animals, and if they are a socially responsible company.

The typical economic version of externalized costs describes that anthropocentric value systems often miss the true value of a healthy thriving environment and all its life (as in they do not account for the quantified value with an appropriate price).

One account of a market failure may be described as when prices for certain goods are artificially low, and do not reflect all the costs of producing a product, from examples of habitat destruction to animal deaths, subsidized animal products such as meat, dairy or eggs, which place a huge burden on non-renewable fresh water supplies, take vast amounts of energy to create large land use changes, and including transportation and refrigeration, all add up to a demand based ecological and individual disaster. It should be noted that approximately 65% of world crops go to feeding exploited animals (70 billion land animals, and rising) on factory farms each year; yet people complain when plant based staples are too expensive, and when droughts stricken southern states.

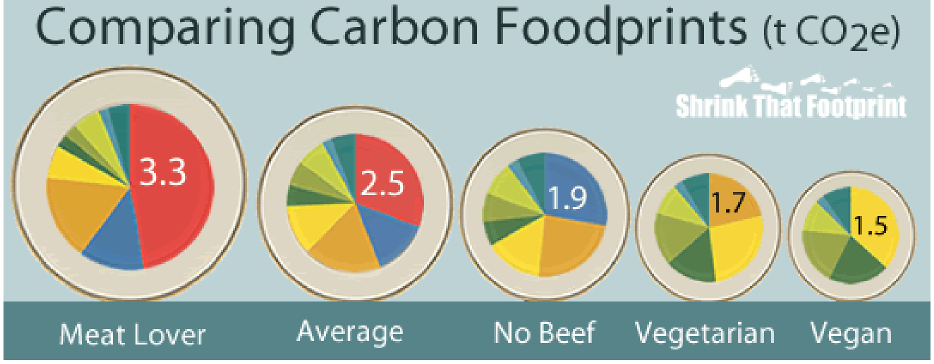


Figure 58: Comparing Carbon Foodprints (Wilson, 2014)

Figure 59 provides the context of “Foodprints” on the global scale; a vegan diet does not have the same land, water and atmospheric impacts.

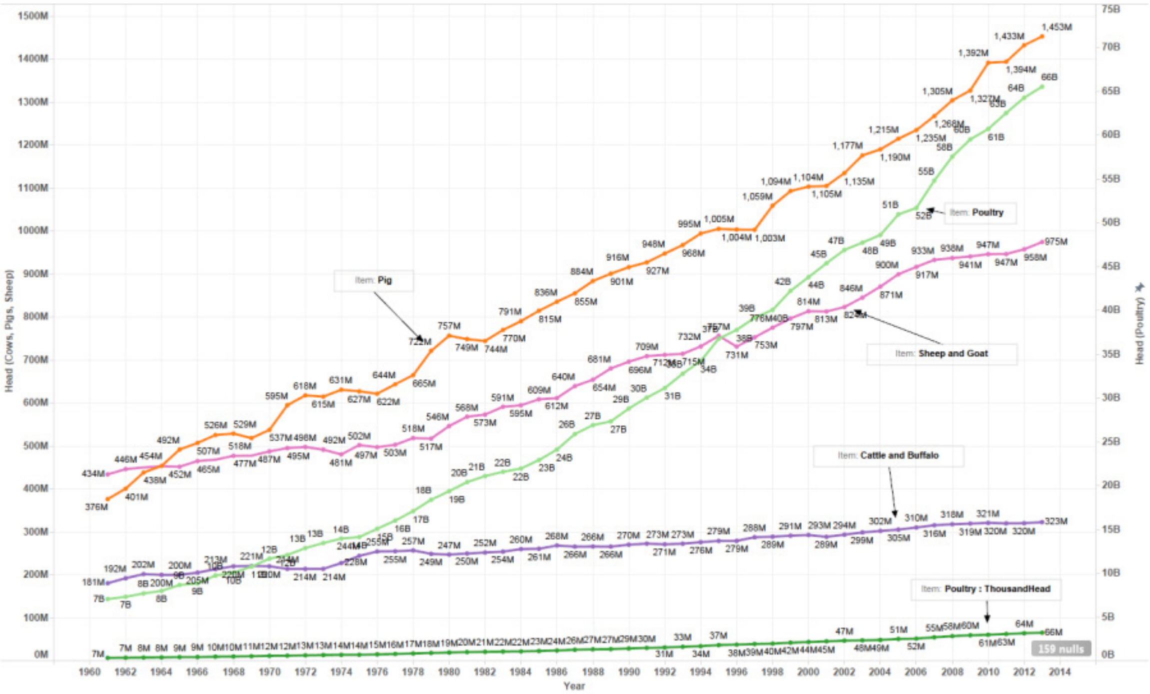
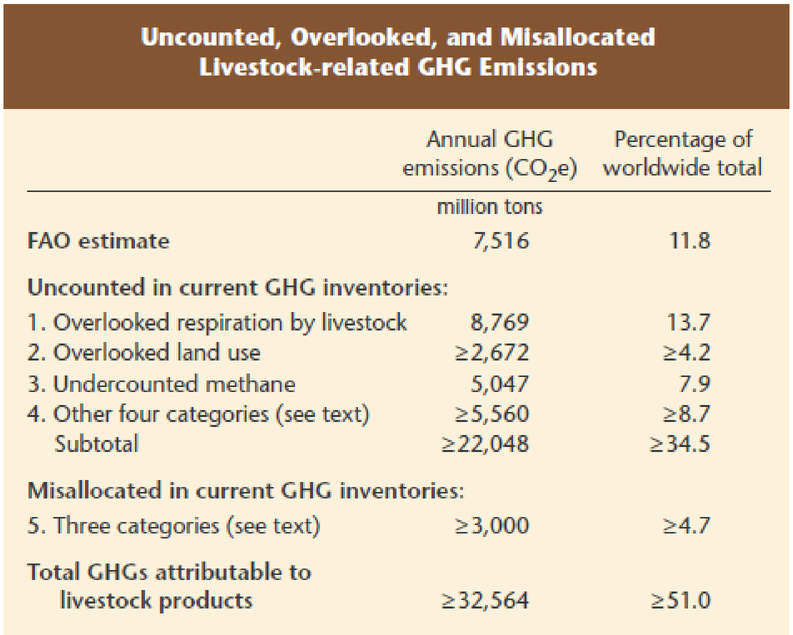


Figure 59: Dual axis - World head of Cattle, Pig, Sheep, Chicken (FAO 2015)

Based on the 600 gallons of water that go into making a single hamburger, Nova Scotia and the rest of the World has some ethical, environmental and urgent decisions to make to increase their drought and soil erosion tolerance. The solution is as simple as Environmental Impact = Technology*Behaviour*Population.



Uncounted, Overlooked, and Misallocated Livestock-related GHG Emissions

	Annual GHG emissions (CO_2e)	Percentage of worldwide total
	million tons	
FAO estimate	7,516	11.8
Uncounted in current GHG inventories:		
1. Overlooked respiration by livestock	8,769	13.7
2. Overlooked land use	≥2,672	≥4.2
3. Undercounted methane	5,047	7.9
4. Other four categories (see text)	≥5,560	≥8.7
Subtotal	≥22,048	≥34.5
Misallocated in current GHG inventories:		
5. Three categories (see text)	≥3,000	≥4.7
Total GHGs attributable to livestock products	≥32,564	≥51.0

Figure 60: Misallocated Livestock GHG Emissions (Goodland and Anhang, World Watch 2009)

Humans as a species have a lot of important questions to face, where we choose to acknowledge and find appreciation for Nature and take only what we need, as put forth in “Prosperity Without Growth” by Tim Jackson and developing without undermining what we do not fully comprehend. It must be considered that the IEA estimated world TPES emissions totalled to 31734 MT in 2014, which is slightly smaller than 32564 MT above. Secondly if we develop more beneficial technologies that release less or no toxins during production (see books: Cradle to Cradle; The Upcycle), if people become aware of and change their behaviour to choose to demand less of the world and be grateful for what they have, and finally as touted by the environmental movement in the 1970s – if we increase educational capacity people will tend to want to have less children on average which also lowers overall demand for material goods. Maslow's hierarchy of needs sets down a person's practical needs from the bottom to the top: food and water, clothing, shelter, and the right to self-determine. This hierarchy can only be balanced with liberty for all, universal values, along with acceptance of self and others.

4.1.5 Future Market Trends and Rising Costs

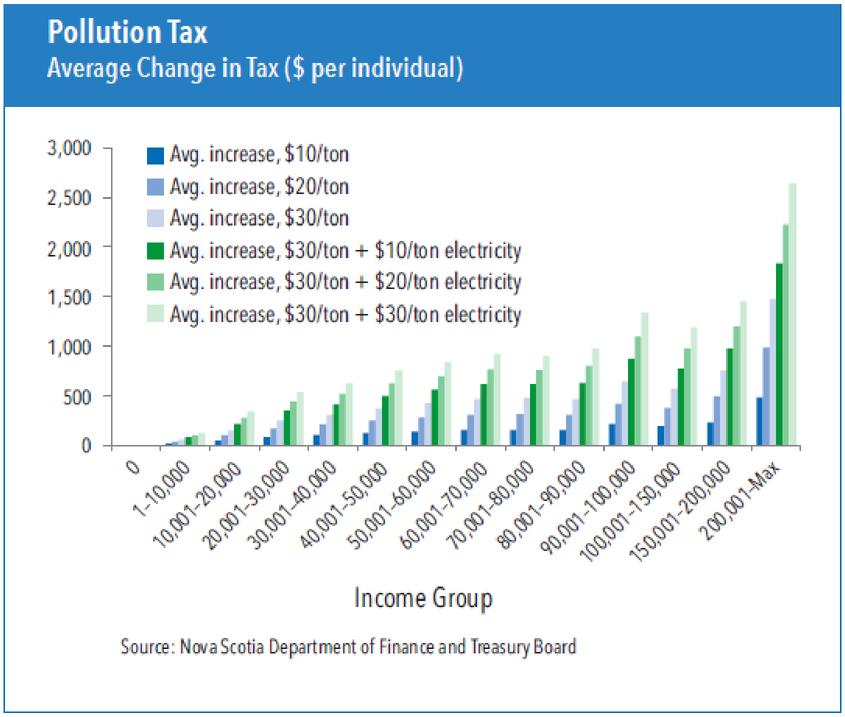
Nova Scotia depends a lot on our resource sector and any large electrical customers that play a huge part in our electricity demands. If we lose a major pulp and paper supplier, or a mining facility begins operation, this drastically changes the demand load profile in our province. The Nova Scotia Department of Energy has electricity forecasts from 8-14TWh up until approximately 2030. After 2030 it gets difficult to predict, as this depends on world energy prices, material costs and availability, new technological developments, more frequent weather events that negatively affect effective GDP, crop losses and subsequent food shortages, transportation of goods, and electrical distribution interruption, whether a war breaks out. All of these factors affect the ability to provide reasonably accurate electricity forecasts. As of the moment BC, Ontario, Quebec and Nova Scotia are deciding on appropriately placed pollution taxes that ramp up slowly over each year. NS government is recommending that the best type is revenue neutral; this will depreciate utility assets.

4.1.6 Pollution Tax

The Nova Scotia Finance Department released the "Nova Scotia Tax and Regulatory Review" report with the lead author Laurel C. Broten on November 2014. In that document the implementation of the revenue-neutral pollution tax was strongly recommended amongst other policy tools. The general idea is that all major sources of GHGs in units of eCO2 along with any harmful releases of toxins in the environment will be taxed, with the costs being passed on to the consumer as the energy sector is tied into all elements of the economy. Using the BC example, the costs started at $10/tonne in 2008 up to $30/tonne after four years.

> “The rates sets are roughly aligned with various international environmental studies on the social cost of carbon emissions and generally established at an average price of about $43 per tonne CO2 equivalent, but with a wide standard deviation of $83 per tonne.” – Page 53 (Broten, November 2014)

A Nova Scotia pollution tax if used similarly to BC’s implementation can lower corporate and personal income taxes to some of the lowest in the G8 and of the Canadian provinces.



Source: Nova Scotia Department of Finance and Treasury Board

Figure 61: Pollution Tax: Average Change in Tax per individual, page 54 (Broten, November 2014)

Paraphrasing regarding BC's success: they state that a report produced by Sustainable Prosperity titled "BC's Carbon Tax Shift After Five Years" came to the conclusion that the tax was a success and noted the 17.4% per capita reduction in consumption in all taxable fuel types – meanwhile the province's economic growth either kept pace or surpassed most provinces in the same period.

Paraphrasing the section on revenue: If Nova Scotia were to adopt a BC style pollution tax, gross provincial revenue would increase up to $430M annually. If electricity generation were excluded until 2020, revenue would be $227M by 2019 and with electricity phased in, reach $430M by 2025.

4.2 Operational Disaster Risks

This section briefly covers some important considerations regarding the safe operation of each of the wind, water, solar, and biomass power plants – along with the three major energy storage options discussed in this work (CAES, Hydrogen fuel cells, and flywheels), adjacent to people and other infrastructure. Each section covers only the most at risk plants as appropriate in the context of the rest of the sections.

4.2.1 Fire Hazards

Utility scale wind turbines are both very tall and built in large clearings so are at low risk of being majorly affected by forest fires. Most of the utility scale wind turbines are designed for lightning strikes, but parts of the blades or nacelle may be damaged and require unplanned maintenance.

Solar PV has risk of electrical fires if the wiring or casing is damaged, but typically the short would cause a circuit breaker to be tripped. Solar concentrating and parabolic technologies focus heat so directly that many hundred degrees of temperature can be reached with large installations; typically this technology is used in warmer climates so there is less risk of equipment failure over cold winters.

Biomass plants follow typical procedures of any thermal combustion style plant, to get the energy from the material the cellulose/woody biomass is burned at high temperatures in a controlled environment. There is always risk of equipment failure, but with proper maintenance this typically is not an issue. The bigger risk of biomass is losing supply to forest fires when forests are too dry during the summer.

4.2.2 Hurricane Damage Potential

Wind turbines if not selected to have a hurricane class IEC wind rating, will be more likely to be damaged in typical high wind storms. Since Nova Scotia is jutting out into the Atlantic it is vital that engineers choose reliable turbines that have been proven to withstand 1 in 100 year storms with gusts up to a certain threshold. See the section on IEC ratings for more info. The rest of the power plants are generally only at risk of high winds that blow projectiles into equipment, or raise large offshore waves that damage any offshore equipment. Stronger storms are becoming the norm that needs to be considered.

4.2.3 Explosion Risk and Mitigation

CAES has risk of high depressurization potential, if using shipping containers, or underground storage, there is the possibility that in a worst case scenario material will fatigue or otherwise fail and will release the compressed air at high velocity and potentially throw debris in the surrounding area.

Compressed Hydrogen has the additional risk of chemical combustion, and therefore will not be stored in too high a mass. NASA has the largest liquid Hydrogen storage tank for a mobile application, at 250 metric tons, which is a considerable amount of energy. Most personal vehicles only have 5-6kg on board, enough to travel ~600km.

4.2.4 Standards and Regulations for Fuel/Energy Use

Petrol stations around the world have provincial and national fuel handling standards to which they adhere. The same has been designed for Hydrogen fuel at pilot stations at both lab and commercial scales. The chemical properties of Hydrogen are well known, from combustion range at percentage of air at standard atmospheric pressure, to energy density and concussive force in various quantities, to how fast it dissipates in the surrounding environment in the event of a leak, rather than pooling on the ground like gasoline will. With several large automakers, many government institutions, and researchers having done considerable research and development on commercial scale utilization of Hydrogen composite compressed storage tanks we can be sure they have done due diligence in their testing and any quality assurance and approval processes.

4.2.5 High Reliability Organizations and Terrorist Threats

Any electrical utility has the express duty to provide safe and reliable energy, in doing so this may mean that certain types of power plants are fenced off and secure to protect individuals from walking on site unaware of the risk and danger to themselves and others that electrical discharge and explosive capacity would have. Proper staff training of how to handle equipment and processes in the safest manner to provide zero safety incidents is vital, both to people, infrastructure, and societal economic activity – as power outages cost money and waste time. With the utmost public trust these companies have to consider the worst case scenarios and comply with provincial and federal government regulations.

4.3 Environmental Impact Assessments

This section quickly highlights some of the main points of interest from a selection of the 30 plus wind farm EIA reports in Nova Scotia, along with a few from Canada, the US, and the UK.

4.3.1 Radar Reflection Considerations for Wind Turbines

Any onshore and offshore wind turbines have to be in compliance with local shipping and air traffic approaches that utilize radar for guidance. The spinning blades of a wind turbine can cause multiple reflections that interfere with normal operations. In the UK all wind farms are set back with enough distance from any areas deemed necessary.

4.3.2 Infra-sound and Proper Setbacks for Siting Wind Turbines

Several of the EIAs did a decent job in representing the computer modeled decibel levels at different wind speeds from each wind turbine at their proposed wind farm. One minor point of contention that may or may not have been considered was the various atmospheric effects of low fog, differing weather events such as ice on the ground or water nearby, or seasonal changes like leaves on the trees that can either amplify or muffle sounds depending on geometric focus points and local topography. Some nearby residents may actually be considerably annoyed by infrasound, rather than just the annoyance that somebody built something that they do not validate. It is vital with all large projects to consider the saying, “all for one, and one for all”. Many international jurisdictions have 2 km setbacks, while in Canada quite a few developers focused on the cheaper places to build, understandably, that were in fact probably too close to people’s homes. Once their contract expires those projects will be reconsidered and possibly re-sited at larger distances with best practices in place.

How does offshore wind infra-sound affect acoustic-sensitive whales and dolphins, which use sound to communicate, feed, breed, and travel thousands of kilometers? How much would that interfere with previously successful evolutionary behaviours?

4.3.3 Animal Kills per Turbine

There are various numbers regarding animal kills per wind turbine, but the North American average runs at about 5-10 bird strikes per year if not built in migration routes, feeding or breeding grounds. If we used our wind turbine heavy example of 4280 5MW turbines, it may effectively kill 21,400-42,800 birds annually in Nova Scotia alone to provide all 75TWh of primary energy supply. With this in mind, it may be wiser in the ecological sense to utilize more solar PV instead. Tidal turbines have not been deployed long enough in the Nova Scotian context to quantify actual fish and other marine animal kills, but computer models can come up with a good estimate using basic statistics with known marine wildlife migration routes and perhaps borrowing from hydropower stats. Please consider the following graphic as a visualization only and not as base fact.

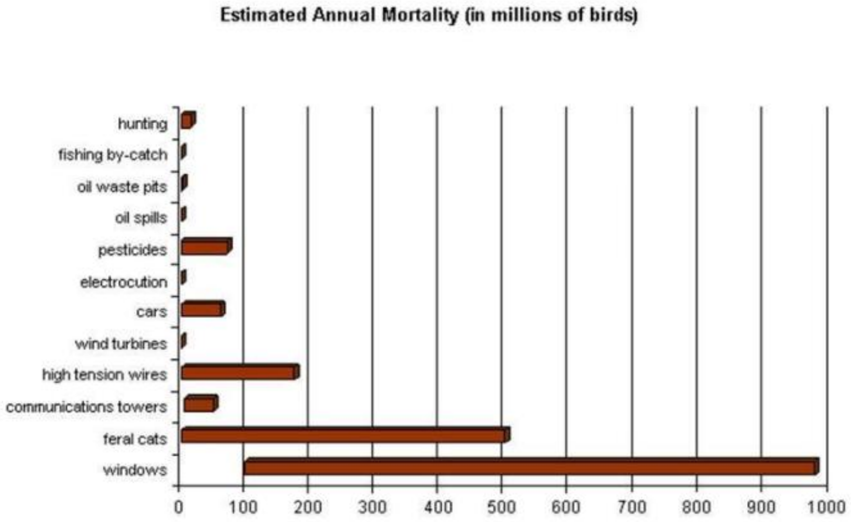


Figure 62: Estimated Annual Mortality (millions of birds) (Bernard 2012)

4.3.4 Resource Extraction – Material Intensity and Mining

Briefly covered in this section are the material limits to development. Starting with the World scarcity of many basic elements, seen represented in the Periodic Table below. The next step taken is to estimate average material needs to build enough wind or solar PV continuing the near 100% simple case.

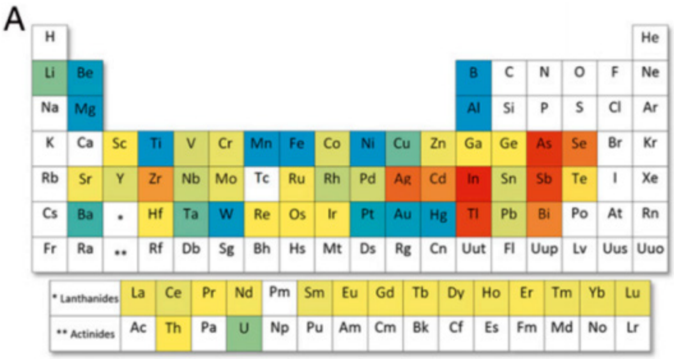


Figure 63: Elements with the greatest supply risk. Red is high, blue is low. (Leber, 2015)

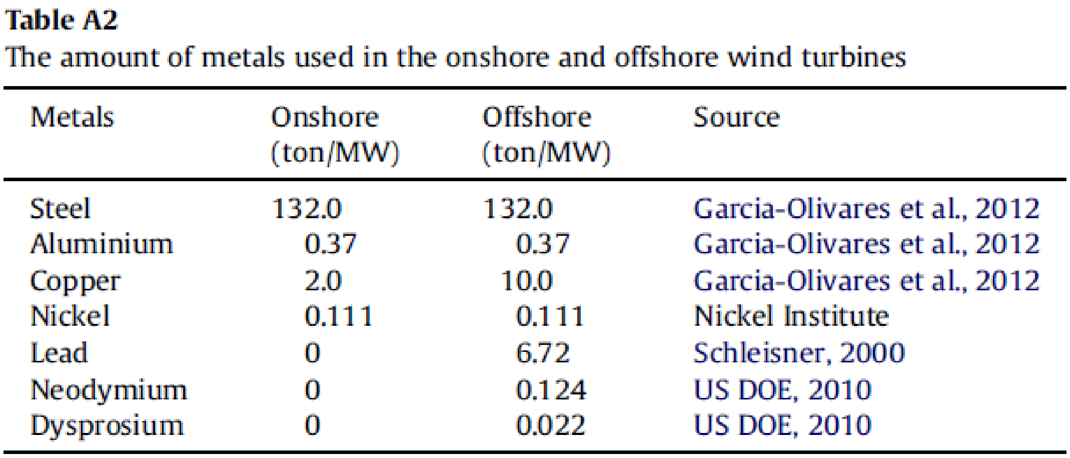


Table A2
The amount of metals used in the onshore and offshore wind turbines

Metals	Onshore (ton/MW)	Offshore (ton/MW)	Source
Steel	132.0	132.0	Garcia-Olivares et al., 2012
Aluminium	0.37	0.37	Garcia-Olivares et al., 2012
Copper	2.0	10.0	Garcia-Olivares et al., 2012
Nickel	0.111	0.111	Nickel Institute
Lead	0	6.72	Schleisner, 2000
Neodymium	0	0.124	US DOE, 2010
Dysprosium	0	0.022	US DOE, 2010

Figure 64: Metals used in onshore and offshore wind turbines (tonnes) (Elshkaki & Graedel, 2013)

If we used the wind heavy example of 4280 5MW turbines, at 21400MW, with the assumption that 20% will be onshore (NSDOE acknowledges there are places to include additional wind in NS), and 80% will be offshore; considering the ~277 turbines which average 1.993 MW/unit already built by mid-2015 at 552 MW, we see the new wind MW necessary from the simple case would be 20848MW. By end of 2016 there will be 363 turbines at 714 MW in NS, including all ComFIT projects (Thompson 2016)

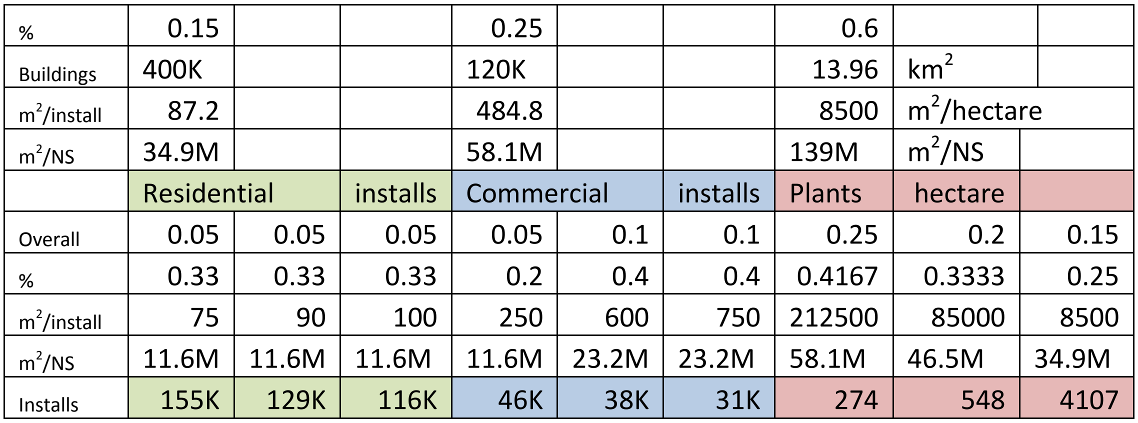
Metals	Onshore Built 2015 (tonne)	Onshore New (tonne)	Offshore New (tonne)	Nova Scotia Total (tonne)
Steel	72,870	492,089	2,259,840	2,824,800
Aluminium	204	1,379	6,334	7,918
Copper	1,104	7,455	171,200	179,760
Nickel	61	413	1,900	2,375
Lead			115,046	115,046
Neodymium (Nd)			2,122	2,122
Dysprosium (Dy)			376	376

Table 15: Metals (tonnes) to build Offshore Wind Farms to supply NS Primary Energy

There are a variety of different solar PV technologies. The best known are multi-junction cells, single junction cells, crystalline cells, thin film cells, and there are emerging variations such as organic cells, inorganic cells and quantum dot cells to name a few.

View the graphic in Appendix J from NREL to see how best in class energy conversion efficiency has improved over time with research and development from 1975 onward. Some important considerations are the availability of rare/expensive materials to create each type of cell, and overall energy in manufacturing and durability/lifespan. Just because a technology is termed "green" or renewable does not mean that it has no environmental impacts in production and operation. Typically it should indicate lower impact in terms of LCA regarding GHGs and of a sustainable nature, than the status quo of fossil fuels.

The table below provides a very general estimate of how many installations – with rather generous installation sizes from slightly smaller to larger – of solar PV in meters squared across the province to meet all our primary energy requirements in the simple solar case of 232M m^2 of monoSi solar PV panels.



%	0.15			0.25			0.6		
Buildings	400K			120K			13.96	km^2	
m^2/install	87.2			484.8			8500	m^2/hectare	
m^2/NS	34.9M			58.1M			139M	m^2/NS	
	Residential 🟩	🟩	installs 🟩	Commercial 🟦	🟦	installs 🟦	Plants 🟥	hectare 🟥	🟥
Overall	0.05	0.05	0.05	0.05	0.1	0.1	0.25	0.2	0.15
%	0.33	0.33	0.33	0.2	0.4	0.4	0.4167	0.3333	0.25
m^2/install	75	90	100	250	600	750	212500	85000	8500
m^2/NS	11.6M	11.6M	11.6M	11.6M	23.2M	23.2M	58.1M	46.5M	34.9M
Installs	155K 🟩	129K 🟩	116K 🟩	46K 🟦	38K 🟦	31K 🟦	274 🟥	548 🟥	4107 🟥

Table 16: Estimated Solar PV installations in Nova Scotia to meet 70TWh Primary Energy (Thompson 2016)

Using the general total required solar PV panel area requirements, the next step is to combine and contrast with four of the major technological options for PV materials.

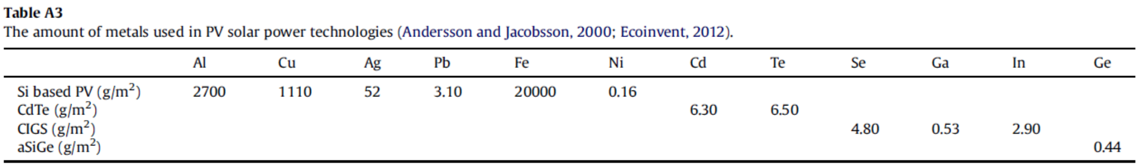


Table A3

The amount of metals used in PV solar power technologies (Andersson and Jacobsson, 2000; Ecoinvent, 2012).

	Al	Cu	Ag	Pb	Fe	Ni	Cd	Te	Se	Ga	In	Ge
Si based PV (g/m^2)	2700	1110	52	3.10	20000	0.16						
CdTe (g/m^2)							6.30	6.50				
CIGS (g/m^2)									4.80	0.53	2.90	
aSiGe (g/m^2)												0.44

Figure 65: Metals used in PV solar power technologies (g/m^2) (Elshkaki & Graedel, 2013)

Highlighted in yellow is the example technology used in the earlier table, a higher efficiency solar PV panel technology would require less panel area to harvest the same amount of electricity but at present moment it would cost significantly more.

NRCAN	365		Primary Energy NS	
	daily-kWh/m^2		70 TWh	
Min/Max	3.3	4.2	70,000,000,000 kWh	
	annual-kWh/m^2			
Min/Max	1204.5	1533		1368.75 Average
m^2	58115401	45662100	*If at 100% Efficiency	
Technology	M m^2	M m^2	Minimum Efficiency %	
aSi	3210.796	2522.768	1.81	
CdTe	1195.79	939.5494	4.86	
CIS	880.5364	691.85	6.6	
monoSi	767.7067	603.1982	7.57	
polySi	957.4201	752.2587	6.07	
Technology	M m^2	M m^2	Maximum Efficiency %	M m^2 Average
aSi	604.1102	474.658	9.62	539
CdTe	464.9232	365.2968	12.5	415
CIS	458.6851	360.3954	12.67	410
monoSi	296.2049	**232.7324**	19.62	264
polySi	330.3889	259.5912	17.59	295

Table 17: Computing the Millions (M) of m^2 of solar PV panels to power 70TWh in NS (Thompson 2016)

tonne/MW	aSi	monoSi	polySi	CdTe	CIS	aSiGe
Al	28.0600	13.6772	15.2556			
Cu	11.5358	5.6228	6.2718			
Ag	0.5404	0.2634	0.2938			
Pb	0.0322	0.0157	0.0175			
Fe	207.8519	101.3125	113.0046			
Ni	0.0017	0.0008	0.0009			
Cd				0.0504		
Te				0.0520		
Se					0.0379	
Ga					0.0042	
In					0.0229	
Ge						0.0035

Table 18: Metals used in onshore solar PV panels in tonnes/MW (converted from Figure 65)

If we used the solar PV heavy example of average 264-539 Million m^2 of panels, at 51142MW to provide 70TWh of primary energy annually we can see below the estimated tonnes of elements used in each solar PV technology class:

tonne	aSi	monoSi	polySi	CdTe	CIS	aSiGe
Al	1,435,045	699,479	780,203			
Cu	589,963	287,563	320,750			
Ag	27,638	13,471	15,026			
Pb	1,648	803	896			
Fe	10,629,959	5,181,324	5,779,282			
Ni	85	41	46			
Cd				2,578		
Te				2,659		
Se					1,938	
Ga					214	
In					1,171	
Ge						178

Table 19: Metals used in onshore solar PV panels measured in tonnes (calculated from Table 18)

Metals (tonne)	Fe	Al	Cu	Ni	Pb	Nd	Dy	Ag
Wind	2,824,800	7,918	179,760	2,375	115,046	2,122	376	
Solar PV monoSi	5,181,324	699,479	287,563	41	803			13,471

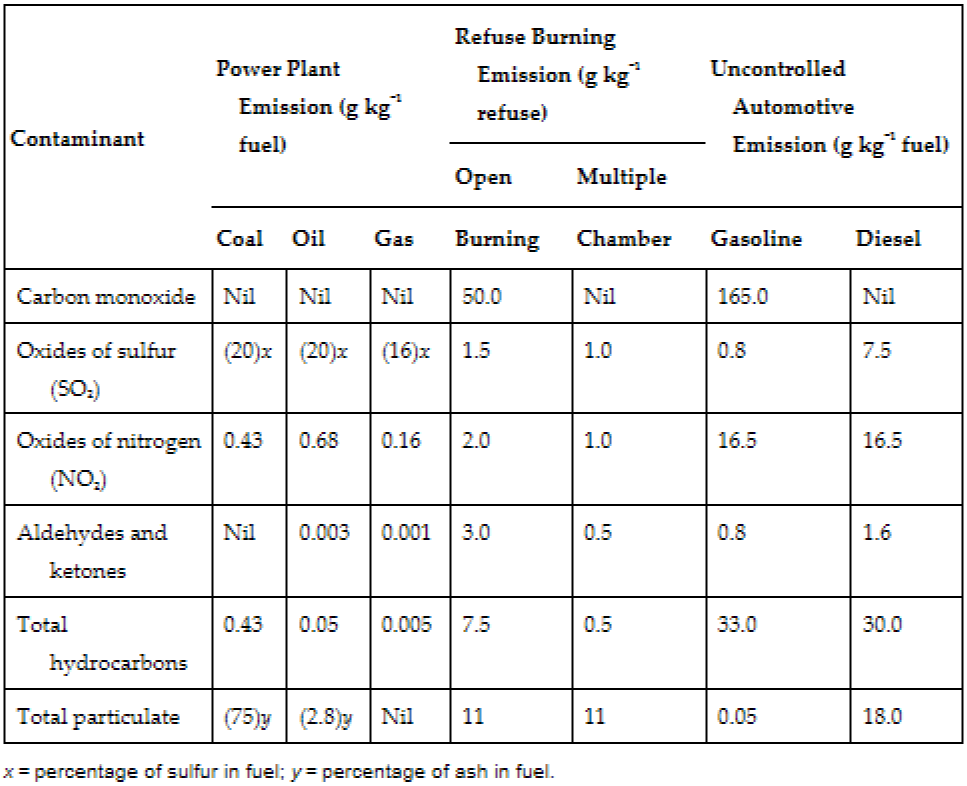
Table 20: Comparison between Wind and monoSi PV technology element breakdown (Thompson 2016)

Compared to wind power at 70 TWh, with a two fold increase in Iron needed, nearly 90 times the Aluminium needed, and almost twice the Copper, solar PV using monoSi technology looks like it may only be better in directly saving many thousands of bird deaths annually during operation, but this brief analysis does not account for mining related animal deaths and environmental toxicity. Notably monoSi saves space due to its relatively higher conversion efficiencies, and appears favourable in terms of supply of elements compared to CdTe and CIS solar PV technologies. Further development in organic and also graphene based solar PV technologies will reshape this category for the better, as it gets cheaper in material and energy costs to manufacture these products. See Appendix L for the "World Wind-only Energy Supply" in 'units' of wind farms and raw materials.

4.4 Health Impact Assessments

4.4.1 Point & Stationary Source Pollution

Both thermal power plants and automobiles produce a significant amount of air pollution, generally characterized in Figure 66 on the next page. Using coal, oil, gas and biomass in stationary plants, and gasoline and diesel all have negative impacts on human and animal cardiovascular health. Mentioned earlier was the topic of PM2.5 and PM10 when talking of particle sizes that human lungs have trouble with processing.



Contaminant	Power Plant Emission (g kg^{-1} fuel)			Refuse Burning Emission (g kg^{-1} refuse)		Uncontrolled Automotive Emission (g kg^{-1} fuel)	
	Coal	Oil	Gas	Open Burning	Multiple Chamber	Gasoline	Diesel
Carbon monoxide	Nil	Nil	Nil	50.0	Nil	165.0	Nil
Oxides of sulfur (SO_2)	(20)*x*	(20)*x*	(16)*x*	1.5	1.0	0.8	7.5
Oxides of nitrogen (NO_2)	0.43	0.68	0.16	2.0	1.0	16.5	16.5
Aldehydes and ketones	Nil	0.003	0.001	3.0	0.5	0.8	1.6
Total hydrocarbons	0.43	0.05	0.005	7.5	0.5	33.0	30.0
Total particulate	(75)*y*	(2.8)*y*	Nil	11	11	0.05	18.0

x = percentage of sulfur in fuel; *y* = percentage of ash in fuel.

Figure 66: Fundamentals of Air Pollution, page 1735 (Vallero, 2014)

If we use the example from chapter 3.1 with the number of vehicles in Nova Scotia assumed at 525,000 vehicles at 1580 Liters/annually, with the knowledge that there are 0.7826 kg/Liter of gasoline, and Nova Scotia's total use would be 650M kg/annually. Calculated from Figure 66 the average emission profile of the entire personal automobile sector would result in the values in Table 21. Both categories do not stack, to compare.

Assume 525,000 Gasoline	Uncontrolled Automotive Emission (tonnes fuel)	
Assume 525,000 Diesel	Gasoline	Diesel
CO	107114	Nil
SO2	519	5266
NO2	10711	11586
Aldehydes and Ketones	519	1123
Total Hydrocarbons	21423	21065
Total Particulates	32	12639
kg/L	0.7826087	0.8464912
kg	649173913	702164473

Table 21: Personal and Transportation Emissions in Nova Scotia (tonnes) (Thompson 2016)

Regarding Thermal Plants, with the data on Nova Scotia Power's website and the CanESS model GWh dataset, I computed a possible solution from a solution curve. See the following tables on Mercury, NOx, and SOx. The table regarding eCO2 may be found in Appendix K. It should be noted that information on biomass-thermal plant emissions was not published on Nova Scotia Power's website, I am certain a reasonable assumption could be used to estimate possible emissions, and perhaps matching with comparable biomass combustion plants around the world, and paired with typical woody material fuel stock as found in Nova Scotia. The three tables on the following pages show published data, from 2005-2014, and then I estimate the forecasted values based on scaling from eCO2 values and total system published data for these pollutants.

Year	Lingan	Point Aconi	Trenton	Point Tupper	Tufts Cove	CTs	Biomass
2004	0	0	0	0	0	0	0
2005	55	2.2	35	13	0	0	0
2006	86	2.5	49	23	0	0	0
2007	82	2.6	41	32	0	0	0
2008	95	2.9	41	24	0	0	0
2009	92	2.7	29	16	0	0	0
2010	50	2.8	19.4	9.5	0	0	0
2011	61	4.4	23	6	0	0	0
2012	53.2	3.6	25.4	11.8	0	0	0
2013	42	3.7	19	7	0	0	0
2014	37.78	1.88	17.14	8.2	0	X	X
2015	37.78	1.88	17.14	8.2	0	X	X
2016	37.78	1.88	17.14	8.2	0	X	X
2017	37.78	1.88	17.14	8.2	0	X	X
2018	37.78	1.88	17.14	8.2	0	X	X
2019	37.78	1.88	17.14	8.2	0	X	X
2020	20.34	1.01	9.23	4.41	0	X	X

Table 22: Mercury (Hg) emissions from NSP Thermal Power Plants (kg)

Year	Lingan	Point Aconi	Trenton	Point Tupper	Tufts Cove	CTs	Biomass
2004	0	0	0	0	0	0	0
2005	15.888	1.571	7.813	3.271	3.723	0	0
2006	12.814	1.426	8.885	3.635	1.277	0	0
2007	8.942	1.766	8.867	3.713	2.529	0	0
2008	6.097	1.857	7.695	3.208	2.524	0	0
2009	5.106	1.759	5.126	1.952	3.052	0.077	0
2010	5.219	1.747	5.577	1.952	3.689	0.047	0
2011	5.797	1.4	5.616	1.084	4.089	0.027	0
2012	4.852	1.745	4.427	1.742	2.867	0	0
2013	6.865	1.357	5.167	1.34	2.245	0	0
2014	7.61	1.72	6.58	2.37	3.09	X	X
2015	6.85	1.55	5.92	2.13	2.78	X	X
2016	6.85	1.55	5.92	2.13	2.78	X	X
2017	6.85	1.55	5.92	2.13	2.78	X	X
2018	6.85	1.55	5.92	2.13	2.78	X	X
2019	6.85	1.55	5.92	2.13	2.78	X	X
2020	5.33	1.2	4.6	1.66	2.16	X	X

Table 23: Nitrogen Oxides (NOx) emissions from NSP Thermal Power Plants (kT)

Year	Lingan	Point Aconi	Trenton	Point Tupper	Tufts Cove	CTs	Biomass
2004	0	0	0	0	0	0	0
2005	40.805	4.541	37.809	6.998	13.58	0	0
2006	46.33	4.445	36.675	15.576	3.59	0	0
2007	55.901	3.892	37.985	7.356	3.41	0	0
2008	58.122	3.564	36.4	7.238	2.148	0	0
2009	55.208	3.627	30.429	9.394	2.205	0.005	0
2010	33.479	3.365	19.257	5.721	0.079	0.003	0
2011	40.818	3.482	16.494	3.834	0.182	0.002	0
2012	37.636	3.448	18.28	6.871	0.025	0	0
2013	40.705	3.545	16.041	6.758	0.757	0	0.047
2014	38.43	3.25	22.37	6.42	2.04	X	X
2015	32.28	2.73	18.79	5.39	1.72	X	X
2016	32.28	2.73	18.79	5.39	1.72	X	X
2017	32.28	2.73	18.79	5.39	1.72	X	X
2018	32.28	2.73	18.79	5.39	1.72	X	X
2019	32.28	2.73	18.79	5.39	1.72	X	X
2020	19.21	1.62	11.18	3.21	1.02	X	X

Table 24: Sulphur Oxides (SOx) emissions from NSP Thermal Power Plants (kT)

It is important to consider the significant negative health effects of using fossil fuel combustion technologies. Mark Jacobson, as part of the Solutions Project (referred to in section 5.2.2) has calculated the costs on the economy and to quality of human health.

It can be seen from this introductory section on environmental and health impacts, that there is much scientific consensus on the decades old policy of health risk assessment, risk management and finally risk management evaluation. With this in mind I consider it wise to promote both electric and hydrogen vehicle technologies, along with more environmentally benign renewable primary energy in its myriad of forms.

4.4.3 Ambient Soil, Water and Air Quality

Last year (2015) in Nova Scotia we instituted a temporary ban on fracking for shale oil (a source of economically cheap natural gas) as the majority of people that live in the countryside in the province typically have dug or drilled drinking water wells. Sadly the more citizens desire clean air in urban environments the greater the likelihood that people will be willing to frack eventually when energy stocks become scarcer. Hopefully greener energy strategies will continue to be pursued with greater funding available for promising research and commercialization as progress marches on.

4.5 Original Contributions of Chapter 4

In summary in Chapter 4, my original contributions in this thesis were towards:

- Review of general assumptions for creating LCOE values,
- Brief summary of forecasted LCOEs,
- Definition of important power plant economic terminology,
- Thorough coverage of Triple Bottom Line approach with basic examples,
- A discussion on externalized costs and market failures using a simple example of food choices and our FoodPrint as it relates to GHG and philosophical underpinnings of Climate Change choices,
- Included a summary of future NSDOE market trends with brief risk assessment,
- Created a succinct summary of the pollution tax from the NS Finance Department and what to expect of economic success and revenues,
- Provided a quick synopsis of operational risks such as fire, hurricane, explosive hazards and standards to mitigate such risks in the context of high reliability organizations,
- An important section assessing the EIAs in the province in terms of radar reflections, infra-sound and siting, animal kills per turbine, resource extraction in terms of material intensity and world supply of elements as it relates to wind turbine and solar PV manufacture,
- Calculated how many tonnes of materials would be required to power NS primary energy supply in the simplified all wind, or all solar PV example,
- Tallied an example emission potential of all personal and transport vehicles in NS and separately computed the standard thermal plant emissions.

Chapter 5: Energy Distribution and Use: Modeling and Mapping

5.0 Introduction

The EnergyPLAN (created by Aalborg University) software is an essential component as it complements the visual data from the NSEM and progresses the goal of improving energy system awareness. The map provides spatial awareness, while EnergyPLAN provides a thorough technical overview of how the power supply, transportation and heating sectors shape our current and forecasted energy demands. EnergyPLAN creates an economic picture of what it may look like to decarbonize our primary energy. Chapter 5 poses the question how much does it cost to decarbonize our economy?

5.1 EnergyPLAN: Nova Scotia Case Study

5.1.1 EnergyPLAN: Deterministic National Energy System Tool

In this section I discuss using the EnergyPLAN software model with the Nova Scotia energy data of the 2010 reference year. Then with the working reference year, create and compare a snapshot of the 2030 forecasted year with the continuation of the near 100% wind energy example. The reference year works as a secondary validation of the earlier provincial fuel cost example from Chapter 3. The 2030 forecasted year includes a range of estimates of what annual investment costs we would have as a province and how much we would either owe or earn depending on several variables that I will explain shortly. The following quote is an excerpt from the textbook Renewable Energy Systems by - H. Lund, which is written about the EnergyPLAN software:

> "EnergyPLAN automates and simplifies the calculations supporting a detailed comparative analysis of regional energy systems' abilities to integrate fluctuating and intermittent renewable energy sources."

Conceptually we see how complex the interconnections in an energy system are, even from a generalized high-level overview diagram, such as the figure below.

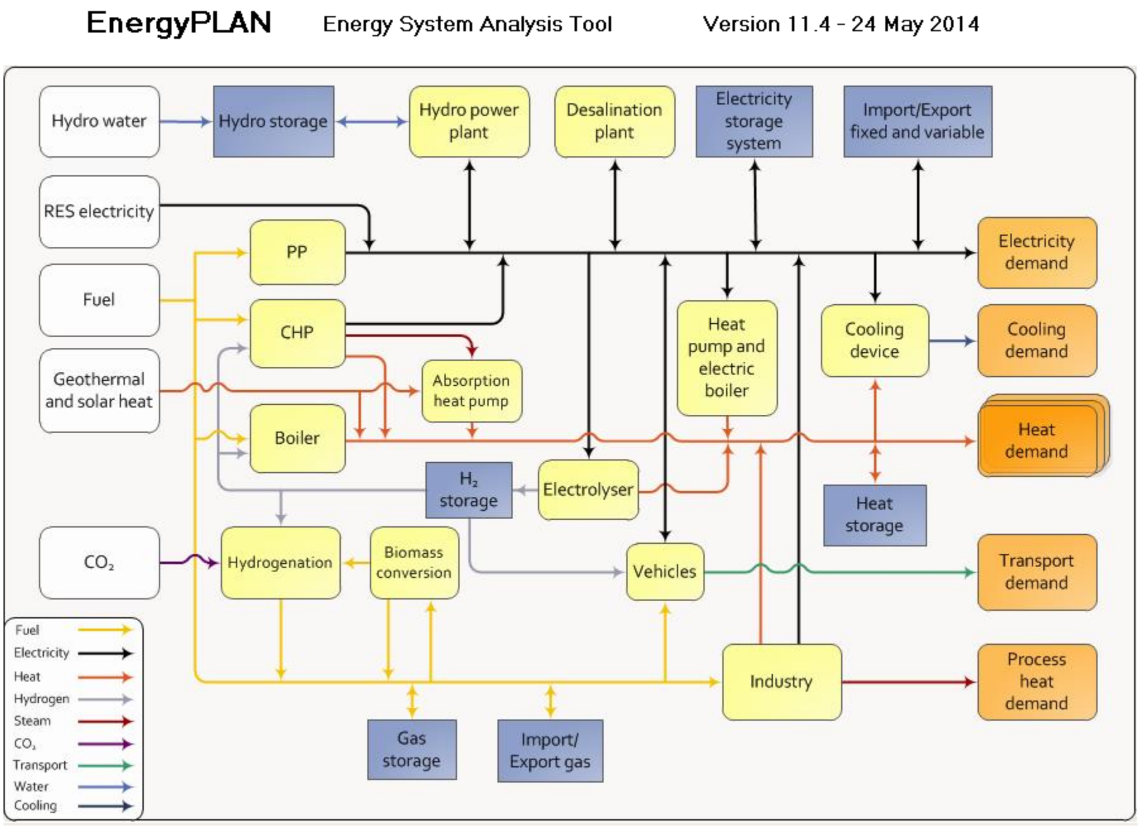


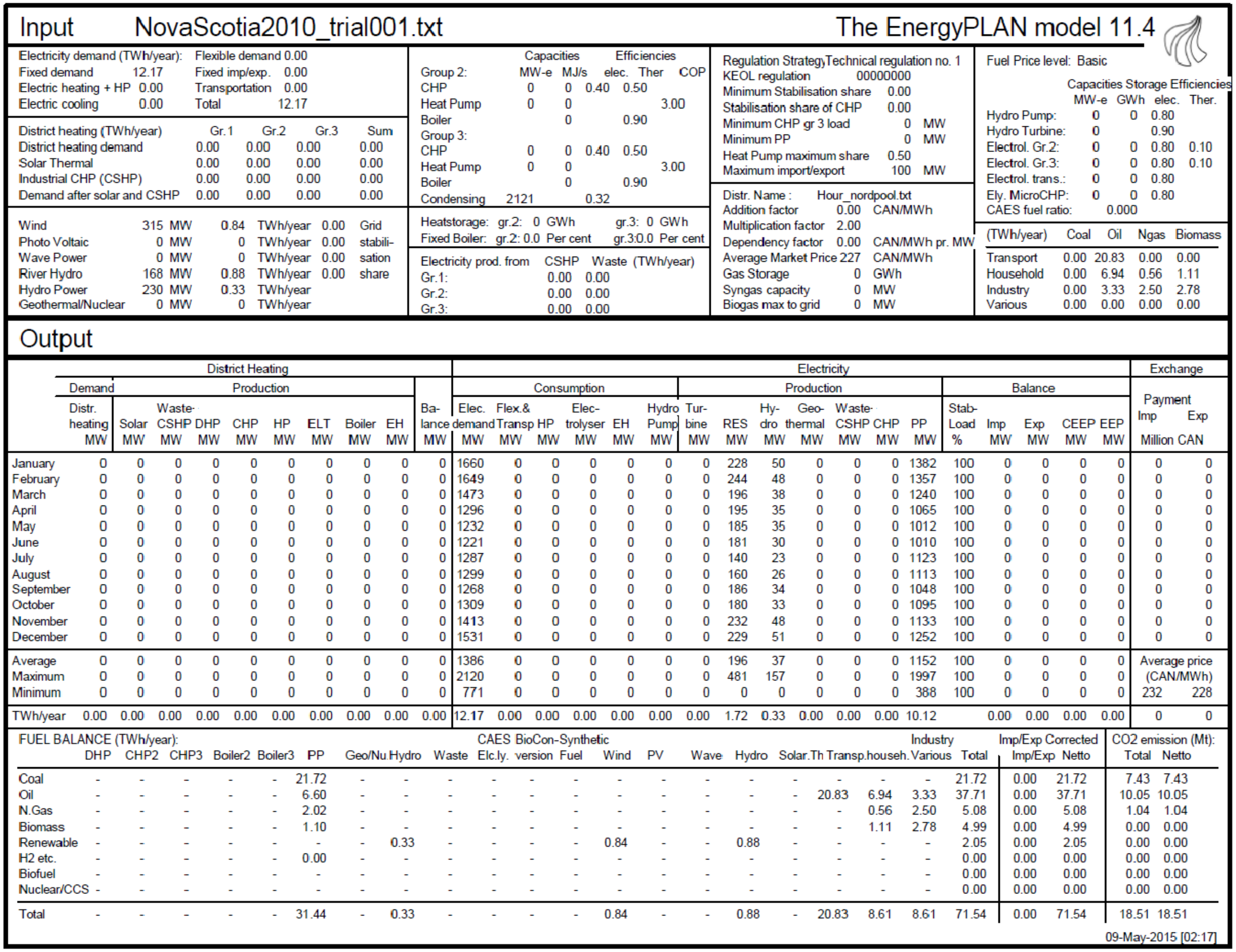
Figure 67: Front page of EnergyPLAN GUI which describes general energy flows

Figure 68 and Figure 69 cover the reference year 2010 with inputs and outputs which describe in detail the current power plant production and energy consumption in various parts of the total primary energy economy in Nova Scotia. Utilizing our estimated average fuel prices and energy consumption values from the first example in Chapter 3, along with the annual hourly system demand from Nova Scotia Power’s OASIS platform, we arrive at our economic conclusion. As mentioned the EnergyPLAN model functions as our secondary method to verify if the original example’s calculations are valid. With that in mind the economic output is very similar at an Annual Fuel Cost of $5.552 B.

The 2010 reference year uses an oil energy input of 20.83TWh for transportation, 6.6TWh for power plants, 6.94TWh for household heating, and 3.33TWh for industry, all from the CanESS model. The other inputs for natural gas and biomass can be seen in both the upper left of the image and in the bottom center on the next page.

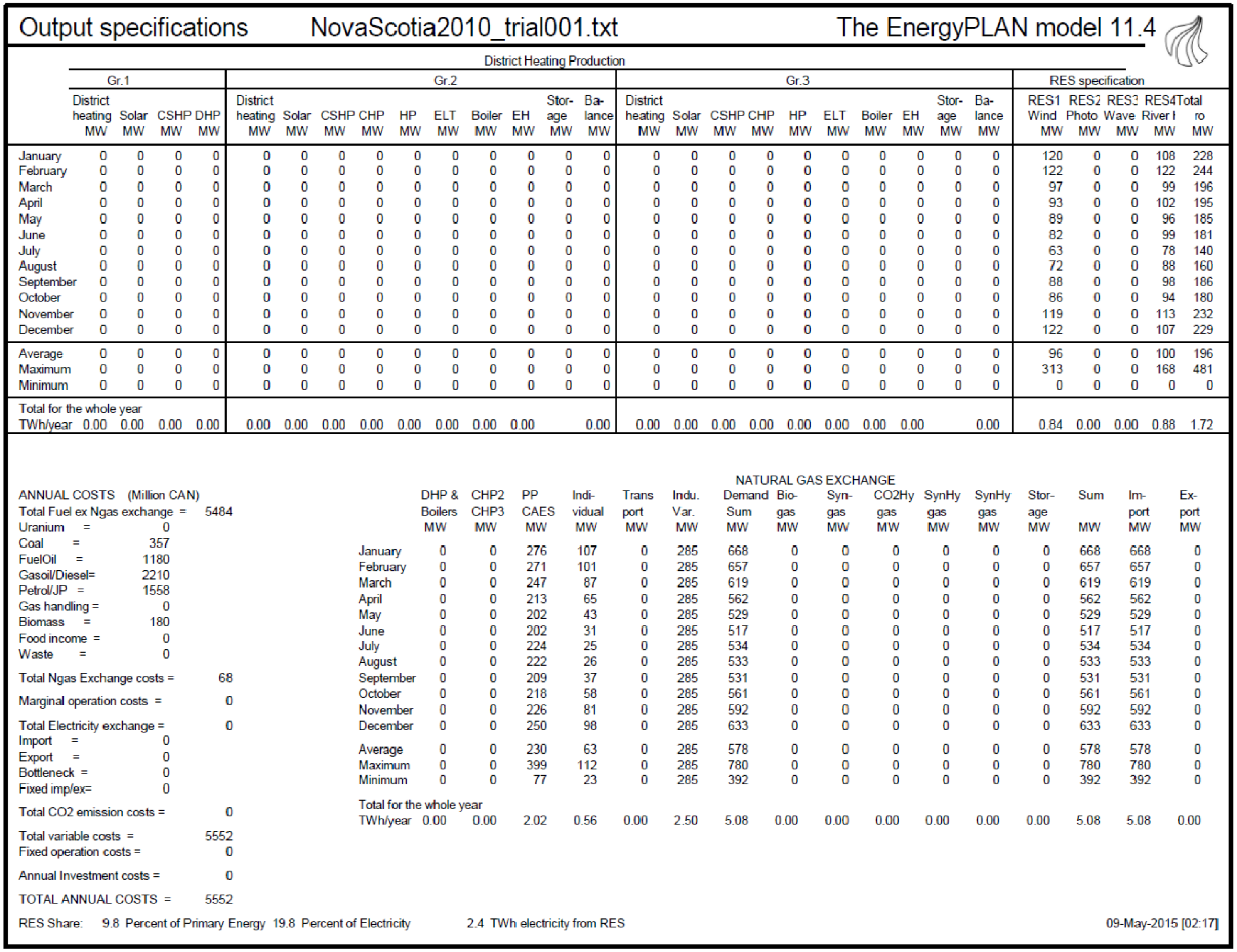
Coal is estimated at 21.72TWh for power plants also from the CanESS model. In total the model estimates a provincial GHG annual emission of 18.51 MT eCO2; which fits closely with a value from the 2005 year in the DOEnv report on provincial emissions.

EnergyPLAN is a deterministic software model, and computes the scenario quickly based on primary energy inputs, and hourly power grid demand profiles. To run a successful model, it requires knowing both the MW and annual GWh for all energy in a region. Entering fuel costs and assumptions will compute the same value each time the model is run. Running the model indicated I originally used the heat rate for coal in the manual calculations in Chapter 3, which lead to a significant overestimate of the fuel cost of coal in NS. The use of a second method to validate the hand calculated scenario proved to be helpful.



```
Input      NovaScotia2010_trial001.txt                                              The EnergyPLAN model 11.4

Electricity demand (TWh/year):  Flexible demand 0.00
Fixed demand          12.17     Fixed imp/exp.   0.00
Electric heating + HP  0.00     Transportation   0.00
Electric cooling       0.00     Total           12.17

District heating (TWh/year)     Gr.1   Gr.2   Gr.3    Sum
District heating demand         0.00   0.00   0.00   0.00
Solar Thermal                   0.00   0.00   0.00   0.00
Industrial CHP (CSHP)           0.00   0.00   0.00   0.00
Demand after solar and CSHP     0.00   0.00   0.00   0.00

Wind               315 MW   0.84  TWh/year  0.00  Grid
Photo Voltaic        0 MW      0  TWh/year  0.00  stabili-
Wave Power           0 MW      0  TWh/year  0.00  sation
River Hydro        168 MW   0.88  TWh/year  0.00  share
Hydro Power        230 MW   0.33  TWh/year
Geothermal/Nuclear   0 MW      0  TWh/year

                  Capacities     Efficiencies
Group 2:          MW-e  MJ/s   elec.  Ther   COP
CHP                  0     0   0.40   0.50
Heat Pump            0     0                 3.00
Boiler                     0          0.90
Group 3:
CHP                  0     0   0.40   0.50
Heat Pump            0     0                 3.00
Boiler                     0          0.90
Condensing        2121         0.32

Heatstorage:   gr.2:  0  GWh         gr.3:  0  GWh
Fixed Boiler:  gr.2: 0.0  Per cent   gr.3:0.0  Per cent

Electricity prod. from    CSHP   Waste  (TWh/year)
Gr.1:                     0.00   0.00
Gr.2:                     0.00   0.00
Gr.3:                     0.00   0.00

Regulation StrategyTechnical regulation no. 1
KEOL regulation              00000000
Minimum Stabilisation share      0.00
Stabilisation share of CHP       0.00
Minimum CHP gr 3 load               0   MW
Minimum PP                          0   MW
Heat Pump maximum share          0.50
Maximum import/export             100   MW

Distr. Name :        Hour_nordpool.txt
Addition factor         0.00  CAN/MWh
Multiplication factor   2.00
Dependency factor       0.00  CAN/MWh pr. MW
Average Market Price  227     CAN/MWh
Gas Storage             0     GWh
Syngas capacity         0     MW
Biogas max to grid      0     MW

Fuel Price level:  Basic

                    Capacities Storage Efficiencies
                    MW-e   GWh   elec.  Ther.
Hydro Pump:           0      0   0.80
Hydro Turbine:        0          0.90
Electrol. Gr.2:       0      0   0.80   0.10
Electrol. Gr.3:       0      0   0.80   0.10
Electrol. trans.:     0      0   0.80
Ely. MicroCHP:        0      0   0.80
CAES fuel ratio:         0.000

(TWh/year)     Coal    Oil    Ngas  Biomass
Transport      0.00  20.83    0.00    0.00
Household      0.00   6.94    0.56    1.11
Industry       0.00   3.33    2.50    2.78
Various        0.00   0.00    0.00    0.00

Output

                              District Heating                            |                                   Electricity                                                            | Exchange
          Demand |                    Production                    |     |             Consumption            |              Production                    |          Balance         |
          Distr.         Waste-                                      Ba-   Elec.  Flex.&       Elec-      Hydro  Tur-        Hy-   Geo-   Waste-             Stab-                          Payment
         heating Solar  CSHP  DHP   CHP   HP   ELT  Boiler  EH      lance demand Transp HP  trolyser EH  Pump   bine  RES  dro  thermal CSHP  CHP   PP    Load  Imp  Exp  CEEP  EEP     Imp     Exp
            MW    MW    MW    MW    MW    MW    MW    MW    MW      MW    MW     MW    MW    MW    MW    MW    MW    MW   MW    MW     MW    MW    MW     %    MW   MW    MW    MW    Million CAN

January      0     0     0     0     0     0     0     0     0       0  1660     0     0     0     0     0     0   228   50     0      0     0  1382   100    0    0     0     0       0       0
February     0     0     0     0     0     0     0     0     0       0  1649     0     0     0     0     0     0   244   48     0      0     0  1357   100    0    0     0     0       0       0
March        0     0     0     0     0     0     0     0     0       0  1473     0     0     0     0     0     0   196   38     0      0     0  1240   100    0    0     0     0       0       0
April        0     0     0     0     0     0     0     0     0       0  1296     0     0     0     0     0     0   195   35     0      0     0  1065   100    0    0     0     0       0       0
May          0     0     0     0     0     0     0     0     0       0  1232     0     0     0     0     0     0   185   35     0      0     0  1012   100    0    0     0     0       0       0
June         0     0     0     0     0     0     0     0     0       0  1221     0     0     0     0     0     0   181   30     0      0     0  1010   100    0    0     0     0       0       0
July         0     0     0     0     0     0     0     0     0       0  1287     0     0     0     0     0     0   140   23     0      0     0  1123   100    0    0     0     0       0       0
August       0     0     0     0     0     0     0     0     0       0  1299     0     0     0     0     0     0   160   26     0      0     0  1113   100    0    0     0     0       0       0
September    0     0     0     0     0     0     0     0     0       0  1268     0     0     0     0     0     0   186   34     0      0     0  1048   100    0    0     0     0       0       0
October      0     0     0     0     0     0     0     0     0       0  1309     0     0     0     0     0     0   180   33     0      0     0  1095   100    0    0     0     0       0       0
November     0     0     0     0     0     0     0     0     0       0  1413     0     0     0     0     0     0   232   48     0      0     0  1133   100    0    0     0     0       0       0
December     0     0     0     0     0     0     0     0     0       0  1531     0     0     0     0     0     0   229   51     0      0     0  1252   100    0    0     0     0       0       0

Average      0     0     0     0     0     0     0     0     0       0  1386     0     0     0     0     0     0   196   37     0      0     0  1152   100    0    0     0     0     Average price
Maximum      0     0     0     0     0     0     0     0     0       0  2120     0     0     0     0     0     0   481  157     0      0     0  1997   100    0    0     0     0      (CAN/MWh)
Minimum      0     0     0     0     0     0     0     0     0       0   771     0     0     0     0     0     0     0    0     0      0     0   388   100    0    0     0     0     232     228

TWh/year  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00    0.00 12.17  0.00  0.00  0.00  0.00  0.00  0.00  1.72 0.33  0.00   0.00  0.00 10.12        0.00 0.00  0.00  0.00       0       0

FUEL BALANCE (TWh/year):                                     CAES BioCon-Synthetic                                                     Industry        | Imp/Exp Corrected | CO2 emission (Mt):
           DHP  CHP2  CHP3  Boiler2 Boiler3   PP   Geo/Nu.Hydro Waste Elc.ly. version Fuel  Wind   PV   Wave Hydro Solar.Th Transp.househ. Various  Total |  Imp/Exp  Netto   |  Total  Netto

Coal        -     -     -      -       -    21.72     -     -     -     -      -      -     -     -     -     -      -       -      -      -     21.72  |   0.00    21.72   |   7.43   7.43
Oil         -     -     -      -       -     6.60     -     -     -     -      -      -     -     -     -     -      -     20.83   6.94   3.33   37.71  |   0.00    37.71   |  10.05  10.05
N.Gas       -     -     -      -       -     2.02     -     -     -     -      -      -     -     -     -     -      -       -     0.56   2.50    5.08  |   0.00     5.08   |   1.04   1.04
Biomass     -     -     -      -       -     1.10     -     -     -     -      -      -     -     -     -     -      -       -     1.11   2.78    4.99  |   0.00     4.99   |   0.00   0.00
Renewable   -     -     -      -       -      -       -   0.33    -     -      -      -   0.84    -     -   0.88     -       -      -      -      2.05  |   0.00     2.05   |   0.00   0.00
H2 etc.     -     -     -      -       -     0.00     -     -     -     -      -      -     -     -     -     -      -       -      -      -      0.00  |   0.00     0.00   |   0.00   0.00
Biofuel     -     -     -      -       -      -       -     -     -     -      -      -     -     -     -     -      -       -      -      -      0.00  |   0.00     0.00   |   0.00   0.00
Nuclear/CCS -     -     -      -       -      -       -     -     -     -      -      -     -     -     -     -      -       -      -      -      0.00  |   0.00     0.00   |   0.00   0.00

Total       -     -     -      -       -    31.44     -   0.33    -     -      -      -   0.84    -     -   0.88     -     20.83   8.61   8.61   71.54  |   0.00    71.54   |  18.51  18.51

                                                                                                                                                         09-May-2015 [02:17]
```

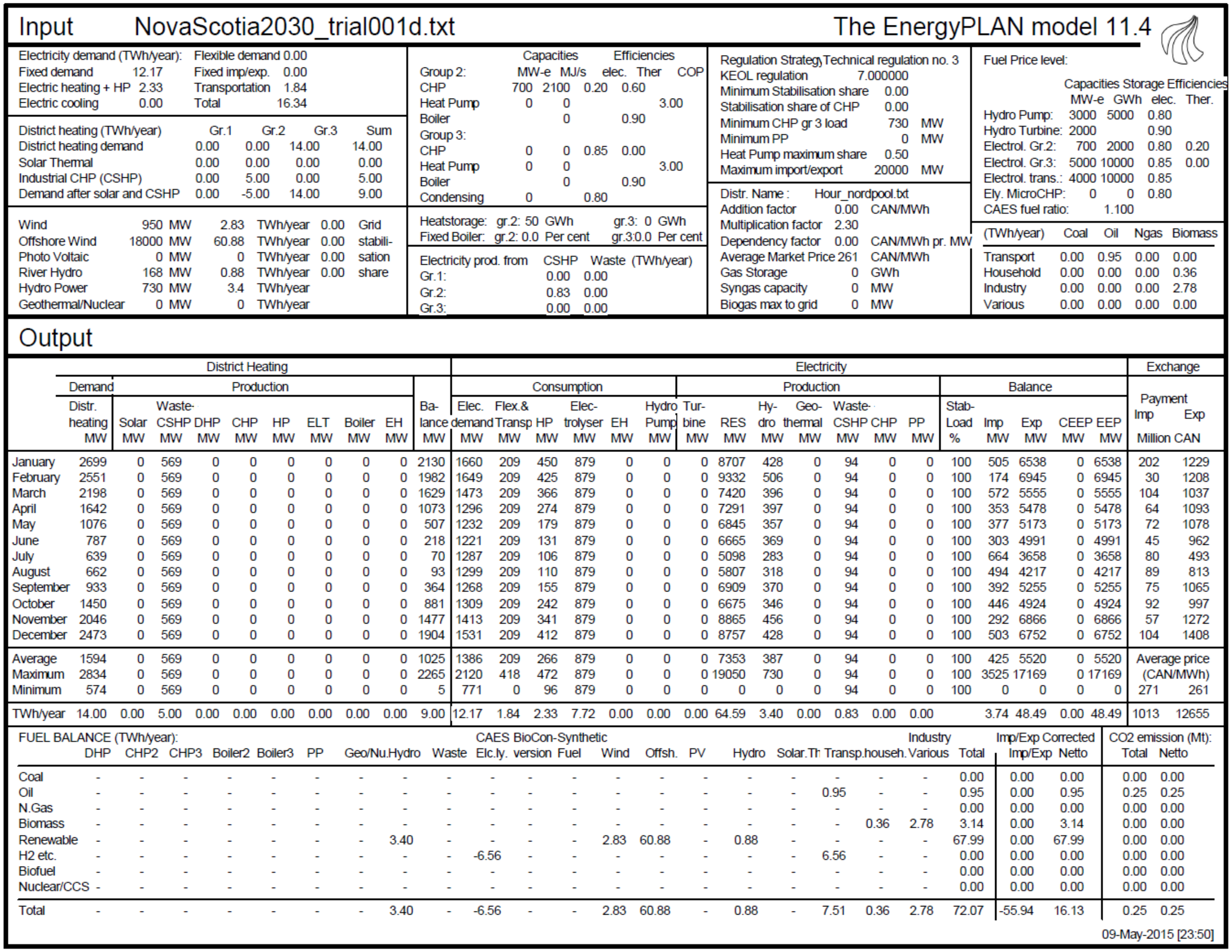
Figure 68: 2010 Reference Year – Nova Scotia with 315MW Onshore Wind A



```
Output specifications        NovaScotia2010_trial001.txt               The EnergyPLAN model 11.4

                                                     District Heating Production
                     Gr.1           |                              Gr.2                              |                              Gr.3                              |          RES specification
          District                  |District                                                 Stor-    Ba-|District                                                 Stor-    Ba-|   RES1   RES2   RES3   RES4Total
          heating  Solar   CSHP    DHP|heating  Solar   CSHP    CHP     HP    ELT Boiler     EH    age  lance|heating  Solar   CSHP    CHP     HP    ELT Boiler     EH    age  lance|   Wind  Photo   Wave River I     ro
               MW     MW     MW     MW|     MW     MW     MW     MW     MW     MW     MW     MW     MW     MW|     MW     MW     MW     MW     MW     MW     MW     MW     MW     MW|     MW     MW     MW     MW     MW

January         0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|    120      0      0    108    228
February        0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|    122      0      0    122    244
March           0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     97      0      0     99    196
April           0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     93      0      0    102    195
May             0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     89      0      0     96    185
June            0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     82      0      0     99    181
July            0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     63      0      0     78    140
August          0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     72      0      0     88    160
September       0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     88      0      0     98    186
October         0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     86      0      0     94    180
November        0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|    119      0      0    113    232
December        0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|    122      0      0    107    229

Average         0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|     96      0      0    100    196
Maximum         0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|    313      0      0    168    481
Minimum         0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0      0      0      0      0      0|      0      0      0      0      0

Total for the whole year            |                                                                      |                                                                      |
TWh/year     0.00   0.00   0.00   0.00|   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00          0.00|   0.00   0.00   0.00   0.00   0.00   0.00   0.00   0.00          0.00|   0.84   0.00   0.00   0.88   1.72


ANNUAL COSTS   (Million CAN)
Total Fuel ex Ngas exchange =   5484
Uranium   =           0
Coal      =         357
FuelOil   =        1180
Gasoil/Diesel=     2210
Petrol/JP  =       1558
Gas handling =        0
Biomass   =         180
Food income =         0
Waste     =           0

Total Ngas Exchange costs =       68

Marginal operation costs  =        0

Total Electricity exchange =       0
Import    =           0
Export    =           0
Bottleneck =          0
Fixed imp/ex=         0

Total CO2 emission costs =         0

Total variable costs  =         5552
Fixed operation costs =            0

Annual Investment costs =          0

TOTAL ANNUAL COSTS  =           5552


                                                         NATURAL GAS EXCHANGE
            DHP &   CHP2     PP  Indi-  Trans  Indu. Demand   Bio-   Syn-  CO2Hy  SynHy  SynHy  Stor-    Sum    Im-    Ex-
          Boilers   CHP3   CAES vidual   port   Var.    Sum    gas    gas    gas    gas    gas    age           port   port
               MW     MW     MW     MW     MW     MW     MW     MW     MW     MW     MW     MW     MW     MW     MW     MW

January         0      0    276    107      0    285    668      0      0      0      0      0      0    668    668      0
February        0      0    271    101      0    285    657      0      0      0      0      0      0    657    657      0
March           0      0    247     87      0    285    619      0      0      0      0      0      0    619    619      0
April           0      0    213     65      0    285    562      0      0      0      0      0      0    562    562      0
May             0      0    202     43      0    285    529      0      0      0      0      0      0    529    529      0
June            0      0    202     31      0    285    517      0      0      0      0      0      0    517    517      0
July            0      0    224     25      0    285    534      0      0      0      0      0      0    534    534      0
August          0      0    222     26      0    285    533      0      0      0      0      0      0    533    533      0
September       0      0    209     37      0    285    531      0      0      0      0      0      0    531    531      0
October         0      0    218     58      0    285    561      0      0      0      0      0      0    561    561      0
November        0      0    226     81      0    285    592      0      0      0      0      0      0    592    592      0
December        0      0    250     98      0    285    633      0      0      0      0      0      0    633    633      0

Average         0      0    230     63      0    285    578      0      0      0      0      0      0    578    578      0
Maximum         0      0    399    112      0    285    780      0      0      0      0      0      0    780    780      0
Minimum         0      0     77     23      0    285    392      0      0      0      0      0      0    392    392      0

Total for the whole year
TWh/year     0.00   0.00   2.02   0.56   0.00   2.50   5.08   0.00   0.00   0.00   0.00   0.00   0.00   5.08   5.08   0.00

RES Share:   9.8  Percent of Primary Energy  19.8  Percent of Electricity        2.4  TWh electricity from RES                    09-May-2015 [02:17]
```

Figure 69: 2010 Reference Year – Nova Scotia with 315MW Onshore Wind B

Figure 70 and 71 are on following two pages with the inputs and outputs figures which describe in detail the forecasted year of 2030 power plant production and energy consumption in various parts of the energy economy. The most important part of this process is as a validation for the near 100% wind primary energy scenario. Here we use the estimate of 950MW onshore wind, 18000MW offshore wind, and Muskrat Falls at 500MW; these are the only renewable energy additions relative to the 2010 reference year. The next major change is the complete transformation of the personal and freight transportation sectors, with 262K Electric vehicles, and 262K FCEVs for personal transport – with 525K FCEVs in the freight transport category. One defining feature is the 20000MW import/export HVDC transmission line to the US states south of our border as this will be a large market which we can sell this excess electricity, as long as we have a level of firm supply available. This particular trial run, demonstrates that we can make an estimated annual profit of near $850 Million, but this depends heavily on construction costs of offshore wind, and using technologies such as large electrolysers to produce the Hydrogen fuel for the transport sectors. Overall, using four trial runs, the total annual costs fluctuated from earning $850 Million, to costing $4 Billion, notably this figure improves with more installed wind as we can sell it to adjacent markets and reduce fuel cost imports. This case fits with the Renewable Energy System (Lund 2014) textbook theory on finding optimization points; note that I do not consider this an optimization point, or the maximum achievable net gain or loss of income, only as a case study of utilizing offshore wind resources as long as done appropriately to meet environmental and social standards. Please refer to section 3.1.1 for discussion of TPES options; the energy sankey would be smaller if we chose more BEVs or heat pumps.



Input NovaScotia2030_trial001d.txt

The EnergyPLAN model 11.4

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	12.17	Fixed imp/exp.	0.00
Electric heating + HP	2.33	Transportation	1.84
Electric cooling	0.00	Total	16.34

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	14.00	14.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	5.00	0.00	5.00
Demand after solar and CSHP	0.00	-5.00	14.00	9.00

Wind	950	MW	2.83	TWh/year	0.00	Grid
Offshore Wind	18000	MW	60.88	TWh/year	0.00	stabili-
Photo Voltaic	0	MW	0	TWh/year	0.00	sation
River Hydro	168	MW	0.88	TWh/year	0.00	share
Hydro Power	730	MW	3.4	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	700	2100	0.20	0.60	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.85	0.00	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	0		0.80		

Heatstorage: gr.2: 50 GWh gr.3: 0 GWh
Fixed Boiler: gr.2: 0.0 Per cent gr.3:0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.83	0.00
Gr.3:	0.00	0.00

Regulation Strategy	Technical regulation no. 3	
KEOL regulation	7.000000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	730	MW
Minimum PP	0	MW
Heat Pump maximum share	0.50	
Maximum import/export	20000	MW

Distr. Name :	Hour_nordpool.txt	
Addition factor	0.00	CAN/MWh
Multiplication factor	2.30	
Dependency factor	0.00	CAN/MWh pr. MW
Average Market Price	261	CAN/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level:

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	3000	5000	0.80	
Hydro Turbine:	2000		0.90	
Electrol. Gr.2:	700	2000	0.80	0.20
Electrol. Gr.3:	5000	10000	0.85	0.00
Electrol. trans.:	4000	10000	0.85	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:		1.100		

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	0.95	0.00	0.00
Household	0.00	0.00	0.00	0.36
Industry	0.00	0.00	0.00	2.78
Various	0.00	0.00	0.00	0.00

Output

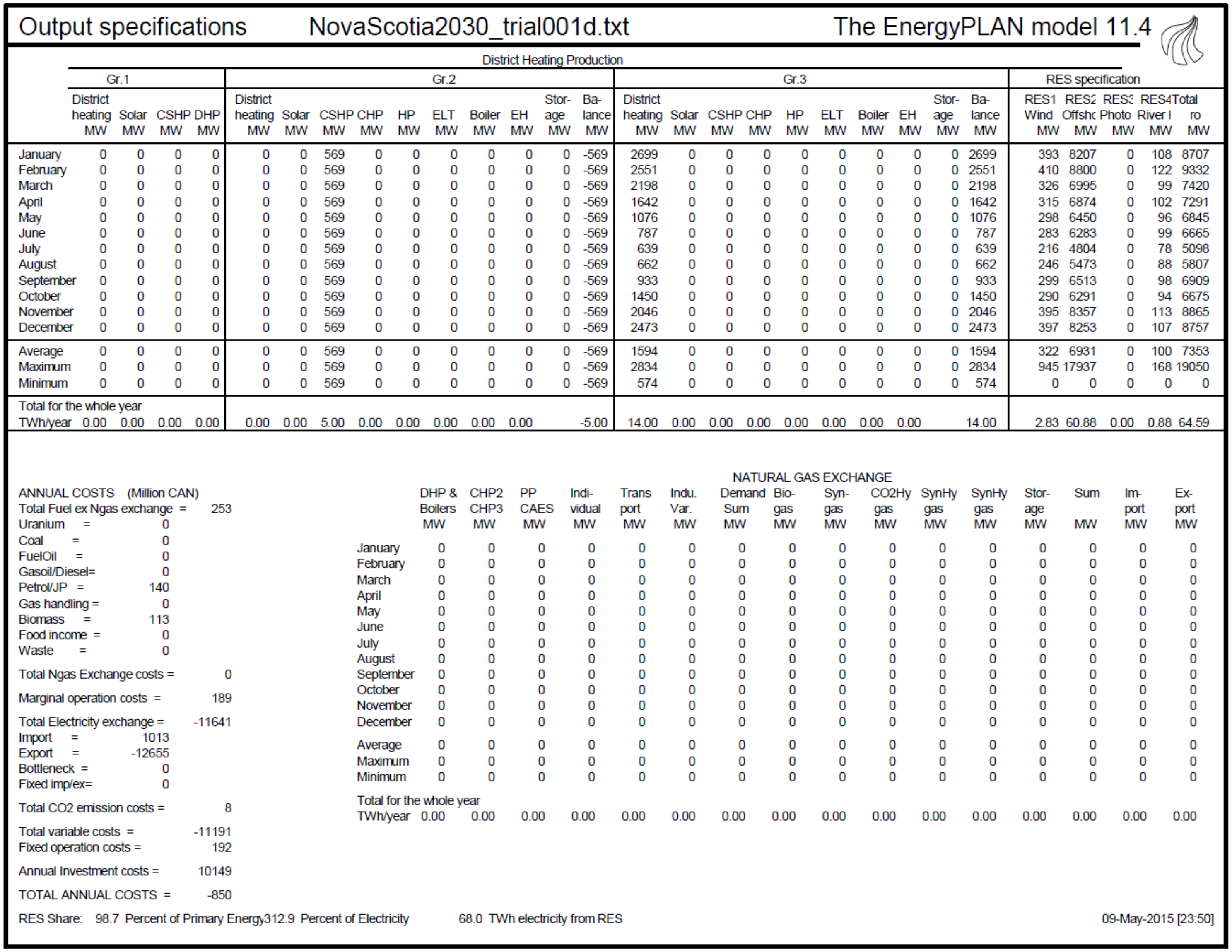
	District Heating										Electricity																		Exchange	
	Demand	Production									Consumption						Production							Balance						
	Distr. heating	Solar	Waste-CSHP	DHP	CHP	HP	ELT	Boiler	EH	Ba-lance	Elec. demand	Flex.& Transp	HP	Elec-trolyser	EH	Hydro Pump	Tur-bine	RES	Hy-dro	Geo-thermal	Waste-CSHP	CHP	PP	Stab-Load	Imp	Exp	CEEP	EEP	Payment Imp	Exp
	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	MW	%	MW	MW	MW	MW	Million CAN	
January	2699	0	569	0	0	0	0	0	0	2130	1660	209	450	879	0	0	0	8707	428	0	94	0	0	100	505	6538	0	6538	202	1229
February	2551	0	569	0	0	0	0	0	0	1982	1649	209	425	879	0	0	0	9332	506	0	94	0	0	100	174	6945	0	6945	30	1208
March	2198	0	569	0	0	0	0	0	0	1629	1473	209	366	879	0	0	0	7420	396	0	94	0	0	100	572	5555	0	5555	104	1037
April	1642	0	569	0	0	0	0	0	0	1073	1296	209	274	879	0	0	0	7291	397	0	94	0	0	100	353	5478	0	5478	64	1093
May	1076	0	569	0	0	0	0	0	0	507	1232	209	179	879	0	0	0	6845	357	0	94	0	0	100	377	5173	0	5173	72	1078
June	787	0	569	0	0	0	0	0	0	218	1221	209	131	879	0	0	0	6665	369	0	94	0	0	100	303	4991	0	4991	45	962
July	639	0	569	0	0	0	0	0	0	70	1287	209	106	879	0	0	0	5098	283	0	94	0	0	100	664	3658	0	3658	80	493
August	662	0	569	0	0	0	0	0	0	93	1299	209	110	879	0	0	0	5807	318	0	94	0	0	100	494	4217	0	4217	89	813
September	933	0	569	0	0	0	0	0	0	364	1268	209	155	879	0	0	0	6909	370	0	94	0	0	100	392	5255	0	5255	75	1065
October	1450	0	569	0	0	0	0	0	0	881	1309	209	242	879	0	0	0	6675	346	0	94	0	0	100	446	4924	0	4924	92	997
November	2046	0	569	0	0	0	0	0	0	1477	1413	209	341	879	0	0	0	8865	456	0	94	0	0	100	292	6866	0	6866	57	1272
December	2473	0	569	0	0	0	0	0	0	1904	1531	209	412	879	0	0	0	8757	428	0	94	0	0	100	503	6752	0	6752	104	1408
Average	1594	0	569	0	0	0	0	0	0	1025	1386	209	266	879	0	0	0	7353	387	0	94	0	0	100	425	5520	0	5520	Average price	
Maximum	2834	0	569	0	0	0	0	0	0	2265	2120	418	472	879	0	0	0	19050	730	0	94	0	0	100	3525	17169	0	17169	(CAN/MWh)	
Minimum	574	0	569	0	0	0	0	0	0	5	771	0	96	879	0	0	0	0	0	0	94	0	0	100	0	0	0	0	271	261
TWh/year	14.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	9.00	12.17	1.84	2.33	7.72	0.00	0.00	0.00	64.59	3.40	0.00	0.83	0.00	0.00		3.74	48.49	0.00	48.49	1013	12655

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Synthetic Fuel	Wind	Offsh.	PV	Hydro	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt): Total	Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.95	-	-	0.95	0.00	0.95	0.25	0.25
N.Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.36	2.78	3.14	0.00	3.14	0.00	0.00
Renewable	-	-	-	-	-	-	-	3.40	-	-	-	-	2.83	60.88	-	0.88	-	-	-	-	67.99	0.00	67.99	0.00	0.00
H2 etc.	-	-	-	-	-	-	-	-	-	-6.56	-	-	-	-	-	-	-	6.56	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	-	-	3.40	-	-6.56	-	-	2.83	60.88	-	0.88	-	7.51	0.36	2.78	72.07	-55.94	16.13	0.25	0.25

09-May-2015 [23:50]

Figure 70: 2030 Forecasted Year – Nova Scotia with 18000MW Offshore Wind A



Output specifications NovaScotia2030_trial001d.txt The EnergyPLAN model 11.4

District Heating Production

	Gr.1 District heating MW	Gr.1 Solar MW	Gr.1 CSHP MW	Gr.1 DHP MW	Gr.2 District heating MW	Gr.2 Solar MW	Gr.2 CSHP MW	Gr.2 CHP MW	Gr.2 HP MW	Gr.2 ELT MW	Gr.2 Boiler MW	Gr.2 EH MW	Gr.2 Stor-age MW	Gr.2 Ba-lance MW	Gr.3 District heating MW	Gr.3 Solar MW	Gr.3 CSHP MW	Gr.3 CHP MW	Gr.3 HP MW	Gr.3 ELT MW	Gr.3 Boiler MW	Gr.3 EH MW	Gr.3 Stor-age MW	Gr.3 Ba-lance MW	RES specification RES1 Wind MW	RES2 Offshc MW	RES3 Photo MW	RES4 River I MW	Total ro MW
January	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	2699	0	0	0	0	0	0	0	0	2699	393	8207	0	108	8707
February	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	2551	0	0	0	0	0	0	0	0	2551	410	8800	0	122	9332
March	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	2198	0	0	0	0	0	0	0	0	2198	326	6995	0	99	7420
April	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	1642	0	0	0	0	0	0	0	0	1642	315	6874	0	102	7291
May	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	1076	0	0	0	0	0	0	0	0	1076	298	6450	0	96	6845
June	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	787	0	0	0	0	0	0	0	0	787	283	6283	0	99	6665
July	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	639	0	0	0	0	0	0	0	0	639	216	4804	0	78	5098
August	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	662	0	0	0	0	0	0	0	0	662	246	5473	0	88	5807
September	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	933	0	0	0	0	0	0	0	0	933	299	6513	0	98	6909
October	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	1450	0	0	0	0	0	0	0	0	1450	290	6291	0	94	6675
November	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	2046	0	0	0	0	0	0	0	0	2046	395	8357	0	113	8865
December	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	2473	0	0	0	0	0	0	0	0	2473	397	8253	0	107	8757
Average	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	1594	0	0	0	0	0	0	0	0	1594	322	6931	0	100	7353
Maximum	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	2834	0	0	0	0	0	0	0	0	2834	945	17937	0	168	19050
Minimum	0	0	0	0	0	0	569	0	0	0	0	0	0	-569	574	0	0	0	0	0	0	0	0	574	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00		-5.00	14.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		14.00	2.83	60.88	0.00	0.88	64.59

ANNUAL COSTS (Million CAN)
Total Fuel ex Ngas exchange = 253
Uranium = 0
Coal = 0
FuelOil = 0
Gasoil/Diesel= 0
Petrol/JP = 140
Gas handling = 0
Biomass = 113
Food income = 0
Waste = 0

Total Ngas Exchange costs = 0

Marginal operation costs = 189

Total Electricity exchange = -11641
Import = 1013
Export = -12655
Bottleneck = 0
Fixed imp/ex= 0

Total CO2 emission costs = 8

Total variable costs = -11191
Fixed operation costs = 192

Annual Investment costs = 10149

TOTAL ANNUAL COSTS = -850

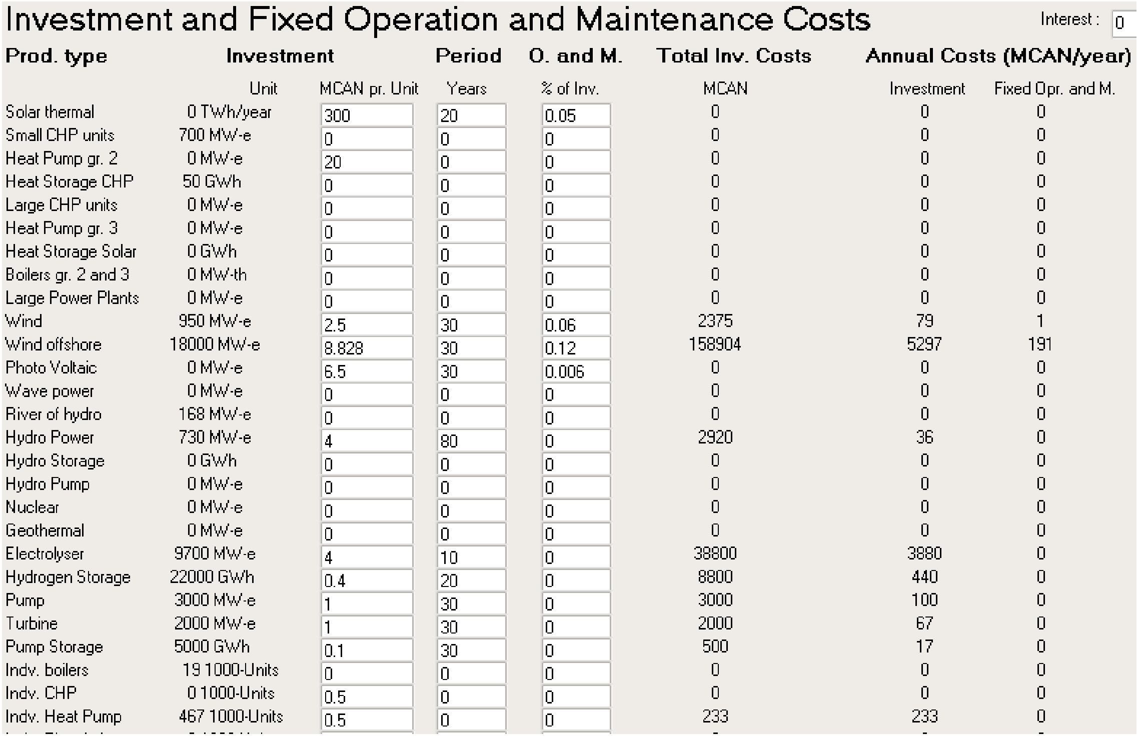
NATURAL GAS EXCHANGE

	DHP & Boilers MW	CHP2 CHP3 MW	PP CAES MW	Indi-vidual MW	Trans port MW	Indu. Var. MW	Demand Sum MW	Bio-gas MW	Syn-gas MW	CO2Hy gas MW	SynHy gas MW	SynHy gas MW	Stor-age MW	Sum MW	Im-port MW	Ex-port MW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

RES Share: 98.7 Percent of Primary Energy312.9 Percent of Electricity 68.0 TWh electricity from RES 09-May-2015 [23:50]

Figure 71: 2030 Forecasted Year – Nova Scotia with 18000MW Offshore Wind B

The following is a snapshot of the technologic economic inputs used in conjunction with the energy inputs and criteria, because of the wide number of published values pertaining to these inputs, I used primarily the values published by NS DOE, seen in Chapter 4, and then augmented them with any missing data from other reports read during the literature review and over the last year.



Investment and Fixed Operation and Maintenance Costs

Interest : 0

Prod. type	Investment		Period	O. and M.	Total Inv. Costs	Annual Costs (MCAN/year)	
	Unit	MCAN pr. Unit	Years	% of Inv.	MCAN	Investment	Fixed Opr. and M.
Solar thermal	0 TWh/year	300	20	0.05	0	0	0
Small CHP units	700 MW-e	0	0	0	0	0	0
Heat Pump gr. 2	0 MW-e	20	0	0	0	0	0
Heat Storage CHP	50 GWh	0	0	0	0	0	0
Large CHP units	0 MW-e	0	0	0	0	0	0
Heat Pump gr. 3	0 MW-e	0	0	0	0	0	0
Heat Storage Solar	0 GWh	0	0	0	0	0	0
Boilers gr. 2 and 3	0 MW-th	0	0	0	0	0	0
Large Power Plants	0 MW-e	0	0	0	0	0	0
Wind	950 MW-e	2.5	30	0.06	2375	79	1
Wind offshore	18000 MW-e	8.828	30	0.12	158904	5297	191
Photo Voltaic	0 MW-e	6.5	30	0.006	0	0	0
Wave power	0 MW-e	0	0	0	0	0	0
River of hydro	168 MW-e	0	0	0	0	0	0
Hydro Power	730 MW-e	4	80	0	2920	36	0
Hydro Storage	0 GWh	0	0	0	0	0	0
Hydro Pump	0 MW-e	0	0	0	0	0	0
Nuclear	0 MW-e	0	0	0	0	0	0
Geothermal	0 MW-e	0	0	0	0	0	0
Electrolyser	9700 MW-e	4	10	0	38800	3880	0
Hydrogen Storage	22000 GWh	0.4	20	0	8800	440	0
Pump	3000 MW-e	1	30	0	3000	100	0
Turbine	2000 MW-e	1	30	0	2000	67	0
Pump Storage	5000 GWh	0.1	30	0	500	17	0
Indv. boilers	19 1000-Units	0	0	0	0	0	0
Indv. CHP	0 1000-Units	0.5	0	0	0	0	0
Indv. Heat Pump	467 1000-Units	0.5	0	0	233	233	0

Figure 72: Investment and Fixed Operation and Maintenance Cost Assumptions

The values entered above are assumptions based on Electricity System Review Figure 54 in Chapter 4 and Bogart 2002. Please take these data from Figure 72 into consideration as simply a starting point, and when better values are proven and can be used as firmly as hydropower LCOE values are known, then we can better tune this economic output to reflect a truer 2030 forecasted year.

5.2 GIS Mapping

In brief this section highlights the complex municipal land use planning that has many spatial considerations to account properly.

5.2.1 Onshore Wind – HRM Model Locations Case Study

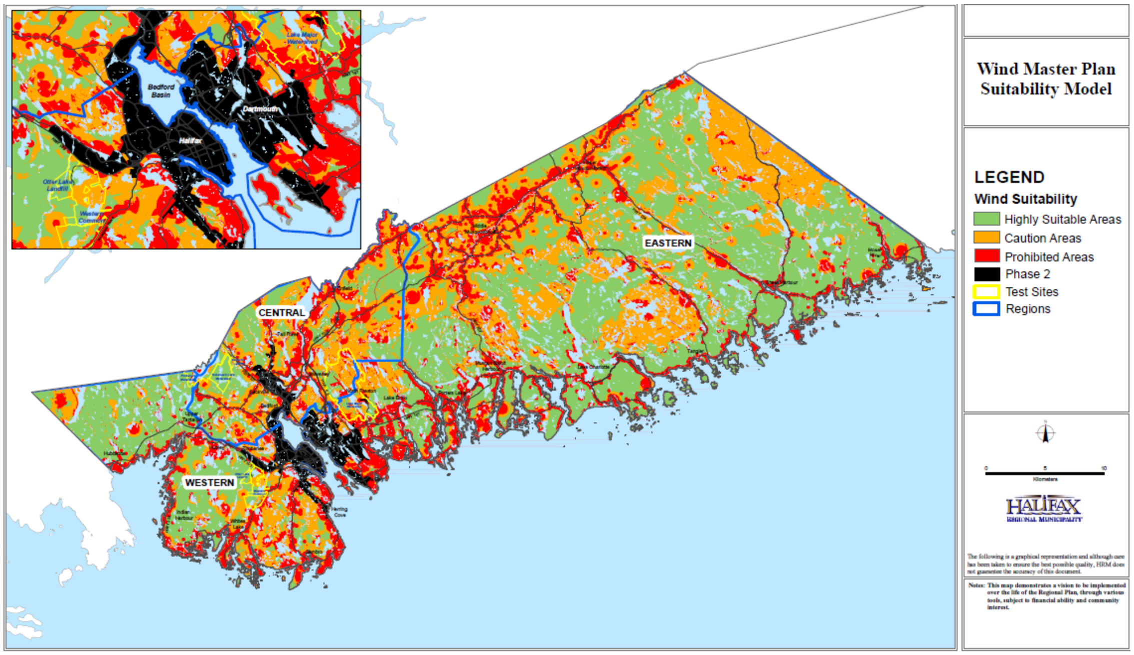


Figure 73: HRM Wind Master Plan Suitability Model (Halifax Regional Municipality, 2006)

HRM staff produced the above synthesis of data, the component parts were approximately ten base maps with various criteria, such as: distance from homes, distance from appropriate power lines, distance from access roads, slope of terrain, archeological significance, major bird breeding and feeding grounds, sensitivity of water sheds to development, wildlife reserves and provincial/municipal park land, and other criteria.

It is important to also consider the strength and annual reliability of the wind resource alongside the HRM map, so it is included below.

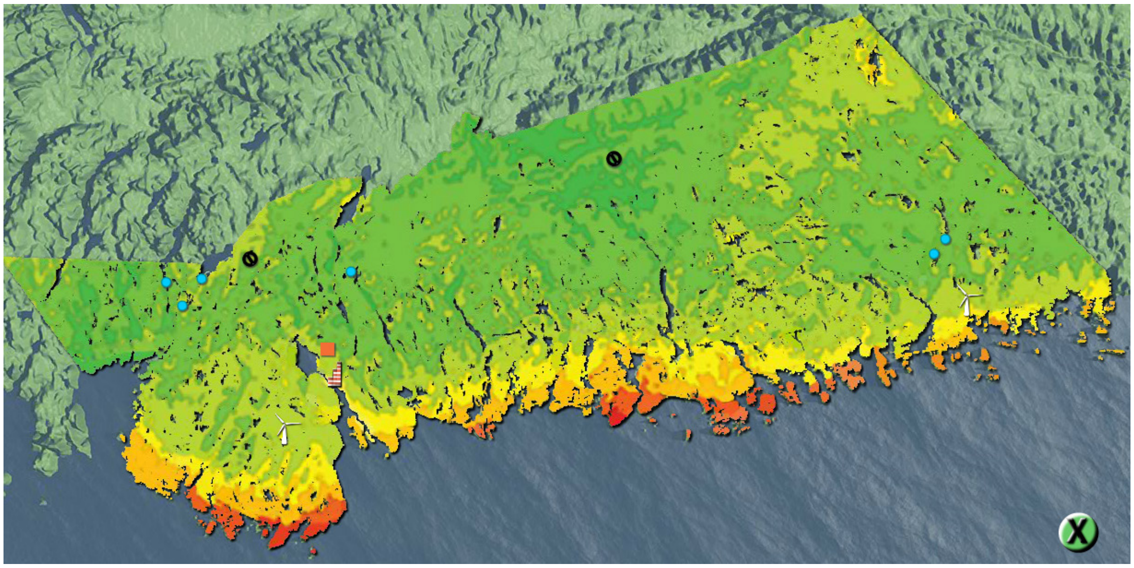


Figure 74: Nova Scotia's Energy Map with HRM & NS Wind Atlas data layer (80m)

We can see the most power would be produced either within several kilometers of the coast onshore, or within 20 km distance offshore up to 20-40 meters in depth to match the European example in Figure 28.

Combining the visual data from this map with the EnergyPLAN 2030 year, we could build several 1000MW wind farms far enough off the coast that most people would not see them. The two primary ocean planning issues would then be shipping traffic and fishing grounds. I know it has been a process in the EU, but typically the wind farms pay to lease the offshore seabed, and if done correctly the subsea structure can be utilized as protected fish habitat. The ocean always turns sunken ships into places for coral and plant life to flourish. The 200 wind turbine subsea structures for each of the 18 – 1000 MW wind farms, so in this example, 3600 wind turbine subsea structures could shelter and nurture ocean life. Floating wind turbines may eventually be cheaper.

5.2.2 Offshore Wind Turbines in Nova Scotia

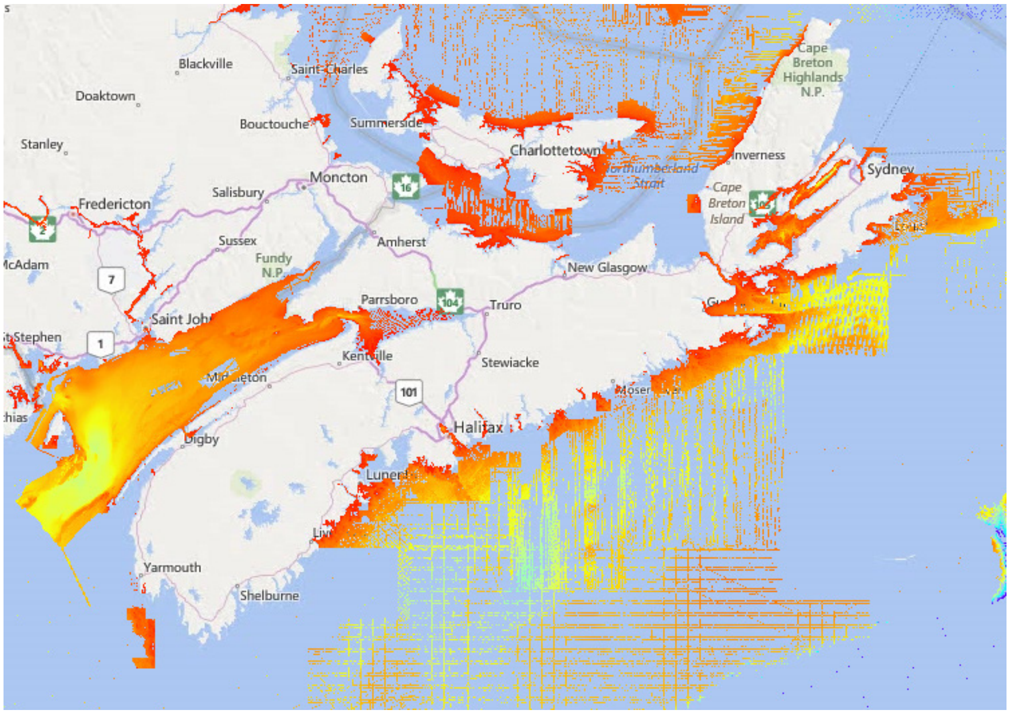


Figure 75: NS Ocean Floor Depths Close to Shore (Geoportal as part of the Government of Canada, 2015)

Recently the NS DOE has established two Marine Renewable Energy Areas in the Bay of Fundy and in Cape Breton. These areas will be developed with various tidal energy technologies, and proven offshore wind energy. With this in mind it should be noted that the EU continues to invest heavily in offshore wind farms, and it seems quite certain the US plans to invest in offshore wind along much of the North Eastern seaboard, Cape Cod already has a planned wind farm marked off.

M. Jacobson 2015, created many offshore and land area visualizations of how much space would be required to power however many TWh from wind, at standard 3MW turbine sizes. This offshore area would be reduced with larger MW class wind turbines. A primary concern from the public should be how such large installation will affect migrating birds. One reasonable suggestion was to include scheduled downtime at certain times of day during spring and fall to reduce unnecessary deaths and further aggravate species loss. This may lower annual power production by a couple of percent, but pays itself back in ecosystem protection. Please see the resource in the US on the topic of national plans http://thesolutionsproject.org. A snapshot of Canada is below.

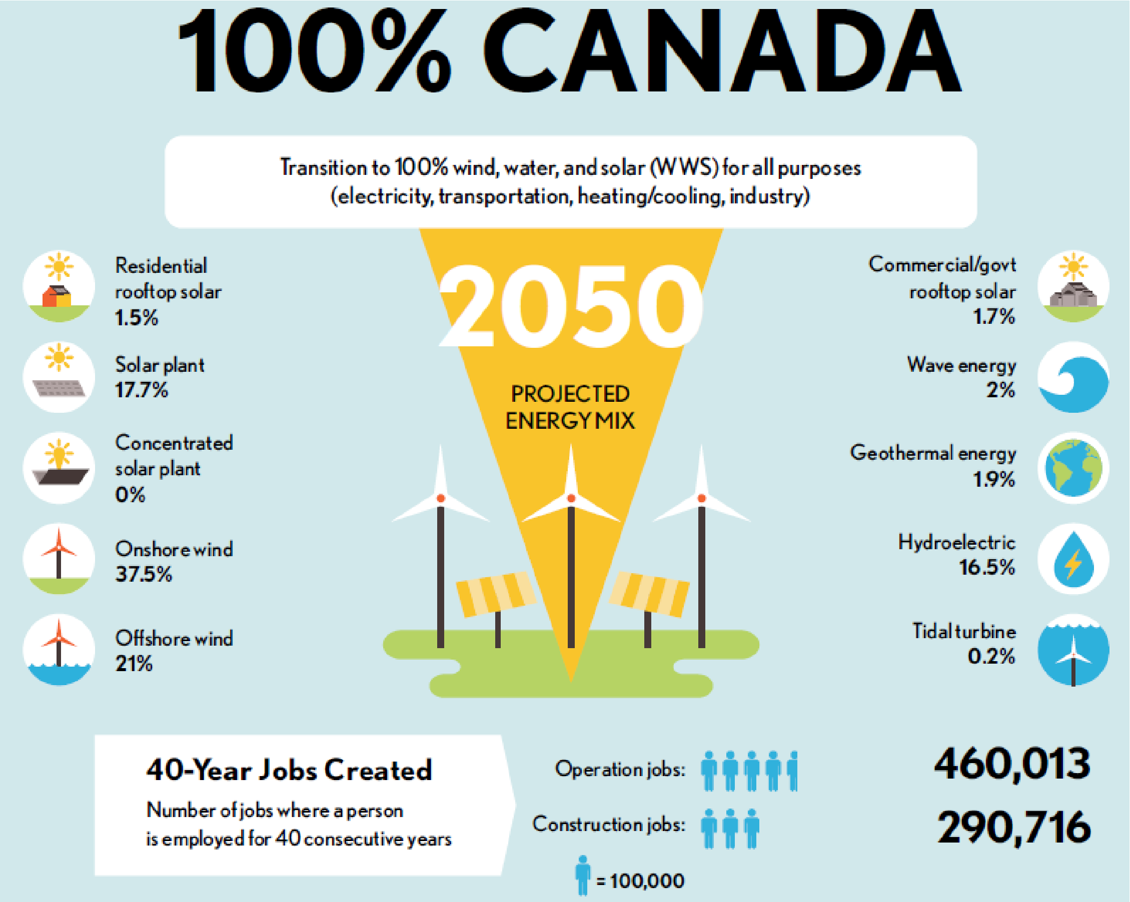


Figure 76: 100% Canada from the Solutions Project year 2050

Note 21% offshore wind, and 21% Solar PV plant with another 37% from onshore wind.

The effects of low frequency sound from offshore wind farms and how that alters fish and marine mammal behavior was mentioned in the literature. If a species uses sound to hunt, navigate and communicate then any new interference would pose a possibly significant risk to their livelihood.

5.2.3 Offshore In-Stream Tidal Turbines – "Fundy Standard"

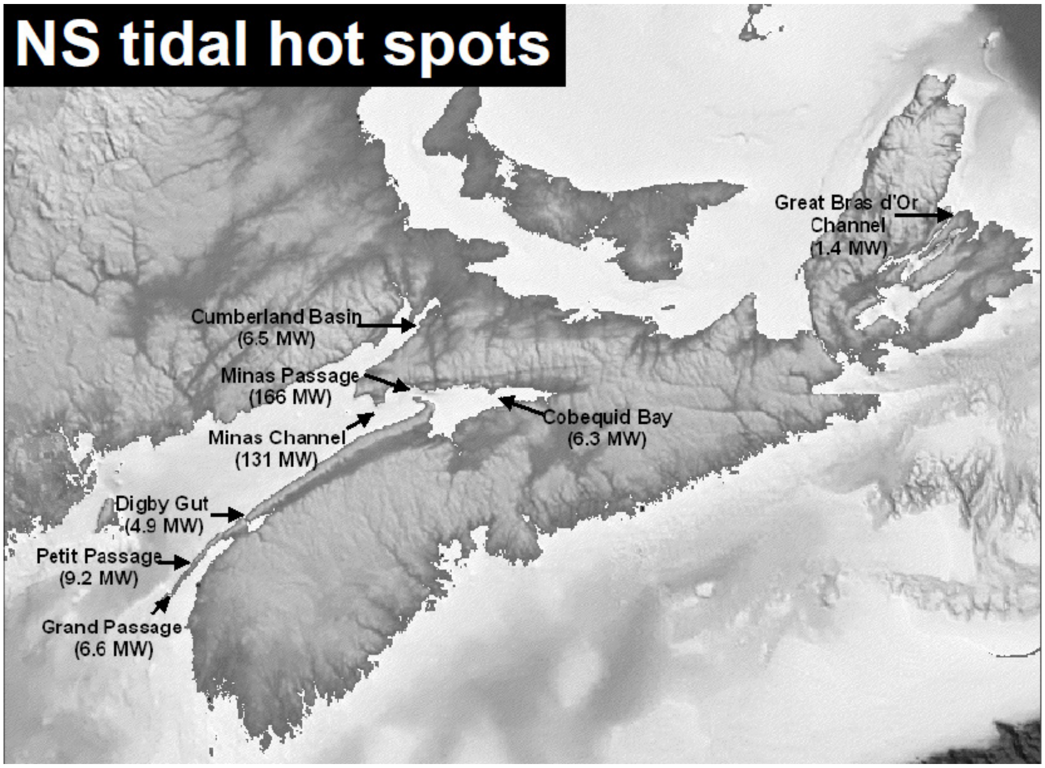


Figure 77: NS DOE Tidal hotspot map from several years ago (MW)

As mentioned in the literature review, upwards of 2000MW potential exists with a marginal (2-3%) reduction in tidal range of regions in the Minas Basin subarea of the Bay of Fundy. The map above is outdated and reflects conservative initial estimates from a smaller section of the tidal area. With the consideration of exporting electricity to the US, and providing generously for domestic use, we could forecast that eventually with proper environmental considerations utilized in the EIA process that a considerable portion of this resource will be put to use powering the renewable energy future.

5.2.4 CAES/H2 Geologic Energy Storage – Atlantic Region Opportunities

This section will only suggest that to ensure the cost of both CAES and H2 energy storage remains low and affordable, that continued surveying of appropriate geologic and economically viable sites are located. Presently this falls under the mandate of the Department of Natural Resources. The Alton Gas facility was originally proposed as a compressed air underground storage facility, but was converted to a natural gas project. These underground storage caverns are created by mining out salt deposits with a technique called solution mining. Salt is removed by pumping water from the Shubenacadie River into the salt cavern to dissolve the salt.

I am uncertain as if the project was completed or not, due to not following the original environmental plan of slowly releasing the 8 million cubic yards of salt by diluting it properly and then releasing it into the tidal river which has a lower level of natural salt balance. According to news reports they decided to rush the release and by doing so threatened the salt balance and health of marine life.

5.3 Original Contributions of Chapter 5

In summary in Chapter 5, my original contributions in this thesis were towards:

- NS EnergyPLAN 2010 reference year creation based on CanESS energy category data, and wind energy tally from NSEM compiled data,
- Validated and corrected coal costs based on heat rate, verified with NSP reports,
- NS EnergyPLAN 2030 forecasted year creation, with discussion of inputs and economic ranges, and approximate investment and fixed O&M costs estimates based on new technologies.
- I ran four trials to test a high wind scenario, a high solar scenario, along with high either BEV or FCEV scenarios, with export scenarios covered briefly tied to level of firm renewables (CAES or Hydrogen fuel bunkers),
- HRM wind master plan suitability model map with a brief review,
- Onshore versus offshore wind around HRM,
- Offshore wind in NS supported by evidence from The Solutions Project,
- Tidal turbines is an emerging industry in NS,
- CAES and H2ES should continue to be assessed as an important provincial resource.

Chapter 6: Nova Scotia Energy Map

6.0 Introduction

In this chapter we focus on the main deliverable of the Nova Scotia Energy Map, and how it is structured as an Energy Information System.

6.1 Design Approach and Implementation

The Nova Scotia Energy Map is designed to be an interactive engaging method for citizens to learn how their energy was produced historically, presently, and utilizes basic game theory by allowing users to add power plants to the map in future energy scenarios, therefore testing general considerations of supporting this or that energy type.

In the conceptual and ongoing design of the energy map, I use the Visual-Audio-Reading-Kinesthetic (VARK) learning approach to demonstrate to online users the present energy regime in Nova Scotia. First I engage visual and kinesthetic learners to grasp how spatial and historical information describes the actions of citizens pursuing electrification. This sheds a light on the possibility that we as a province will continue to build more power plant installations in efforts to maintain a level of advanced technology within a global resource context. With this general movement in mind, I aim to consider not only the energy details, but seriously ask how much and by which technology approach, we affect our environmental health of both individuals and species.

I have written instructions on the energy map's website for reading centred learners, with some helpful tooltips and labels where necessary. I have made available a 5 minute short descriptive video with audio that demonstrates how to use features in the map. See video on YouTube at: https://www.youtube.com/watch?v=Yojk-vL2YR8

6.1.1 Early Energy Map Work

Figure 78: First version of Energy Map in 2007

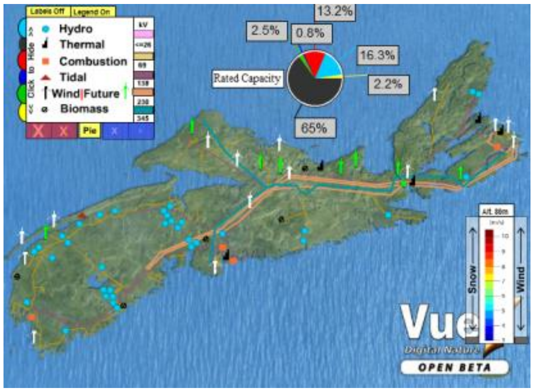


Figure 79: Version 12 of the earlier designs in 2009

The first version of the energy map began in the summer of 2007. The idea was conceived when I attempted to use the Canada Wind Atlas map and place a few wind farms to get a general sense which wind resources were being best used. Later versions included: popups with general information about that category of power plant, a layer with names of power plants, a scalable pie chart, popups with some actual data, adding a ‘snow’ and also a solar map. Version 16 was the first of the thesis releases, and included a better rendered map with the newer Vue 11 Infinite software. It also contained a completely restructured interface, the days of the early legend were gone, and now a new dropdown tabs interface emerged.

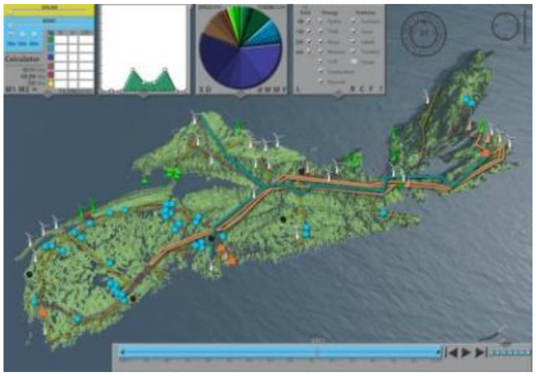


Figure 80: Version 16, December 2013

Version 17 was the release aimed at the Halifax OpenData Contest launched in January 2014, and included an animated ocean; colour legends with a target reticule & numeric output so users could identify how much energy was actually at each location on the renewable resource maps; a FCEV solar and wind calculation tab, which demonstrates how many panels or turbines would fuel however many FCEVs annually.

Version 18 fixed some minor technical data with the HRM zoom option. The most recent is Version 19. This version contains many updates and new minor features, such as: abstracting the data into actual database tables for wind farms and emission data for thermal plants, annual GWh for each wind farm, dynamically setting the wind farms from a green colour to white once they enter the year following when they should have been built, fixed a minor timer error that only appeared in the debug version when hovering over wind farms with pluses (indicator to zoom in), updated text in the webpage itself along with optimizing the images for the web.

Through all of the versions from 1 - 19, the file was named “netXX.swf”, but more importantly the public facing version name started at file net18.swf using the nameplate “v01.0.0” found directly in the lower left hand corner. Minor releases start on the right hand side as per the normal versioning conventions of most apps and software, these are typically on a weekly or monthly scale, while middle numbers represent the natural iteration of the first variations, the left most number is for major releases only, which something like “v02.0.0” would encompass.

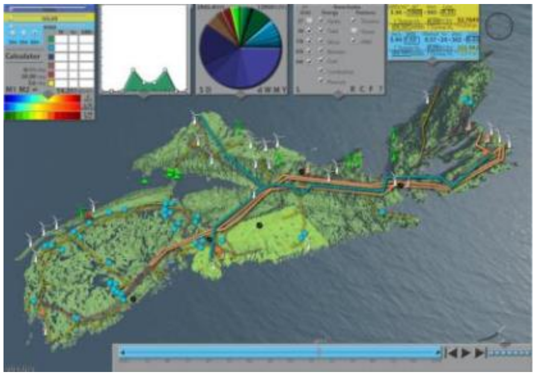


Figure 81: “v01.0.3”, Oct 2014

6.1.2 Feature Descriptions

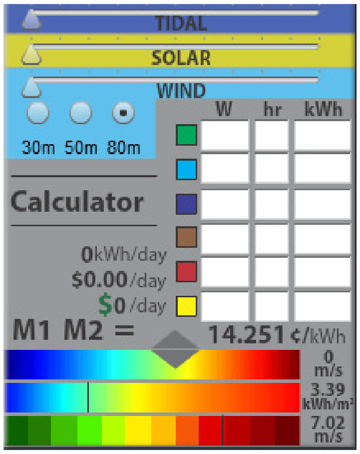


Figure 82: Map and Calculator Tab

Caption: Sliders display solar, wind and tidal maps. Colour legends match each map's coordinates and display a numerical output. The calculator takes general individual power usage grouped by category (computer, lights) and outputs how much money it would cost to operate your household.

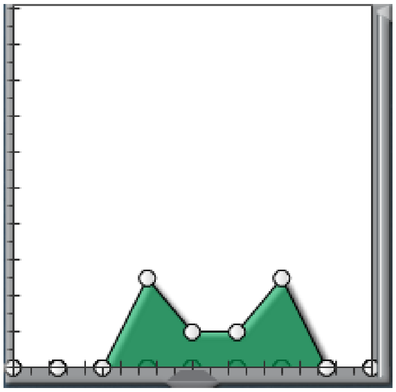


Figure 83: LineGraph Group Tab

Caption: The line graphs represent household daily energy use patterns. Drag the points to model your energy use in three hour increments. Click on the matching colour box on the 1st tab to compute the amount at $0.142 kWh, which is changeable. I used this method to estimate my power bill accurately.

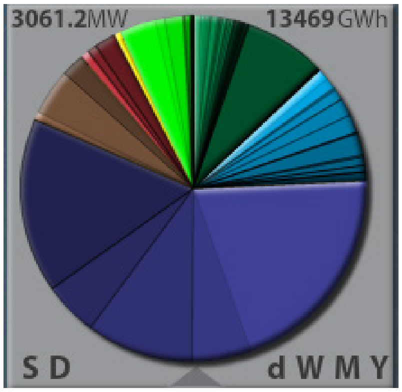
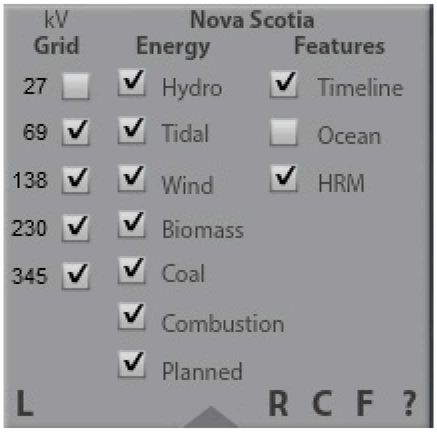


Figure 84: PieGraph Tab

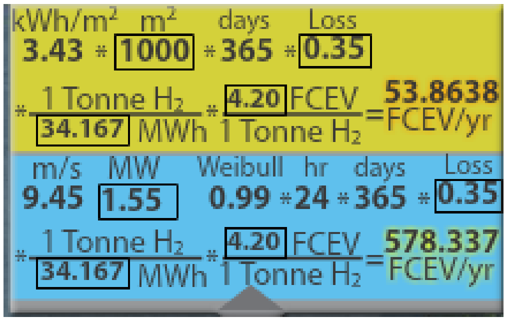
Caption: This represents rated capacity in MW of each plant, each power category has a colour and each unit is a different shade. The annual production is measured in GWh. In the upper right is a simplified total of all the rated capacity if all plants operated at an average level all year.



kV Grid		Nova Scotia Energy	Features
27	☐	☑ Hydro	☑ Timeline
69	☑	☑ Tidal	☐ Ocean
138	☑	☑ Wind	☑ HRM
230	☑	☑ Biomass	
345	☑	☑ Coal	
		☑ Combustion	
		☑ Planned	

Figure 85: Map Options Tab

Caption: The checkboxes enable viewing elements on the map. The 'F' is for full screen; click again when it changes into an 'X' to view normally. Elements covered are: all major transmission lines to 27kV, power plants with planned units, an animated ocean, zoom enabled HRM region, and a timeline tool.



$$\underset{\text{kWh/m}^2}{3.43} * \underset{\text{m}^2}{\boxed{1000}} * \underset{\text{days}}{365} * \underset{\text{Loss}}{\boxed{0.35}} * \frac{1 \text{ Tonne } H_2}{\boxed{34.167} \text{ MWh}} * \frac{\boxed{4.20} \text{ FCEV}}{1 \text{ Tonne } H_2} = \frac{53.8638}{\text{FCEV/yr}}$$

$$\underset{\text{m/s}}{9.45} \; \underset{\text{MW}}{\boxed{1.55}} \; \underset{\text{Weibull}}{0.99} * \underset{\text{hr}}{24} * \underset{\text{days}}{365} * \underset{\text{Loss}}{\boxed{0.35}} * \frac{1 \text{ Tonne } H_2}{\boxed{34.167} \text{ MWh}} * \frac{\boxed{4.20} \text{ FCEV}}{1 \text{ Tonne } H_2} = \frac{578.337}{\text{FCEV/yr}}$$

Figure 86: FCEV Equations Tab

Caption: This presents two modifiable solar and wind energy equations that output how many Hydrogen fuel cell electric hybrid vehicles (FCEVs) would have fuel for a year, depending on the cursor location on the map. Change the wind map elevation to see how large wind farms can power more FCEVs. The outlined boxes contain editable values.

Presently in operational use BEVs have lower GHG emissions to fuel up than FCEVs using the same primary energy supply, but it is vital to consider the entire Lifecycle Cost Assessment in regards to materials, embodied energy and air pollution, which is not covered in this thesis. Looking at synergies with the electric grid and the transportation sector, there are definitely unique energy and environmental consequences of favouring either technology.

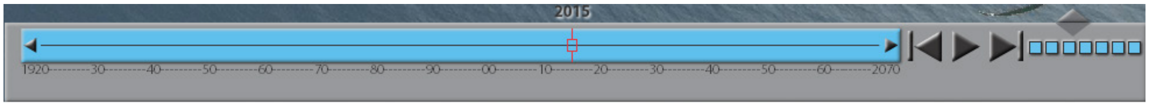


Figure 87: Timeline Tab

Caption: The timeline on the bottom of the map allows the user to play through the evolution of the power plant construction in Nova Scotia. Click and drag the year indicator, skip forward or back, go 'frame by frame', and change the play back speed with the blue boxes on the right of the timeline.

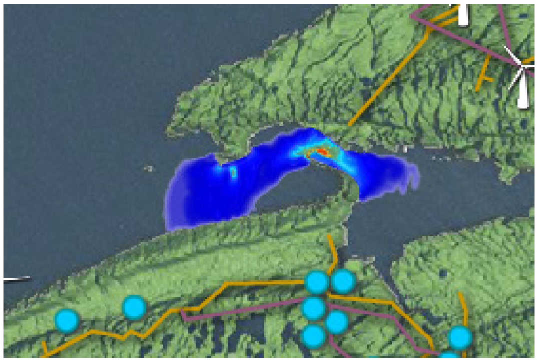


Figure 88: Tidal Map

Caption: When the tidal map is visible, click once on it to zoom in, and then click to change the view. After several clicks it will 'zoom out' back to the main view of the full map.

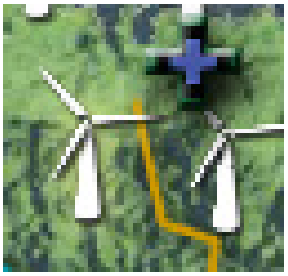


Figure 89: Wind Farm "Plus Symbol"

Caption: Wind turbines that display a plus symbol indicating the presence of a zoom enabled wind farm map, simply click on the turbine to zoom. Only wind farms that had four or more units have maps. Currently there are 9 WF maps.

Figure 90: Amherst Wind Farm Map

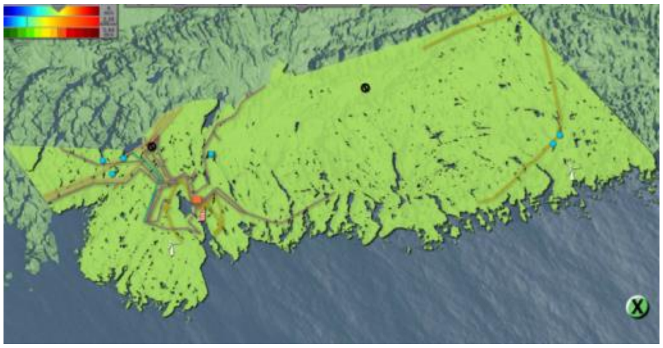
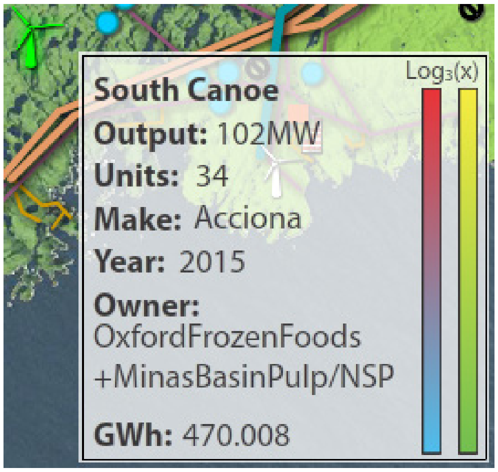


Figure 91: Green HRM Region

Caption: Click HRM (Halifax Regional Municipality) area to zoom in. Once zoomed in feel free to access the modified 4th tab by viewing the transmission and distribution lines, the smallest this map goes is only to the 27 kV level. There is a road map with red street lines where the majority of the smaller feeder distribution (5-11kV) power lines are built. A large portion of the gas stations were added to the map, to show the general distribution in populated areas around the municipality, this is important as it relates to the fuel supply chain, which could optionally be considered for similar locations for Hydrogen fuel stations and pumps at existing stations. Building footprints were included to visualize where commercial wind turbines cannot be too close.



South Canoe
Output: 102MW
Units: 34
Make: Acciona
Year: 2015
Owner: OxfordFrozenFoods +MinasBasinPulp/NSP
GWh: 470.008

Figure 92: Power Plant Popups

Caption: Each power plant category has a unique popup, reflecting main technology characteristics. The two bars on the right was an attempt to display a scale to compare GWh of all the power plants on the blue/red bar, and LCA eGHG emissions on the green/yellow bar.

6.1.3 Visualization Choices and Why

Many people prefer the option to see data through a map interface if it is spatial data, as they can use their ability to landmark and put information in geographical context. The initial design intent was to put the renewable resource maps side by side with the power plants, to visualize where the resources were being underutilized.

The engagement sub-objective: to encourage public education for those interested in learning about their energy system – is to allow exploration by adding power plants on the map, to see how it shapes our power grid profile. Realistically it takes large engineering firms many months, with computer simulations and detailed knowledge, to create precise and reasonable future energy scenarios, but the concept of learning how the annual GWh, with firm energy supply and ability to adapt to fluctuations, play out in both an economic sense and a conceptual one. In this way citizens will gain basic knowledge of actions to reduce GHG emissions right in their home province.

Canadian Wind Atlas Wind Rose:

The wind rose from the Canadian Wind Atlas that the authors chose to display only has information on wind direction and frequency of the wind in each direction. So for example from the image shown, there is a line indicating the wind has blown from approximately the South West 20% of the year, and approximately South West South 15% of the year. This is one method to get a sense of wind direction. The most important factor in wind farm power production is the wind histogram discussed later. Another type of wind rose also displays wind speed information (histogram style data) with each line on the wind rose comprised of wedges

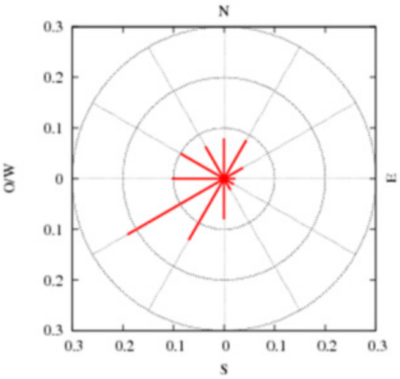


Figure 93: CWA Wind Rose

of varying widths that indicate wind speed and their frequency in each direction and directional frequency. For the purposes of deciding which is more appropriate from the data provided from the Canadian Wind Atlas I prefer to separate the data like the CWA authors have into two images as these graphics are simpler to read.

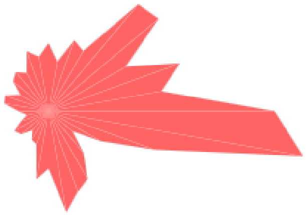


Figure 94: Wind Rose v1

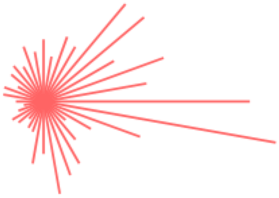


Figure 95: Wind Rose v2

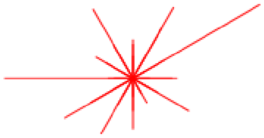


Figure 96: Wind Rose v3

Server Side PHP script to create SVG Wind Rose from CSV files:

Brian (Suda, 2014) created a PHP script that draws similar style wind roses to the Canadian Wind Atlas, but it is customizable in other ways in terms of colour and shading and number of lines. I originally intended to use this method to create my own PHP wind rose in a similar style in the energy map, but decided it was a low priority feature in the short run.

Wind Histograms:

Histogram data has been collected from the Canada Wind Atlas and will not be used to be visually displayed in the map; instead it provides data for the calculations of annual energy for the “add plant” feature. Verification of database sourced data to the values from the Canada Wind Atlas map itself is vital to confirm proper use of the GIS files. Each province has several overlapping Regional Rectangles (Figure 19), composed of 178 by 178 smaller rectangles. The Wind Atlas recommends removing the boundary data by at least 34 small rectangles on all sides as it was only mathematically necessary for creating the regional climate model but may introduce error on the local levels.

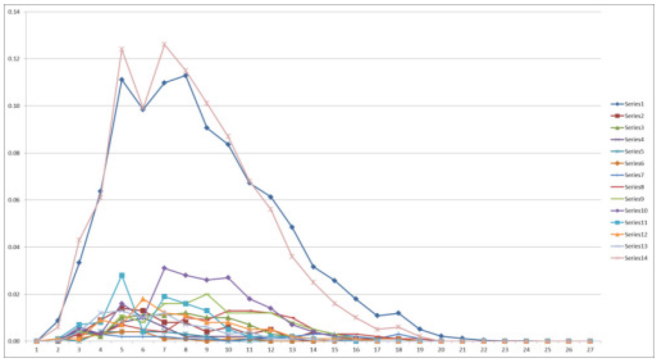


Figure 97: Example Histogram CWA data near Amherst

The top blue line is data from a location near Amherst from the Canada Wind Atlas map interface. While the top light orange line is from adding each of the lower bottom lines, each of which represents 1 of 12 sectors of 30 degrees around the compass. The sectors add up to 99.59622% of the climatic wind values. It is now certain that rounding error has occurred regarding this value; due to rounding error from the process of extracting the smaller zipped raw dataset relative to the RPN zipped FST file.

On a similar but different issue, when comparing, it is uncertain whether rounding error has occurred in the CWA interface data and the raw RPN data, as it adds up to 98.6%. It is thought the reason there is an almost 1 percent difference in these two histograms is because the CWA drawn histogram only displays up to 20 meters/second wind speeds. This error would therefore in some cases be larger than a percent in stronger wind resources, with higher storm frequency. Figure 98 visualizes in a non-standard way the13 directional sectors on the wind rose, with a histogram per sector.

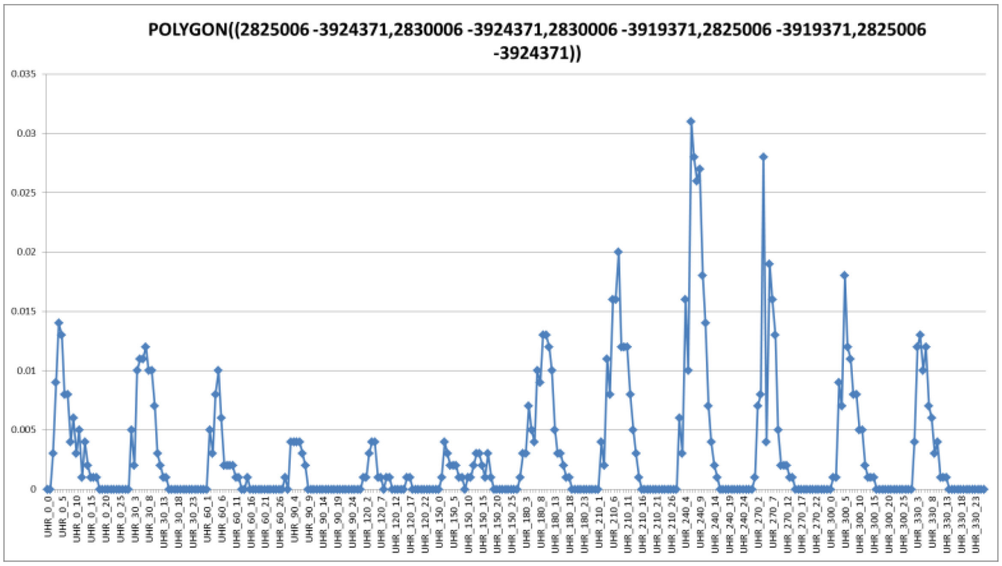


Figure 98: Amherst CWA Histogram Data broken down by 30° sector in side-by-side format

In the above figure one can see the frequency at which the wind tends to blow from specific directions as well as how strong the wind blows. The complete dataset contains both sets of information which can create the wind histogram and the wind rose. Since I am most interested in the overall histogram I focused solely on the directionless total histogram, and processed the directional wind rose data separately.

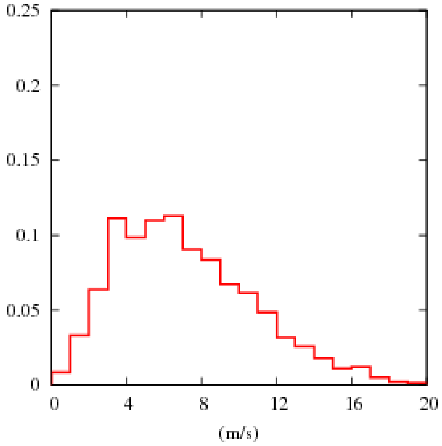


Figure 99: CWA Wind Histogram

Figure 99 to the left is how the Canada Wind Atlas elected to display the Wind Histogram data. The datasets for both the wind rose and the wind histogram have been preprocessed using equations in Excel from the current very large state. Reducing server workload and improving response time in the Energy Map as it queries and draws these data is essential.

6.2 Analysis of Energy Information System

The general design principles were quite unstructured from a formal computer engineering standpoint. Basic features were thought up by a process of brain storming, and then methods of achieving those features and data acquisition were researched. Each feature was designed separately and worked as standalone functions.

As the complexity grew it was occasionally necessary to modify existing functions within the main class. This involved considerable trial and error unfortunately, but with thorough manual testing for example the checkboxes with power plant categories, became especially complex when testing out the timeline feature and ensuring visibility of each unit, also tied into the rated capacity or “pie graph” tab.

Originally the data was handled quite crudely, simply using arrays encapsulated within the program, which worked for the bare minimum level of power plant data.

As the project grew in scope, and requirements grew alongside, it was recommended by my advisor to put the data appropriately in MySQL and import them into the energy map. This worked using PHP to get the data, and form XML to send to the map when the map initially loads. Flash has native XML interpreters, and there were only a few minor exceptions such as nesting semi-colons in the double quoted MySQL data that would otherwise break this or that part of the system. It was a worthwhile skill building and maintenance exercise.

My software development style has changed over the years, but the best way to classify the NSEM is using the Object-orientated methodology approach; whereas classes, functions and objects are the majority of the work. The secondary methodology followed the Prototyping Life Cycle Model; where a requirement for a new feature was thought up, designed and then built, tested by myself, refined until quality control targets were made, and then used as the working version of the energy map.

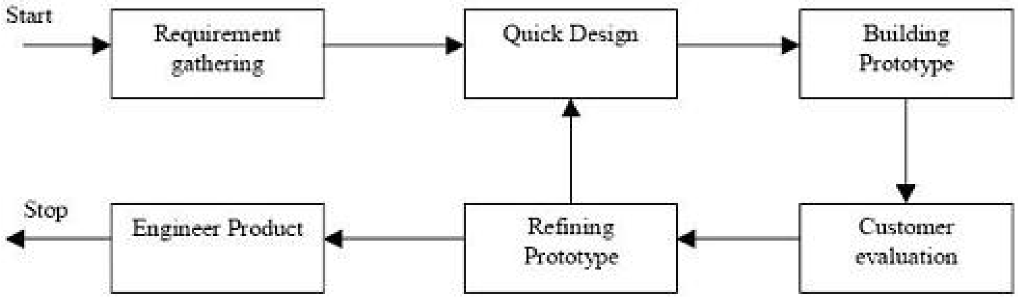
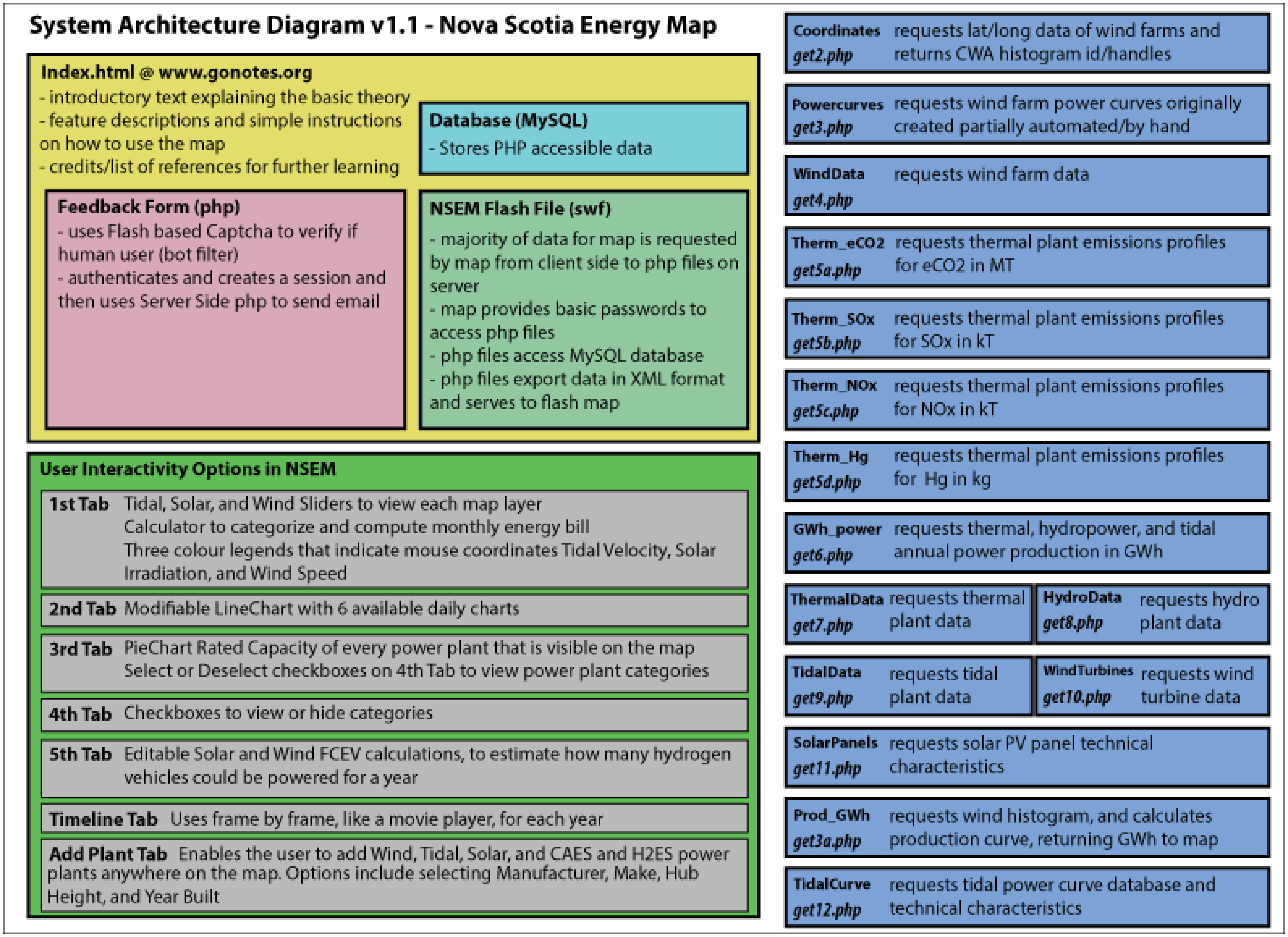


Figure 100: Prototyping Life Cycle Model (Freetutes.com, 2011)

If I were to rewrite and port the ActionScript3 code over to JavaScript and use the Canvas element in HTML5, I would take the time to seriously consider ensuring full-fledged Object-orientated methodology design standards be utilized. This would mean a large reorganization of the code, but since many of the common native objects and classes to ActionScript3 are not necessarily easily duplicated in JavaScript, it would just be a matter of pushing forward and breaking new ground anyway.

6.2.1 System Architecture Diagram

On the following page is the general system architecture of the website, Nova Scotia Energy Map, and 15 PHP files that access and process data from the database and serve the output in XML format back to the energy map.



System Architecture Diagram v1.1 - Nova Scotia Energy Map

Index.html @ www.gonotes.org
- introductory text explaining the basic theory
- feature descriptions and simple instructions on how to use the map
- credits/list of references for further learning

Database (MySQL)
- Stores PHP accessible data

Feedback Form (php)
- uses Flash based Captcha to verify if human user (bot filter)
- authenticates and creates a session and then uses Server Side php to send email

NSEM Flash File (swf)
- majority of data for map is requested by map from client side to php files on server
- map provides basic passwords to access php files
- php files access MySQL database
- php files export data in XML format and serves to flash map

User Interactivity Options in NSEM

1st Tab	Tidal, Solar, and Wind Sliders to view each map layer Calculator to categorize and compute monthly energy bill Three colour legends that indicate mouse coordinates Tidal Velocity, Solar Irradiation, and Wind Speed
2nd Tab	Modifiable LineChart with 6 available daily charts
3rd Tab	PieChart Rated Capacity of every power plant that is visible on the map Select or Deselect checkboxes on 4th Tab to view power plant categories
4th Tab	Checkboxes to view or hide categories
5th Tab	Editable Solar and Wind FCEV calculations, to estimate how many hydrogen vehicles could be powered for a year
Timeline Tab	Uses frame by frame, like a movie player, for each year
Add Plant Tab	Enables the user to add Wind, Tidal, Solar, and CAES and H2ES power plants anywhere on the map. Options include selecting Manufacturer, Make, Hub Height, and Year Built

Coordinates *get2.php*	requests lat/long data of wind farms and returns CWA histogram id/handles
Powercurves *get3.php*	requests wind farm power curves originally created partially automated/by hand
WindData *get4.php*	requests wind farm data
Therm_eCO2 *get5a.php*	requests thermal plant emissions profiles for eCO2 in MT
Therm_SOx *get5b.php*	requests thermal plant emissions profiles for SOx in kT
Therm_NOx *get5c.php*	requests thermal plant emissions profiles for NOx in kT
Therm_Hg *get5d.php*	requests thermal plant emissions profiles for Hg in kg
GWh_power *get6.php*	requests thermal, hydropower, and tidal annual power production in GWh
ThermalData *get7.php*	requests thermal plant data
HydroData *get8.php*	requests hydro plant data
TidalData *get9.php*	requests tidal plant data
WindTurbines *get10.php*	requests wind turbine data
SolarPanels *get11.php*	requests solar PV panel technical characteristics
Prod_GWh *get3a.php*	requests wind histogram, and calculates production curve, returning GWh to map
TidalCurve *get12.php*	requests tidal power curve database and technical characteristics

Figure 101: System Architecture Diagram v1.1 - Nova Scotia Energy Map

6.2.2 List of Implemented and Planned Features

The following is a list of implemented features, item 12 highlighted in bold is a working prototype now online, items 12a-15 in italics are planned features under consideration.

1. WWS maps, calculator, resource indicators tab
2. Interactive daily usage line graphs tab
3. Category power plant rated capacity pie graph with total scaled GWh output tab
4. Map check box options tab, with full screen button and tab collapse button tab
5. Editable wind and solar equations that compute coordinates' resource capable of powering X FCEVs annually tab
6. Adjustable timeline tab with frame by frame, fast forward and slow speed settings, jump to end or beginning and drag current year/frame
7. Zoom-able tidal map with several levels of zoom and visualization
8. Wind farm plus symbol indicates custom drawn maps
9. Zoom-able green HRM region with additional layers
10. Power plant popups with category specific data
11. NSEM now scales to fit browser width when narrowing the window, uses CSS applied to flash object and associated div tags
12. **Add plant tab with WWSE**
    a. *Add Transportation Option (BEVs and FCEVs)*
13. *Forecast.io real-time/nowcasted wind speed data and energy production*
    a. *F.io wind rose/F.io daily/weekly histogram*
14. *CWA wind rose/CWA wind histogram*
15. *Line Graphs: GWh and GHG*

6.2.3 Tech-Tree Timeline

On the following page is the “Tech-Tree” Timeline of the NSEM, and demonstrates the implemented system (A, B, C, D and E) and possible planned features (G) described in section 6.4.

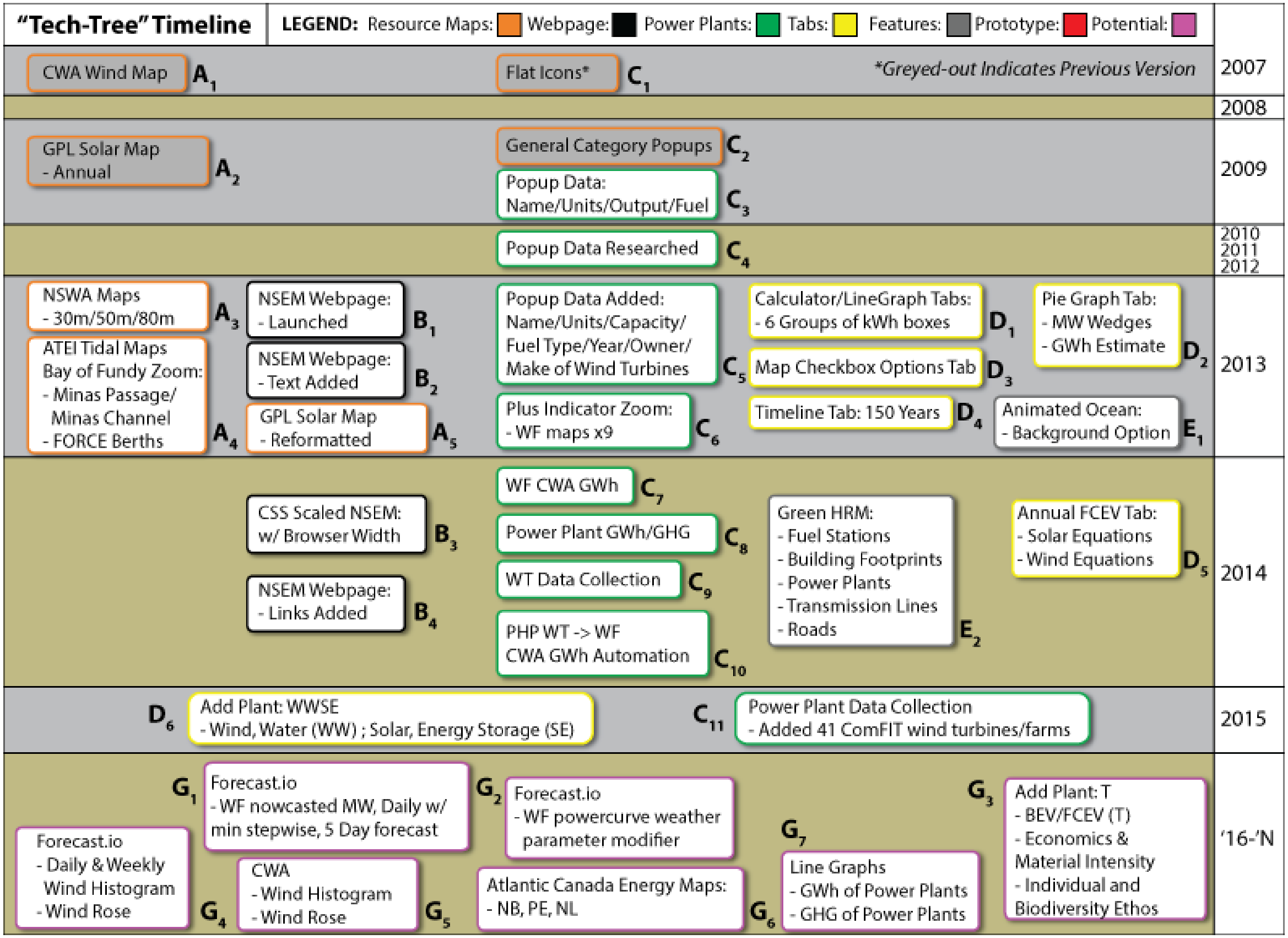


Figure 102: "Tech-Tree" Timeline which demonstrates the implemented and planned features

6.2.4 Self-Built Classes used by the Energy Map

Presented here is a list of self-built classes in the NSEM.

* "Main.as" is not actually a formal class, in terms of being developer initiated, but is rather part of the main document class internal to the Adobe Flash Professional development environment.

#	Class Name	Purpose/Function	Lines of Code w/ comments
1	Main.as*	Majority contained in object orientated code*	3863
2	Holder.as	Full screen variable holder	47
3	LineChart.as	Draws/updates the 6 line graphs when called	357
4	PieClass.as	Draws/updates pie graph when called	232
5	App1.as	Loads 15 datasets using PHP/MySQL	1586
6	Plants.as	Add Plant feature, reads data and displays lists	2064

Table 25: Self-Built Classes used by Nova Scotia Energy Map

LOC with comments/disabled code: 8149, LOC without comments approximately: 5000. Many of the functions in the main class may eventually be moved into their own classes, at the time of the initial coding it was faster to create them in the main class considering it was only one developer creating and making edits to them over the years. Normally, best practices with large teams of software developers, or community built content, would have the majority of functions written and imported as object-orientated classes for easy editing, versioning, and modularity. If this project continues and encompasses NB, PE, and NL, then it may make sense to tidy up the programming on the way. A major weakness of my programming style is that I have not tested to ensure logic was the most efficient in processing speed, or in terms of visual layout. If this were to be optimized for lower power devices such as tablets and part of the smart phone market that are Adobe Flash capable (such as the Android – Puffin Browser app), then that would be a major consideration and area for improvement. The six custom built classes are listed on the following pages.

Name: Main.as*

Created by: Jacob Thompson, **LOC:** 3863

Purpose: Created initially as the complete program (internal to the Adobe Flash Professional development environment, i.e. in a layer on the stage), this class has various initializing functions and listeners that were built to achieve certain feature functionality.

- From the dropdown tab animations and operational logic;
- hovering actions over map icons;
- the calculator functionality to compute kWh and scale from Wh to kWh and so on;
- the sliders alpha display with each energy resource map;
- visibility arrays for checkboxes and timeline interactions;
- planned plants green shading until year is complete;
- play ocean animation option;
- grid visible transmission lines;
- setup plants function to set text in popups from loaded data, creates master array;
- “zoom” wind farm feature and wind hover mouse cursor change with plus icon and fade on hover out or timer event;
- Formatting of each popup window power plant category styling;
- Power plant category specific popup window colouring functions and glow feature;
- Line chart modifiers, and scale features;
- Timeline player controls, play options, frame location and blue boxes;
- Update visibility function and update visibility HRM function;
- Data loading functions;
- Initializes pie class object;
- “zoom” HRM in and out, with how it affects object visibilities; and
- Various event handlers throughout.

Function: This is the main body of work not including the Line Chart, Pie Chart, Hit Tester, ColourUtils, Add Plant, and load data Classes.

Name: Holder.as

Created by: Jacob Thompson, **LOC:** 47

Purpose: This variable stores the states and some minor logic when switching back and forth to full screen mode and normal viewing mode of the Flash object.

Function: Necessary for full screen implementation.

Name: LineChart.as (Daily Usage Feature)

Created by: Jacob Thompson, **LOC:** 357

Purpose: Draws Line Chart objects, in this case we have by default up to six due to space limitations in the calculator viewing area. The concept is to either start with the line charts and work out daily electricity costs by back-computing with the calculator, or start with the calculator and draw an average line chart of daily electricity usage. This is intended to be the middle ground from the overly simple calculators to the tediously meticulous spreadsheets that can be nearly impossible to complete.

- 6 line chart objects, each is a different colour, and takes front position when the coloured box next to it is clicked (on the calculator tab);
- Each small circle, or handle, is meant to be drag and drop friendly, to raise or lower the power usage throughout the day at 3 hour intervals;
- Click the calculator coloured boxes to re-compute the kWh and money spent; and
- The scale feature is currently buggy and will be fixed in a later release (going from calculator to line chart direction).

Function: To be an easy tool for homeowners (kWh) and companies (MWh) to assess how their behaviours with power usage can cost them significantly – and with that motivation encourages individual awareness of simple measures to save money.

Name: PieClass.as (Rated Capacity Feature)

Created by: Jacob Thompson, **LOC:** 232

Purpose: Draws and updates the pie chart tab anytime an associated option changes; such as the timeline iterates one frame or more, an unchecked box hides a power plant category on the map and on the pie chart.

- 7 pie chart categories, one for each power category, each is a different colour;
- Secondary to that each colour is broken down into shades from lighter to darker to represent the size (in width) of individual power stations/farms;
- The MW number on the upper left is a tally of each pie category with all the plants;
- The GWh number is currently a simple ratio of capacity factor, assumed to average over all the various types of power plants (incorrectly), this will be fixed later by using the actual GWh values produced by each power plant.

Function: A visual way to display the total province's power in rated capacity all at once, broken down by categories.

Name: App1.as

Created by: Jacob Thompson, **LOC:** 1586

Purpose: Gets data from server and feeds it into the client side energy map.

Function: Approximately a dozen loaders get data from the server in XML format, interprets it appropriately and sorts and stores the information in a few easy to access arrays to be read later by features like the popups and the pie chart.

Name: Plants.as (*Add Plant Feature)*

Created by: Jacob Thompson, **LOC:** 2064

Purpose: Enables adding wind, solar and tidal power plant, along with CAES and H2ES power plants to the map. WWS technologies can be selected from a list, and configured on an individual or farm scale.

- First three functions set the models (wind, tidal, and solar separately);
- Next sets the heights (wind only);
- Draw plant function used for each of wind, tidal, solar, and each energy storage
- About 500 lines of code dedicated to the change handler function, whenever a state change occurs from choosing a different option in a dropdown list of turbines, or adding more plants and other options;
- Drop plant/move plant function when placing a new power plant;
- "Highlight" or select a plant, gives it focus and displays information entered in the Add Plant interface; and
- Glow option when hovering over only the Add Plant power plants using a different colour than the already built power plants.

Function: The main prototype gamification feature; allows the general public to create scenarios with which ever arrangement and power production possibilities of power plants possible. Calls get3a.php when user requests wind histograms and calculates production curve and final GWh for location on map, based on proximity to geographic coordinates.

6.2.5 External Open-Source Classes Imported into Energy Map

Two public classes were modified from the internet.

Name: ColourUtils.as

Created by: Justin Windle, **LOC:** 329

Purpose: To match mouse coordinates with colours on screen, and can compare with other colours to demonstrate matching.

Function: Used to measure wind speed colours and match with legend to demonstrate how much wind speed at each mouse location. Also used on the solar and tidal maps and legends. Output value was then used in the equations tab to calculate how many Hydrogen cars could be powered for a year based on energy and installed capacity.

Name: HitTester.as

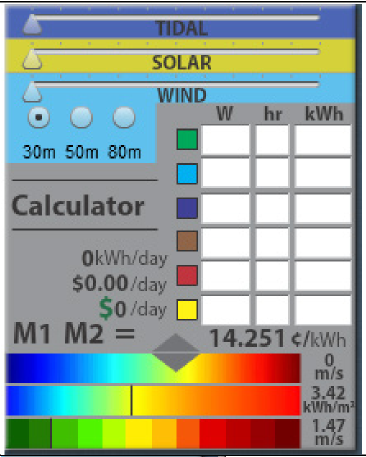
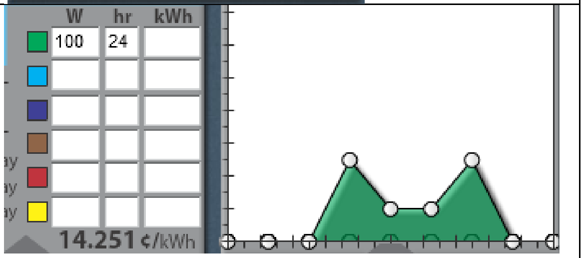
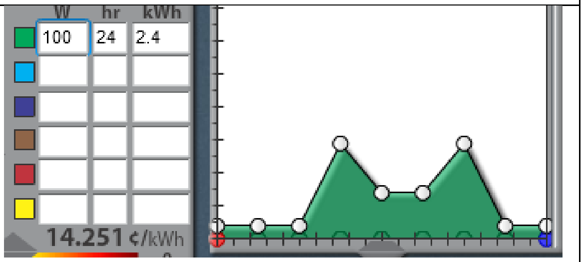
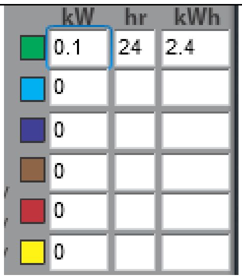
Created by: Doug McCune, **LOC:** 44

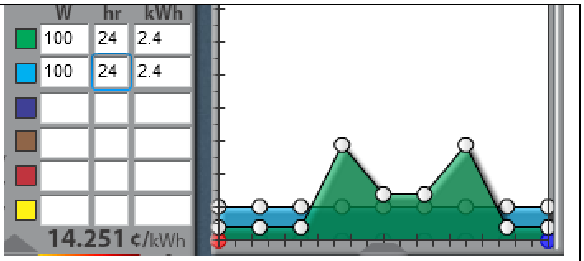
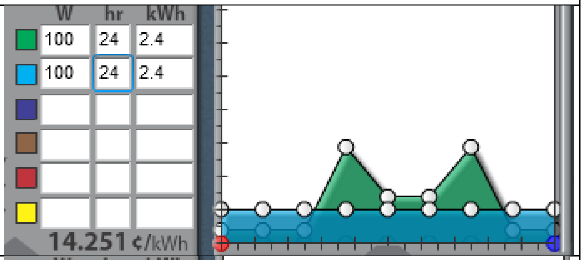
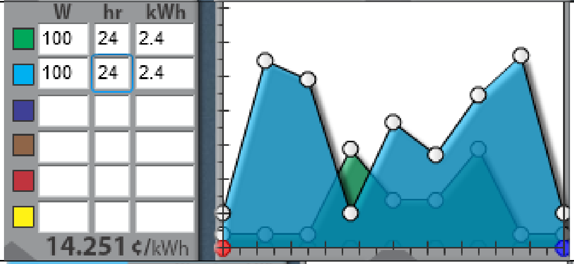
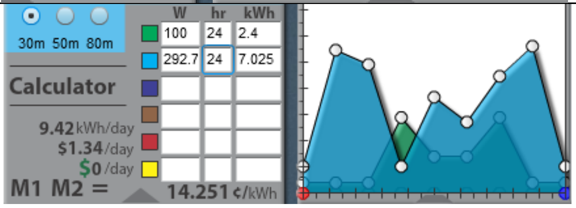
Purpose: To determine mouse hovering over an object on a particular layer

Function: Also used when mouse hovering over renewable energy layers, specifically the tidal speed map.

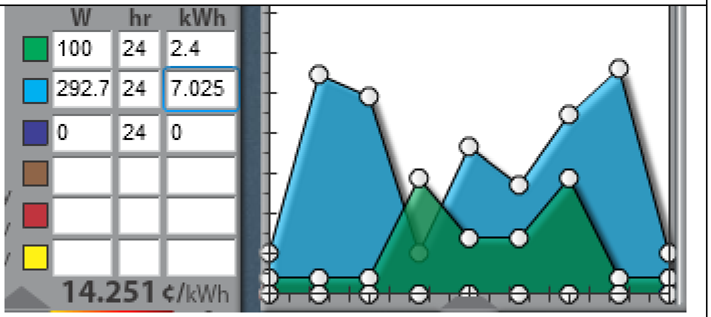
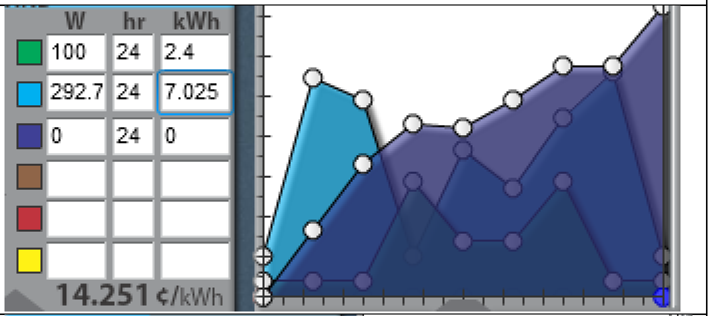
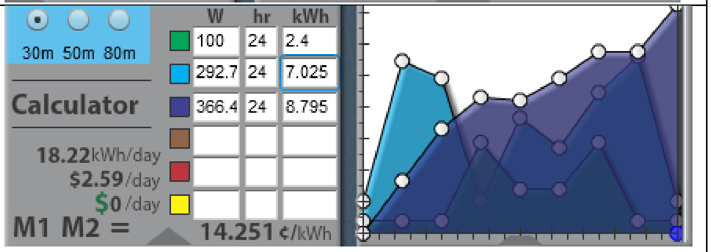
6.3 Feature Walkthrough

1. Calculator (connected to the Line Graph)

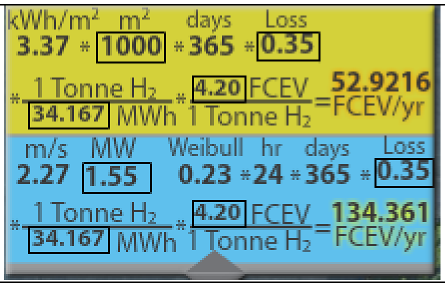
Caption	Screen
The Calculator section on the 1st Tab is a unique way to estimate household or commercial power usage.	 TIDAL SOLAR WIND ○ ○ ○ 30m 50m 80m W hr kWh Calculator 0kWh/day $0.00/day $0 /day M1 M2 = 14.251 ¢/kWh 0 m/s 3.42 kWh/m² 1.47 m/s
To begin using the calculator, enter how many watts would total any particular category; for example all the lightbulbs in your house. And then estimate how many hours they are all on in hours. I entered 100 for Watts (W), and 24 hours in this example.	 W hr kWh 100 24 14.251 ¢/kWh
Press Enter, in either of the W or hr calculator box entry fields in the same row to compute the answer of 2.4 kWh. If you click in another row it will compute whatever values were in that other row respectively. In this case it alters the curve that already exists in the Line Graph by adding more to it.	 W hr kWh 100 24 2.4 14.251 ¢/kWh
Click on the W, and see that it changes to kW (1000 Watts) and the decimal place changes if a value was already entered. Click again for MW, and once more to return to W. Likewise, if you click on kWh, it will cycle to MWh, and GWh, use whichever option is appropriate and that displays in the space provided.	 kW hr kWh 0.1 24 2.4 0 0 0 0 0

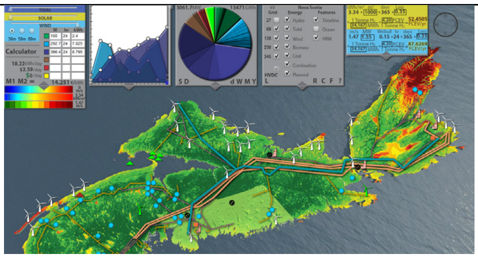
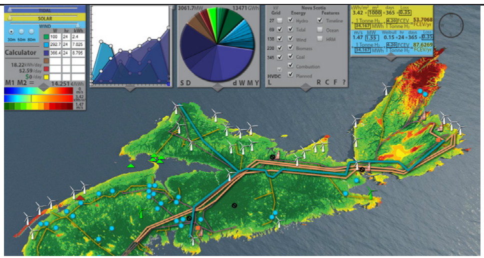
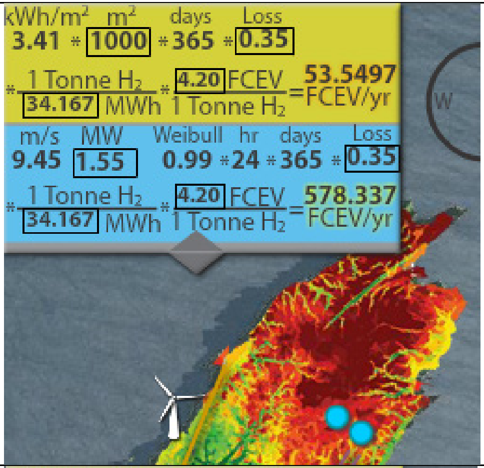
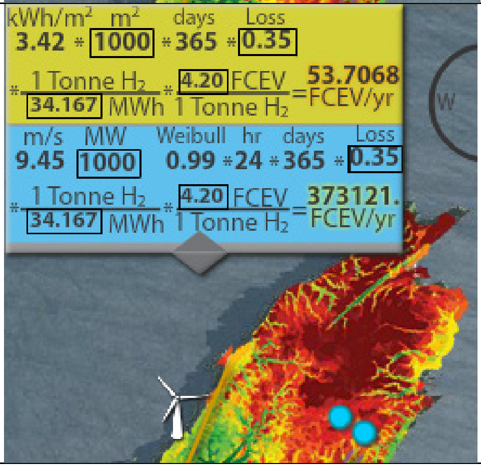
Inputting values in another row and pressing enter will draw a new flat-lined average on the Line Graph tab. *Note that even though the same values were input, the heights of the lines displayed on the Line Graph tab do not match, this is incorrect behavior.*	 W hr kWh 100 24 2.4 100 24 2.4 14.251 ¢/kWh
Click on the associated colour box on the right of the calculator input fields, to bring that colour Line Graph to the front of the stack or depth of field.	 W hr kWh 100 24 2.4 100 24 2.4 14.251 ¢/kWh
It is possible to drag the white circles also known as handles to readjust the energy used during the day. This is a good way to set your energy usage estimates visually. See the next step to calculate the new energy total.	 W hr kWh 100 24 2.4 100 24 2.4 14.251 ¢/kWh
Clicking on the associate colour that matches the Line Graph, in this case, blue. Will re-compute the kWh total for that day, and average the Watts over a 24 hr period. It should be noted that every time Enter is pressed or a coloured box is clicked the Cost of energy used per day is tallied over all six boxes and uses the editable 14.251 Cents/kWh at the bottom of the Calculator tab.	 ● ○ ○ 30m 50m 80m Calculator 9.42 kWh/day $1.34/day $0/day M1 M2 = W hr kWh 100 24 2.4 292.7 24 7.025 14.251 ¢/kWh

2. Line Graph (connected to the Calculator)

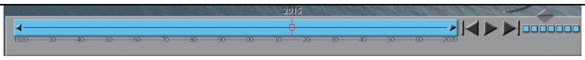
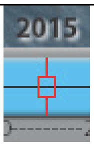
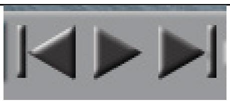
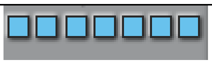
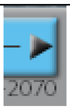
Caption	Screen
To continue the example of the combined Calculator and Line Graph feature, if the user clicks a coloured box that has no values entered yet, the zeroed-line-graph will display and take focus. The next step is to drag and drop each handle to create the desired energy behavior.	 W hr kWh 🟩 100 24 2.4 🟦 292.7 24 7.025 🟦 0 24 0 14.251 ¢/kWh
Please see one example of how energy behavior may be set in the image on the right.	 W hr kWh 🟩 100 24 2.4 🟦 292.7 24 7.025 🟦 0 24 0 14.251 ¢/kWh
Again, click on the purple colour box to compute the price of all six categories of energy usage. Clicking any coloured box will recalculate the total costs, but will not recalculate every row at once.	 ● ○ ○ 30m 50m 80m Calculator 18.22kWh/day $2.59/day $0/day M1 M2 = W hr kWh 🟩 100 24 2.4 🟦 292.7 24 7.025 🟦 366.4 24 8.795 14.251 ¢/kWh

3. FCEV Equations

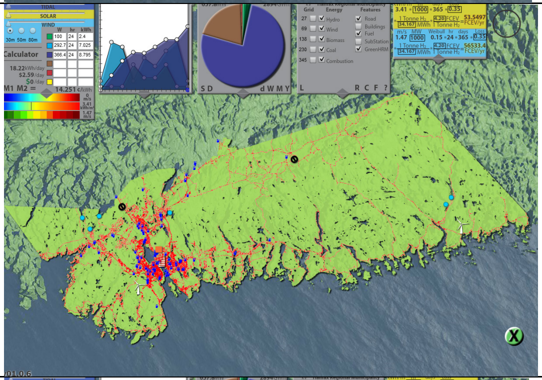
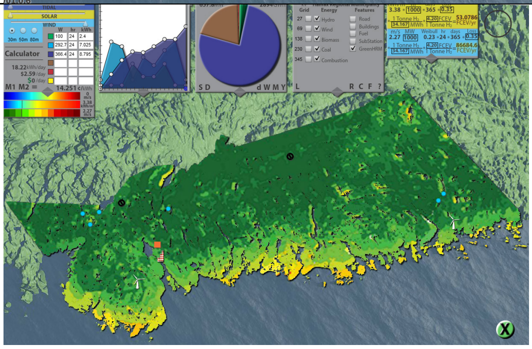
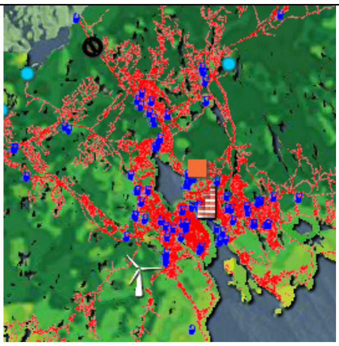
Caption	Screen
The FCEV Equations section on the 5th Tab is a straight forward way to estimate how many Hydrogen Vehicles will be powered by user defined numbers of Solar PV panels and Wind Turbines at the mouse coordinates on the map.	 kWh/m² m² days Loss $3.37 * \boxed{1000} * 365 * \boxed{0.35} * \frac{1\ \text{Tonne}\ H_2}{\boxed{34.167}\ \text{MWh}} * \frac{\boxed{4.20}\ \text{FCEV}}{1\ \text{Tonne}\ H_2} = \frac{52.9216}{\text{FCEV/yr}}$ m/s MW Weibull hr days Loss $2.27\ \boxed{1.55}\ 0.23 * 24 * 365 * \boxed{0.35} * \frac{1\ \text{Tonne}\ H_2}{\boxed{34.167}\ \text{MWh}} * \frac{\boxed{4.20}\ \text{FCEV}}{1\ \text{Tonne}\ H_2} = \frac{134.361}{\text{FCEV/yr}}$

The values will compute whether the wind or solar maps are visible, but it helps to move the sliders all the way to the right on the 1st Tab to see where there is more or less energy. Low and high energy is output on the Colour Legends on the 1st Tab, along with a numerical output for wind, solar, and tidal.	
Optionally, turn off the HRM layer with the checkbox on the 4th Tab, to hide the Green HRM section of the map, so that it is easier to view the wind and solar maps.	
Hovering the mouse over the dark red regions of the wind map demonstrate that the FCEV Equations are constantly recalculating (on a timer at regular intervals), and see how the same wind turbine would be able to power significantly more Hydrogen vehicles at locations like these than low wind areas on the map.	 kWh/m² m² days Loss 3.41 * 1000 * 365 * 0.35 $* \frac{1 \text{ Tonne } H_2}{34.167 \text{ MWh}} * \frac{4.20 \text{ FCEV}}{1 \text{ Tonne } H_2} = \frac{53.5497}{\text{FCEV/yr}}$ m/s MW Weibull hr days Loss 9.45 1.55 0.99 * 24 * 365 * 0.35 $* \frac{1 \text{ Tonne } H_2}{34.167 \text{ MWh}} * \frac{4.20 \text{ FCEV}}{1 \text{ Tonne } H_2} = \frac{578.337}{\text{FCEV/yr}}$
A simple change in the editable MW box (all parts with boxes in these equations are user editable) to 1000 MW, to represent an offshore wind farm, really demonstrates just how many FCEVs could be powered annually. Since the wind is comparably strong offshore this is a reasonable example, but elevation would play a definitive factor on wind characteristics that is not covered with this basic method.	 kWh/m² m² days Loss 3.42 * 1000 * 365 * 0.35 $* \frac{1 \text{ Tonne } H_2}{34.167 \text{ MWh}} * \frac{4.20 \text{ FCEV}}{1 \text{ Tonne } H_2} = \frac{53.7068}{\text{FCEV/yr}}$ m/s MW Weibull hr days Loss 9.45 1000 0.99 * 24 * 365 * 0.35 $* \frac{1 \text{ Tonne } H_2}{34.167 \text{ MWh}} * \frac{4.20 \text{ FCEV}}{1 \text{ Tonne } H_2} = \frac{373121.}{\text{FCEV/yr}}$

4. Timeline

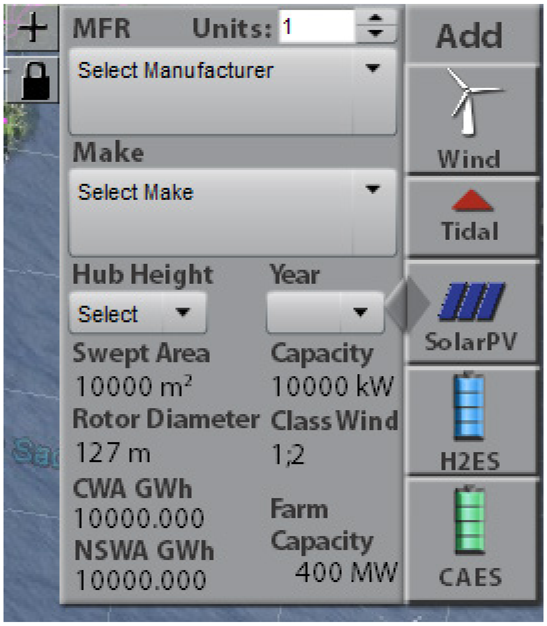
Caption	Screen
The Timeline Tab is a conventional method to not only select the year viewed, but also animate the historical and eventually future developments played like a movie clip.	
The year selected, or current frame, is visible over the associated target reticule. This red reticule may be clicked and while holding down, dragged to a new year.	
Skipping to the end or beginning of the timeline, or simply playing the years is achieved with standard controls.	
These are a unique way to indicate normal play back speed, or to go faster or slower.	
Clicking anything on the right side of the middle blue block will play back faster than normal. While clicking any blue block on the left side will play slower than normal. Simply click on the middle block to return to normal speed.	
On both the far left, and far right, there are a left and right arrow. These enable going ahead or back frame by frame.	

5. Green HRM

Caption	Screen
The Green HRM area is a helpful way to zoom in and see the area where approximately half of Nova Scotia's population resides.	
Once you click to zoom (one level of zoom only), the 4th Tab checkbox options changes to suit the new data layers. The data for HRM polygon came from HRMOpenData, including roads and building footprints.	
Similarly to the main map, both wind and solar maps can be displayed. Used in conjunction with buildings and roads we can get a general idea of where possible wind farms may be far enough away from populated areas and in a suitable wind regime. Offshore is not included with the particular Nova Scotia Wind Atlas data that I utilized.	
Gasoline and diesel fuel stations can be viewed in blue, with partial data for HRM. This sets the stage to demonstrate how many fill up points are necessary, and would be required similarly with Hydrogen fuel, since tank fill ups and the range of distance are about the same. Using BEVs would require a very different set up, with plugins at home and work and other public parking places.	
Finally, to exit the HRM region, simply click the X to zoom out back to the full Nova Scotia Energy Map.	

6.3.1 Proof of Concept - Add Plant Feature – D_6:

Presently the D_6 feature, known as the “Add Plant” feature, has been built and is online. A simple but critical component is utilizing the Lat/Long equations that I created for translating x, y coordinates on the energy map into matching Lat/Long coordinates so when the wind farm/turbine is placed on the map it correctly sources the associated CWA wind histogram dataset. Next it processes that data together with the selected make and model of the wind turbines at that new user defined wind farm, to compute the simple GWh the wind farm would produce on an average year.



Units: 1

Swept Area 10000 m²

Capacity 10000 kW

Rotor Diameter 127 m

Class Wind 1;2

CWA GWh 10000.000

NSWA GWh 10000.000

Farm Capacity 400 MW

Figure 103: Add Power Plant Feature

A hub height equation was added to this feature, along with the ability to directly type in the Lat/Long coordinates and have the WF/WT appear at the correct location on the map. The following quote describes a wind energy hub height equation:

> “Wind Energy Converter**:** WEC power is calculated based on measured wind speed data, imported as a time series of average speeds for the duration of the

> time step. The wind speed data must be correlated to the proper height of the WEC being modeled. This is accomplished using the wind shear power law:"
>
> $$U_{\text{hub}} = U_{\text{anem}} \left(\frac{z_{\text{hub}}}{z_{\text{anem}}} \right)^{\alpha}$$
>
> **Figure 104: Hub Height Calculation**
>
> "Where U_{hub} and U_{anem} are the wind speeds at the WEC hub height (Z_{hub}) and the data collection height (Z_{anem}), and α is the wind shear coefficient specific to the WEC site. The values of α used in the case studies are: 0.2 for the micro-grid case study (assumed based on the coastal terrain), and 0.325 for the constrained case study. The extractable power from the wind is a function of air density, ρ_{α}, its stream-speed, U, the turbine area, A_{WEC}, and power coefficient, C_{WEC}."
>
> (Manchester, 2014)

Both the wind turbine database of 270 turbines is available from a drop down list in the prototype, as well as a list of 2000 Solar PV panels, along with the tidal turbines database of 23 turbines. Both CAES and H2ES are generalized, i.e. not technology specific to date, as there are many variations, so far these sections have working interfaces built, but eventually will need to be tied in with "linking" energy storage with WWS to demonstrate capacity factor improvements with later versions of the energy map. Please refer to the https://www.youtube.com/watch?v=Yojk-vL2YR8 YouTube video for a quick walkthrough of the Add Plant feature in action.

6.4 How to Implement Potential Features G1-G7

This section describes ongoing work on the NSEM after the timeframe of the thesis. The first potential feature (G_3) involves adding a transportation icon to the Add Plant feature, with BEV and FCEV technologies listed, acting as Energy Storage similarly to that option but specialized for vehicles and V2G; also the new overall sub-feature is including general economics and material intensity per MW installed capacity, along with highlighting general individual and biodiversity effects of technology operations and mitigation strategies. The other two involve Forecast.io nowcasted (G_1) 24 hour, at 1 minute interval resolutions and possibly a five day wind speed forecast, where nowcasted energy production will be displayed. The second part of that feature (G_2) is to allow users to enable or disable weather parameters, such as, temperature, pressure, humidity, and hub height with the existing wind turbines at each already built wind farm. The option may be available to swap wind turbines to see if they would perform better in terms of energy performance or not over the same period.

Eventually I plan to add four more 'features'. The first one (G_4) covering Forecast.io wind histograms and wind roses, which can be implemented using the classes I mentioned earlier, that still need to be brought to full functionality. The second one (G_5) involves creating the CWA wind roses and wind histograms from existing datasets. The third one (G_6) involves expanding to include the rest of Atlantic Canadian provinces: NB, PE, and NL, which will simply involve applying the same method to create the Nova Scotia Energy Map with the appropriate data for each. The final planned feature to date (G_7) will make use of the existing Line Graph class but modify it heavily and resize the display to fit the viewing area to visualize the GWh and GHG progression over the years.

Chapter 7: Conclusions and Future Work

7.1 Thesis Summary

In summary, it was asked at the beginning of this research whether "we can decarbonize our economy and improve our technologic level." The answer is a resounding "yes we can." There are many variations in the implementation and technology niches for each province depending on their renewable resources, first and foremost, but also by the energy requirements of each region. The two strongest motivators for making progress towards this 2030 decarbonization end are:

i) The prevention of a 3 degree Celsius average temperature rise with expected negative climate change impacts on our current energy heading and with that the devastation of 30% of the planet's species which are currently on the path to extinction with the status quo.

ii) The vastly improved urban air quality changes from switching to Battery electric and also Hydrogen electric transportation, and additionally not having to rely on fossil fuel thermal plants in populated areas when so many proven technologies exist already and are improving each year.

The economic case that I worked through by hand and then validated with the EnergyPLAN model indicates either a similar but slightly lower annual fuel cost in the Nova Scotia first category, or if focused on exporting to our neighbours, we could become a strong regional energy exporter and with ongoing investment even be able to make a healthy net income in the process, depending on loan interest rates. We will definitely improve our energy security by simply making it all within our province, but we should always consider that all renewable energy technologies, however green-the-moniker requires substantial mining for base materials, future technology developments aside, while encompassing extensive manufacturing and transportation costs to initially get everything set up.

With the knowledge that decarbonization is achievable, beneficial, inspiring to each of the generations taking part, motivating, and practically just using good common sense; I look forward to the ever increasing individual and societal energy system awareness within the framework of a healthy environment, economy, and society that will march forward with all the possibilities thereafter.

It is up to all the stakeholders, for each and every one of us who is interested in energy and how it is used, to discover their niche where we can help each other find the skills through training and create permanent career opportunities. I sincerely urge the readers that in doing so we will improve quality of life in terms of environmental and health benefits, by following global best practices to implement a serious decarbonization plan as soon as possible to protect our shared future.

7.2 Objectives Achieved

Over the period of the research I began to have hope, because there were many people working on solutions to our pending energy and climate crisis. I can now confidently state that decarbonization is technically and economically realistic. This to me is a significant conclusion in itself.

With the collection of data and visualizations presented in the form of the Nova Scotia Energy Map, I have drastically improved my own understanding of our provincial energy. I feel like the feedback regarding the map from a number of people over the years has made the concept of “Energy System Awareness” more salient; in that it is actually helping academics and members of the general public quickly get up to speed on provincial energy resources and production.

Running the EnergyPLAN model was a milestone mark, as it took a fair amount of data to utilize. The trials run demonstrate that there are many ways to shape our energy future, and running batches to test for optimization points on the multi-level solution curves would be a significant next step for further refining the research.

The Add Plant prototype has been publically released as of December 2015, I am confident this proof of concept will continue to grow after the thesis is finished. The introduction to creating an interface for this basic level of gamification was a challenge, and has given me renewed appreciation for video game designers and developers. The Forecast.io nowcasted wind speed feature has not been implemented due to time constraints.

7.3 Future Plans

This section describes possible plans with the energy map evolution into an easier to use on multiple platforms educational tool. That will eventually expand to include Atlantic Canadian provinces in its scope.

7.3.1 Responsive Design

I intend to eventually port the Flash based ActionScript3 over to HTML5 with JavaScript as the main language, so that finally it will be easy to access on both smart phones and tablets; as of right now it is limited to mouse-only interactivity on large enough screens such as laptops and desktops. Using optimized hardware level language would also improve processing times not having to embed the Flash based map itself, so the potential to use Android and iOS specific apps is something I am open to learning.

7.3.2 Atlantic Canadian Mapping Potential

All the major data has been collected for Atlantic Canada in terms of power plants, provincial energy flows, renewable resource maps (except NL wind), with the exception of easily accessed hourly system data for each of NB, PE, and NL. Following a similar process to how the NS energy map was created, it would be significantly faster to develop the other provinces' maps within a reasonable timeframe. One interesting possible feature will be to include EnergyPLAN along with the map as a background processing tool, whereas when using the Add Plant Feature, the user will be able to run basic simulations and determine whether they should build more or less power plants or implement other energy measures.

Finally, thank you for reading. May the wind, sun, and tides forever keep us moving forward as we walk a little softer on the Earth.

References

There are two sets of references in this thesis. This is the first set which covers direct references and citations or quotes. While the second set covers very important and related but not directly used data, articles, books or maps. This may be helpful for the next researcher.

Acadia Centre for Estuarine Research. (2015). Acadia centre for estuarine research (ACER). Retrieved from http://acer.acadiau.ca

Acadia Tidal Energy Institute. (2015). Acadia tidal energy institute (ATEI). Retrieved from http://tidalenergy.acadiau.ca

Ackermann, T. (2012). *Wind power in power systems* Wiley. Retrieved from https://books.google.ca/books?id=y7430s86pQAC

Agnolucci, P., Akgul, O., McDowall, W., & Papageorgiou, L. G. (2013). The importance of economies of scale, transport costs and demand patterns in optimising hydrogen fuelling infrastructure: An exploration with SHIPMod (spatial hydrogen infrastructure planning model). *International Journal of Hydrogen Energy, 38*(26), 11189-11201. doi:http://dx.doi.org/10.1016/j.ijhydene.2013.06.071

Agnolucci, P., & McDowall, W. (2013). Designing future hydrogen infrastructure: Insights from analysis at different spatial scales. *International Journal of Hydrogen Energy, 38*(13), 5181-5191. doi:http://dx.doi.org/10.1016/j.ijhydene.2013.02.042

Allen, M. (August 2014). Electric range for the Nissan leaf & Chevrolet volt in cold weather. Retrieved from http://www.fleetcarma.com/nissan-leaf-chevrolet-volt-cold-weather-range-loss-electric-vehicle/

Ballard. (2012). *Economics of fuel cell solutions for material handling.* ().Ballard. doi:http://www.ballard.com/files/PDF/Material_Handling/MH_EconBenefits_FCvelocity_041411.pdf. (H2 Fuel Cell forklift economics with Ballard technology.)

Ballard. (2013). Ballard fuel cell MW class. Retrieved from http://www.ballard.com/fuel-cell-products/cleargen-multi-mw-systems.aspx

Berg, W. (2014). Triple bottom line approach to sustainability. Retrieved from http://www.olf.org.za/article/does-wealth--health/

Black, V. (2012). Cost and performance data for power generation technologies. *National Renewable Energy Laboratory, Golden, CO,* doi:http://bv.com/docs/reports-studies/nrel-cost-report.pdf

Bogart, S. L. (2002). Comparison of investment and related requirements for selected hydrogen vehicle system pathways. *Journal of Fusion Energy, 21*(3-4), 181-191. doi:10.1023/A:1026298614834

Bollen, M. H., & Hassan, F. (2011). *Integration of distributed generation in the power system* John Wiley & Sons. Retrieved from https://books.google.ca/books?id=rOeRW59djz8C

Bouchard, S., Landry, M., & Gagnon, Y. (2012). *Forest biomass to energy atlas of New Brunswick.* ().KC Irving Chair in Sustainable Development, Universite de Moncton. doi:http://www2.gnb.ca/content/dam/gnb/Departments/en/pdf/Maps-Cartes/201210BiomassReport.pdf

Broten, L. C. (November 2014). *Nova scotia tax and regulatory review.* ().Nova Scotia Finance Department. doi: http://www.novascotia.ca/finance/docs/tr/Tax_and_Regulatory_Review_Nov_2014.pdf

Brunet, Y. (2013). *Energy storage* Wiley.

Canada Energy Systems Analysis Research. (2014). CanESS energy and GHG visualizations. Retrieved from http://www.cesarnet.ca/visualization/

CEPA Environmental Registry. (April 2013). Setting Canadian standards for sulphur in heavy and light fuel oils - Environment Canada. Retrieved from http://www.ec.gc.ca/lcpe-cepa/default.asp?lang=En&n=51485387&offset=2&toc=show

Choi, B. K., & Kang, D. (2013). *Modeling and simulation of discrete event systems* Wiley. Retrieved from https://books.google.ca/books?id=0QpwAAAAQBAJ

Colella, W. G., Jacobson, M. Z., & Golden, D. M. (2005). Switching to a U.S. hydrogen fuel cell vehicle fleet: The resultant change in emissions, energy use, and greenhouse gases. *Journal of Power Sources, 150*(0), 150-181. doi:http://dx.doi.org/10.1016/j.jpowsour.2005.05.092

Corbetta, G., Pineda, I., & Moccia, J. (January 2014). *The European offshore wind industry - key trends and statistics 2013.* (). Europe: European Wind Energy Association. doi:http://www.ewea.org/fileadmin/files/library/publications/statistics/European_offshore_statistics_2013.pdf

Curtin, S., & Gangi, J. (September 2010). *The business case for fuel cells.* (). Washington, DC, USA: Fuel Cells 2000. doi:http://www.fuelcells.org/uploads/BusinessCaseforFuelCells.pdf. (H2 Fuel Technology Deployment and Demonstration Report regarding North America, Europe, and Asia.)

Dalton, J. (2012). *Financing of renewable electricity projects in Atlantic Canada prepared for Atlantic energy gateway - Atlantic Canada opportunities agency.* (). Nova Scotia Department of Energy: Power Advisory LLC. doi: http://energy.novascotia.ca/sites/default/files/aeg_financing_of_renewable_electricity_projects_in_atlantic_.pdf

Dawson, B., & Spannagle, M. (2008). *The complete guide to climate change* Taylor & Francis.

Delucchi, M. A., & Jacobson, M. Z. (2011). Providing all global energy with wind, water, and solar power, part II: Reliability, system and transmission costs, and policies. *Energy Policy, 39*(3), 1170-1190. doi:http://dx.doi.org/10.1016/j.enpol.2010.11.045

Elshkaki, A., & Graedel, T. E. (2013). Dynamic analysis of the global metals flows and stocks in electricity generation technologies. *Journal of Cleaner Production, 59*(0), 260-273. doi:http://dx.doi.org/10.1016/j.jclepro.2013.07.003

Environment Canada. (21 August 2008). Canada wind energy atlas. Retrieved from http://www.windatlas.ca/en/maps.php

Food and Agriculture Organization of the United Nations (2015). *Livestock Primary Data*

doi: http://faostat3.fao.org/download/Q/QC/E

FAO 2002 (Food and Agriculture Organization) – Climate Change and Forests, doi: http://www.fao.org/docrep/003/y0900e/y0900e06.htm

Feldman, D., Barbose, G., Margolis, R., Wiser, R., Darghouth, N., & Goodrich, A. (1 November 2012). *Photovoltaic (PV) pricing trends: Historical, recent, and near-term projections.* (No. DOE/GO-102012-3839). USA: National Renewable Energy Laboratory. doi:http://www.nrel.gov/docs/fy13osti/56776.pdf. (U.S. Department of Energy SunShot program)

(Global) Forest Resources Assessment 2015. *Forest Land Use Data Explorer 2015*, doi: http://www.fao.org/forest-resources-assessment/explore-data/en/

Fertig, E., & Apt, J. (2011). Economics of compressed air energy storage to integrate wind power: A case study in ERCOT. *Energy Policy, 39*(5), 2330-2342. doi:http://dx.doi.org/10.1016/j.enpol.2011.01.049

Freetutes.com. (2011). Prototyping software life cycle model. Retrieved from http://www.freetutes.com/systemanalysis/sa2-prototyping-model.html

Frischauf, N., Acosta-Iborra, B., Harskamp, F., Moretto, P., Malkow, T., Honselaar, M., . . . Soucek, A. (2013). The hydrogen value chain: Applying the automotive role model of the hydrogen economy in the aerospace sector to increase performance and reduce costs. *Acta Astronautica, 88*(0), 8-24. doi:http://dx.doi.org/10.1016/j.actaastro.2013.01.002

Fundy Energy Research Network. (2015). Fundy energy research network (FERN). Retrieved from http://fern.acadiau.ca

Fundy Ocean Research Center for Energy. (2015). Fundy ocean Research Center for Energy (FORCE). Retrieved from http://fundyforce.ca

Gasset, N., Gagnon, Y., Poitras, G. J. & Brothers, C. (October 2005). Prince Edward island wind atlas. Retrieved from http://www.gov.pe.ca/envengfor/windatlas/

Geoportal as part of the Government of Canada. (2015). *Ocean floor bathymetry ESRI map tool across Canada and Nova Scotia*. Canada: Geoportal as part of the Government of Canada. doi:http://geoportal.gc.ca/eng/Maps/Esrimap/11/

Goodland, Robert and Anhang, Jeff (December 2009). World Watch Institute. Volume 22. No 6. *Livestock and Climate Change: What if the key actors in climate change are…cows, pigs, and chickens?* url: http://www.worldwatch.org/node/6294 doi: http://www.worldwatch.org/files/pdf/Livestock%20and%20Climate%20Change.pdf

Government of Newfoundland and Labrador, Nalcor Energy, Emera, & HydroQuebec. (November 2010). In John Sopinski (Ed.), *Muskrat falls - Churchill power play* The Globe and Mail. doi:http://ns1758.ca/electric/globe-muskratfalls-2010nov18-rev.jpg

Goggin, Michael (2008). *Storage Not Needed to Accommodate Higher Levels of Wind Energy* doi: http://www.theenergycollective.com/michaelgoggin/2223136/storage-not-needed-accommodate-higher-levels-wind-energy

GreenPowerLabs. (2009). Annual solar map of nova scotia. Retrieved from http://www.greenpowerlabs.com/portfolio/solar-map-ns/

Halcyon Tidal Power LLC. (2014). *1100MW halcyon proposed project at scots bay* Halcyon Tidal Power LLC. doi:http://www.halcyontidalpower.com/wp-content/uploads/2014/03/scots-bay-map-NEW.jpg

Halifax Regional Municipality. (2006). *HRM wind master plan suitability model A2.* ().Halifax Regional Municipality. Retrieved from http://www.halifax.ca/regionalplanning/documents/FigureA1WindMasterPlanSuitabilityModelVersionTwo.pdf

Halifax Regional Municipality. (June 2015). SolarCity. Retrieved from http://www.halifax.ca/solarcity/

Hatch. (2008). *Nova scotia wind integration study – final report.* (). Nova Scotia, Canada: Hatch Ltd. doi:http://energy.novascotia.ca/sites/default/files/NS-Wind-Integration-Study-FINAL.pdf.

HRM OpenData. (2013). HRM OpenData. Retrieved from http://www.halifax.ca/opendata/

Hughes, L., & Scott, S. (1992). *Prospects for a hydrogen economy in Atlantic Canada.* (). Halifax, Nova Scotia, Canada: Saint Mary's University. doi:http://lh.ece.dal.ca/enen/h2paris.pdf

Jacobson, M. Z. (2009). Review of solutions to global warming, air pollution, and energy security. *Energy & Environmental Science, 2*(2), 148-173. doi:10.1039/B809990C

Jacobson, M. Z., & Delucchi, M. A. (2011). Providing all global energy with wind, water, and solar power, part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy, 39*(3), 1154-1169. doi:http://dx.doi.org/10.1016/j.enpol.2010.11.040

Jacobson, M. Z., Delucchi, M. A., Bazouin, G., Bauer, Z. A. F., Heavey, C. C., Fisher, E., . . . Yeskoo, T. W. (2015). 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 united states. *Energy & Environmental Science, 8*(7), 2093-2117. doi:10.1039/C5EE01283J

Karsten, R. H., Greenberg, D., & Tarbotton, M. (November 2011). Final report to OEER/OETR for assessment of the potential of tidal power from minas passage and minas basin research time frame: October, 2009 to September, 2011.(Project Number: 300-170-09-11), 25. doi:http://tethys.pnnl.gov/sites/default/files/publications/Karsten,%20Greenberg,%20and%20Tarbotten%202011.pdf

Karsten, R. H., Greenberg, D., Tarbotton, M., Walters, R., Culina, J., & O'Flaherty-Sproul, M. (2010). *Presentation of assessment of the potential of tidal power from minas passage and minas basin.* (). OEER/FORCE Tidal Energy Workshop: Acadia University. doi:http://www.oera.ca/wp-content/uploads/2013/05/Presentation-Richard-Karsten-Project.pdf

Karsten, R. H., McMillan, J. M., Lickley, M. J., & Haynes, R. D. (2008). Assessment of tidal current energy in the Minas Passage, Bay of Fundy. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy, 222*(5), 493-507.

Kim, J., & Moon, I. (2008). The role of hydrogen in the road transportation sector for a sustainable energy system: A case study of Korea. *International Journal of Hydrogen Energy, 33*(24), 7326-7337. doi:http://dx.doi.org/10.1016/j.ijhydene.2008.09.050

Lavalin. (2009). *Transmission and system operator options for nova scotia – final report.* (). Nova Scotia, Canada: Lavalin. doi:http://energy.novascotia.ca/sites/default/files/Transmission%20and%20System%20Operator%20Options%20for%20Nova%20Scotia.pdf. (Canadian-US Maritimes Region Transmission Grid Options)

Leber, J. (2015). A periodic table of elements that the world is running out of. Retrieved from http://m.fastcompany.com/3044467/a-periodic-table-of-elements-that-the-world-is-running-out-of

Li, Y., Wang, X., Li, D., & Ding, Y. (2012). A trigeneration system based on compressed air and thermal energy storage. *Applied Energy, 99*(0), 316-323. doi:http://dx.doi.org/10.1016/j.apenergy.2012.04.048

Li, Z., Gao, D., Chang, L., Liu, P., & Pistikopoulos, E. N. (2008). Hydrogen infrastructure design and optimization: A case study of china. *International Journal of Hydrogen Energy, 33*(20), 5275-5286. doi:http://dx.doi.org/10.1016/j.ijhydene.2008.06.076

Lipp, J. (February 2008). *Achieving local benefits: Policy options for community energy in nova scotia.* ().Nova Scotia Department of Energy.

Lipp, J., Pattenden, M., & Tampier, M. (October 2006). *Towards a green power vision and strategy for Atlantic Canada.* ().Toronto, Ont. : Pollution Probe ; Halifax, N.S. : Marine & Environmental Law Institute, Dalhousie Law School. doi:https://www.yumpu.com/en/document/view/29465348/towards-a-green-power-vision-and-strategy-for-pollution-probe.

Lund, H. (2014). *Renewable energy systems: A smart energy systems approach to the choice and modeling of 100% renewable solutions* Elsevier Science.

Manchester, S. (2014). Regenerative air energy storage for renewable energy integration: System modeling and optimization., 32.

Mathiesen, B. V. (2008). *Fuel cells and electrolysers in future energy systems* doi:http://vbn.aau.dk/ws/files/38596264/Fuel_cells_and_electrolysers.pdf

McDonough, W., & Braungart, M. (2010). *Cradle to cradle: Remaking the way we make things* Farrar, Straus and Giroux.

McDonough, W., & Braungart, M. (April 2013). *The upcycle: Beyond sustainability - designing for abundance* (1st ed.). North America: Farrar, Straus and Giroux.

Natural Resources Canada. (2010). Office of energy efficiency: 2008 Canadian vehicle survey update report. Retrieved from http://oee.nrcan.gc.ca/publications/statistics/cvs08/chapter2.cfm?attr=0

Natural Resources Canada. (2014). *RETScreen energy planning tool* (4th ed.). Canada: Natural Resources Canada.

Nebraska Energy Office. (16 April 2015). Annual average electricity price comparison by state (USA). Retrieved from http://www.neo.ne.gov/statshtml/204.htm

Nova Scotia Department of Energy. (2010a). Nova scotia wind atlas. Retrieved from http://www.nswindatlas.ca

Nova Scotia Department of Energy. (2010b). *Renewable electricity plan.* ().Nova Scotia Department of Energy. doi:http://energy.novascotia.ca/sites/default/files/renewable-electricity-plan.pdf. (NS Provincial Energy Goals and Policies)

Nova Scotia Department of Energy. (2012). *Phase 1 – muskrat falls map* Nova Scotia Department of Energy. doi:http://powerinourhands.ca/pdf/Muskrat%20Falls%20Project%20Map.pdf

Nova Scotia Department of Energy. (2015a). Marine renewable energy in nova scotia. Retrieved from http://energy.novascotia.ca/renewables/marine-renewable-energy

Nova Scotia Department of Energy. (2015b). *Marine renewable energy resources plain language overview.* (). doi:http://energy.novascotia.ca/sites/default/files/files/Plain%20Language%20Overview_MRE%20Act.pdf

Nova Scotia Department of Energy. (2015c). *Offshore oil map for future bids - has general outline of sea floor depth at 50 and 100 meters.* doi:http://energy.novascotia.ca/sites/default/files/Future_Call_Areas_16_17_0.jpg

Nova Scotia Department of Energy. (May 30 2014). *Market trends for the supply & demand of electricity in nova scotia.* ().ICF International. doi:http://energy.novascotia.ca/sites/default/files/files/Electricity-Review-NS-DOE-Market-Trends-Report.pdf. (Electricity System Review)

Nova Scotia Department of Environment. (2009). *Toward a greener future: Nova scotia's climate change action plan.* ().Nova Scotia Department of Environment. doi:http://climatechange.novascotia.ca/sites/default/files/uploads/ccap.pdf.

Nova Scotia Power. (2013). *Nova scotia power major facilities map 2013 - page 1 2014 annual capital expenditure plan* Nova Scotia Power. doi:https://www.nspower.ca/site/media/Parent/20131213%20NS%20Power%202014%20ACE%20Plan%20REDACTED%20-%20REFILED%2020131213.pdf

Nova Scotia Power. (2016a). *Nova scotia power air emissions reporting.* Nova Scotia Power. doi: http://www.nspower.ca/en/home/about-us/environmental-commitment/air-emissions-reporting/default.aspx

Nova Scotia Power. (2016b). *Nova scotia power total system emissions - all plants.* Nova Scotia Power. doi: http://www.nspower.ca/en/home/about-us/environmental-commitment/air-emissions-reporting/total-system-emissions-all-plants.aspx

National Renewable Energy Laboratory (NREL) (2010). *Analysis of Hydrogen and Competing Technologies for Utility-Scale Energy Storage - page 4* doi: http://www.nrel.gov/docs/fy10osti/47547.pdf

PEI Energy Corporation. (June 2003). *PEI wind-hydrogen symposium 2003.* ().PEI Energy Corporation. doi:http://www.gov.pe.ca/photos/original/dev_outcomes.pdf. (PEI Wind-Hydrogen Symposium 2003)

Bernard, Mike (2012). *Want to save 70 million birds a year? Build more wind farms*. doi: http://reneweconomy.com.au/2012/want-to-save-70-million-birds-a-year-build-more-wind-farms-18274

Robb, D. (2011). The CAES for wind. *Renewable Energy Focus, 12*(1), 18-19. doi:http://dx.doi.org/10.1016/S1755-0084(11)70014-X

Seel, J., Barbose, G., & Wiser, R. (2013). *Why are residential PV prices in Germany so much lower than in the united states.* (). doi:http://emp.lbl.gov/sites/all/files/german-us-pv-price-ppt.pdf

Silverstein, H. B. (1981). Canada and hydrogen systems: An energy policy for a nation. *International Journal, 36*(2), 294-310. doi:10.2307/40201957

SocialWorkJobs.com. (2014). Business ethics and social responsibility. Retrieved from http://www.socialwork-jobs.com/wp-content/uploads/2015/05/Business-Ethics-and-Social-Responsibility.jpg

Stuart, E. K. (2006). Energizing the island community: A review of policy standpoints for energy in small island states and territories. *Sustainable Development, 14*(2), 139-147. doi:10.1002/sd.299

Suda, B. (2014). Deterministic design module - draw SVG wind rose. Retrieved from https://github.com/briansuda/Deterministic-Design

Szumilas, A., Swerhun, B., & Lye, J. (2011). Watts at stake?: Protecting North America's energy infrastructure from cascading failure and terrorist threats. *Dalhousie Journal of Interdisciplinary Management, 7*(Fall), 1-13. doi:http://dx.doi.org/10.5931/djim.v7i2.66

Tarbotton, M., & Larson, M. (2006). *Canada ocean energy atlas (phase 1) potential tidal current energy resources analysis background.* ().Triton Consultants Ltd. doi:http://www.marinerenewables.ca/wp-content/uploads/2012/11/Canada-Ocean-Energy-Atlas-Phase1-Potential-Tidal-Current-Energy-Resources-Analysis-Background.pdf

Theckedath, D. (1 February 2010). *Where is the hydrogen economy? background paper.* (No. 2010-16-E).Library of Parliament. doi:http://publications.gc.ca/collections/collection_2010/bdp-lop/bp/2010-16-eng.pdf

Thompson, J. L. (4 June 2015). Nova Scotia’s Energy Map. Retrieved from www.gonotes.org

Vallero, D. (2014). *Fundamentals of air pollution* Elsevier Science.

Valpy, B., & English, P. (2014). *Future renewable energy costs: Onshore wind - how technology innovation is anticipated to reduce the cost of energy from European onshore wind farms.* (). Europe: BVG Associates. doi: http://www.kic-innoenergy.com/wp-content/uploads/2014/09/KIC_IE_OnshoreWind_anticipated_innovations_impact.pdf

Wikipedia. (2015). Tesla model S - battery lifespan and charger. Retrieved from https://en.wikipedia.org/wiki/Tesla_Model_S

Wilson, L. (2014). The carbon FoodPrint of 5 diets compared. Retrieved from http://shrinkthatfootprint.com/food-carbon-footprint-diet

Wind Energy The Facts. (2009). Development of the cost of offshore wind power up to 2015. Retrieved from http://www.wind-energy-the-facts.org/development-of-the-cost-of-offshore-wind-power-up-to-2015.html

Secondary References

Abbaspour, M., Satkin, M., Mohammadi-Ivatloo, B., Hoseinzadeh Lotfi, F., & Noorollahi, Y. (2013). Optimal operation scheduling of wind power integrated with compressed air energy storage (CAES). *Renewable Energy, 51*(0), 53-59. doi: http://dx.doi.org/10.1016/j.renene.2012.09.007

EA Energy Analyses. (2008). *Large scale wind power in New Brunswick: A regional scenario study towards 2025*. EA Energy Analyses. doi:http://www.uwig.org/LargeScaleWindPowerinNBAugust%202008.pdf.

Elam, C. C., Padr├│, C. E. G., Sandrock, G., Luzzi, A., Lindblad, P., & Hagen, E. F. (2003). Realizing the hydrogen future: The international energy agency's efforts to advance hydrogen energy technologies. *International Journal of Hydrogen Energy; CANCUN-01, 28*(6), 601-607. doi: http://dx.doi.org/10.1016/S0360-3199(02)00147-7

Environment: The Science Behind the Stories 2015, Jay Withgott

Ecofys, World GHG Emissions Flow Chart 2010, nieuws.asnbank.nl/download/161902/worldghgemissionsflowchart.pdf

Fisher, M. (2013). *HTML5 for flash developers* Packt Publishing. Retrieved from https://books.google.ca/books?id=O2DWzWRnQPwC

Global Carbon Project Data 2015, Reference of the full global carbon budget 2015: "Le Quéré, C, R Moriarty, RM Andrew, JG Canadell, S Sitch, JI Korsbakken, P Friedlingstein, GP Peters, RJ Andres, TA Boden, RA Houghton, JI House, RF Keeling, P Tans, A Arneth, DCE Bakker, L Barbero, L Bopp, J Chang, F Chevallier, LP Chini, P Ciais, M Fader, RA Feely, T Gkritzalis, I Harris, J Hauck, T Ilyina, AK Jain, E Kato, V Kitidis, K Klein Goldewijk, C Koven, P Landschützer, SK Lauvset, N Lefèvre, A Lenton, ID Lima, N Metzl, F Millero, DR Munro, A Murata, JEMS Nabel, S Nakaoka, Y Nojiri, K O'Brien, A Olsen, T Ono, FF Pérez, B

Pfeil, D Pierrot, B Poulter, G Rehder, C Rödenbeck, S Saito, U Schuster, J Schwinger, R Séférian, T Steinhoff, BD Stocker, AJ Sutton, T Takahashi, B Tilbrook, IT van der Laan-Luijkx, GR van der Werf, S van Heuven, D Vandemark, N Viovy, A Wiltshire, S Zaehle, and N Zeng 2015 Global Carbon Budget 2015 Earth System Science Data, 7, 349-396 doi:10.5194/essd-7-349-2015", http://cdiac.ornl.gov/GCP/

Hoffheinz, G., Kelly, N., & Ete, A. (2007). Evaluation of hydrogen demonstration systems & united kingdom hydrogen infrastructure. 1-129. doi:http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.115.6659&rep=rep1&type=pdf

International Energy Agency – World Energy Statistics 2014, (newer version) https://www.iea.org/publications/freepublications/publication/key-world-energy-statistics-2015.html

Koper, A. J. (2014). *The development of an effective wind energy regime in nova scotia* VDM Publishing.

Kroposki, B. (2006). *Renewable electrolysis integrated system development and testing.* National Renewable Energy Laboratory. doi:http://www.hydrogen.energy.gov/pdfs/review06/pd_7_kroposki.pdf

Lubis, L. I., Dincer, I., Naterer, G. F., & Rosen, M. A. (2009). Utilizing hydrogen energy to reduce greenhouse gas emissions in Canada's residential sector. *International Journal of Hydrogen Energy, 34*(4), 1631-1637. doi: http://dx.doi.org/10.1016/j.ijhydene.2008.12.043

Lund, H. (2015). In Connolly D., . . . Maya-Drysdale D.(Eds.), *EnergyPLAN: Deterministic national energy planning tool* (12th ed.). Denmark: Department of Development and Planning, Aalborg University.

Madlener, R., & Latz, J. (2013). Economics of centralized and decentralized compressed air energy storage for enhanced grid integration of wind power. *Applied Energy; Sustainable*

Development of Energy, Water and Environment Systems, 101(0), 299-309. doi: http://dx.doi.org/10.1016/j.apenergy.2011.09.033

Marano, V., Rizzo, G., & Tiano, F. A. (2012). Application of dynamic programming to the optimal management of a hybrid power plant with wind turbines, photovoltaic panels and compressed air energy storage. *Applied Energy; Energy Solutions for a Sustainable World - Proceedings of the Third International Conference on Applied Energy, may 16-18, 2011 - Perugia, Italy, 97*(0), 849-859. doi: http://dx.doi.org/10.1016/j.apenergy.2011.12.086

Naterer, G. F., Fowler, M., Cotton, J., & Gabriel, K. (2008). Synergistic roles of off-peak electrolysis and thermochemical production of hydrogen from nuclear energy in Canada. *International Journal of Hydrogen Energy, 33*(23), 6849-6857. doi: http://dx.doi.org/10.1016/j.ijhydene.2008.09.011

New Brunswick System Operator.*10-year outlook: An assessment of the adequacy of generation and transmission facilities in New Brunswick 2011-2021*.New Brunswick System Operator. Retrieved from www.nbpower.com

New Brunswick System Operator. (2007). *Maritimes area wind power integration study summary report - NBSO.* ().New Brunswick System Operator doi:http://www.uwig.org/nbso_wind_study_project_final_summary_report_may_2007.pdf

Nguyen, L. (8 October 2009). *Hydrogen and fuel cells: It Won't take miracles.* ().California Fuel Cell Partnership. doi: http://cafcp.org/sites/files/20091008_FourMiracles.pdf

Nova Scotia Power. (2007-2012). *Monthly generating facility net energy output table 2007-2012. oasis.* ().Nova Scotia Power. Retrieved from http://oasis.nspower.ca/en/home/oasis/forecasts-and-assessments.aspx

Nova Scotia Power. (2012). *NSPI April 2012 - utility performance benchmarking analysis.* ().Nova Scotia Power.

doi:https://www.nspower.ca/site/media/Parent/NSPI%202013%20GRA%20-%201%20DE%20Appendices%20-%20REDACTED.pdf

Nova Scotia Power. (2013). *10 year load and resource assessment. oasis – forecasts and assessments.* ().Nova Scotia Power. Retrieved from http://oasis.nspower.ca/site/media/oasis/10%20Year%20Load%20and%20Resource%20Assessment%20Jun%2028%202013.pdf

Nova Scotia Power. (2013). *Nova scotia power major facilities map 2013 - page 1 of 2014 annual capital expenditure plan* Nova Scotia Power. doi:https://www.nspower.ca/site/media/Parent/20131213%20NS%20Power%202014%20ACE%20Plan%20REDACTED%20-%20REFILED%2020131213.pdf

Nova Scotia Power. (2014). *18 month forecast and assessment. oasis Apr 2014 – forecasts and assessments.* ().Nova Scotia Power. Retrieved from http://oasis.nspower.ca/site/media/oasis/18%20Month%20Forecast%20and%20Assessment%20Apr%202014%20-%20Sep%202015.pdf

Nutaro, J., Phani, T. K., Shankar, M., Miller, L., & Mullen, S. (2008). Integrated modeling of the electric grid, communications, and control. *Int J of Energy Sector Man, 2*(3), 420-438. doi:10.1108/17506220810892955

Pape-Salmon, A., Dogterom, J., Wieler, C., & Anielski, M. (2003). *Low-impact renewable energy policy in Canada: Strengths, gaps and a path forward* Pembina Institute for Appropriate Development. doi: http://www.pembina.org/reports/lire030310.pdf

Pearre, N. S., & Swan, L. G. (2013). Renewable electricity and energy storage to permit retirement of coal-fired generators in nova scotia. *Sustainable Energy Technologies and Assessments, 1*(0), 44-53. doi: http://dx.doi.org/10.1016/j.seta.2013.01.001

QGIS. (2015). *QGIS* Software Mapping Tool (2.8.2 ed.). USA: QGIS.

Steve Bogart 2016, Create your own Sankey Diagram 2016, http://sankeymatic.com/build/

Stoddard, M. D., Murrow, D. K., Koontz, R., & Environment Northeast. (2006). *Climate change roadmap for New England and eastern Canada*. Rockport, ME: Environment Northeast. doi:http://www.usclimatenetwork.org/resource-database/full_climate_roadmap.pdf

Symes, D., Al-Duri, B., Dhir, A., Bujalski, W., Green, B., Shields, A., & Lees, M. (2012). Design for on-site hydrogen production for hydrogen fuel cell vehicle refueling station at University of Birmingham, U.K. *Energy Procedia; WHEC 2012 Conference Proceedings of 19th World Hydrogen Energy Conference, 29*(0), 606-615. doi: http://dx.doi.org/10.1016/j.egypro.2012.09.070

Trees Planted Carbon Estimate 2016, Greenhouse Gas Calculator. https://treecanada.ca/en/programs/grow-clean-air/carbon-calculator/

Woods, S. (2013). *Building touch interfaces with HTML5: Develop and design speed up your site and create amazing user experiences* Pearson Education. Retrieved from https://books.google.ca/books?id=YJjhXTU3X0YC

Yang, Y., Enjeti, P., Blaabjerg, F., & Wang, H. (2013). Suggested grid code modifications to ensure wide-scale adoption of photovoltaic energy in distributed power generation systems. Paper presented at the *Industry Applications Society Annual Meeting, 2013 IEEE,* 1-8. doi:http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6682485

Appendix A: Burnside PV Potential

Burnside Solar Energy Potential

1.2 Million Square meters of Roof Area, 669 buildings, average 42.5 square meters per building. (HRM OpenData, 2013)

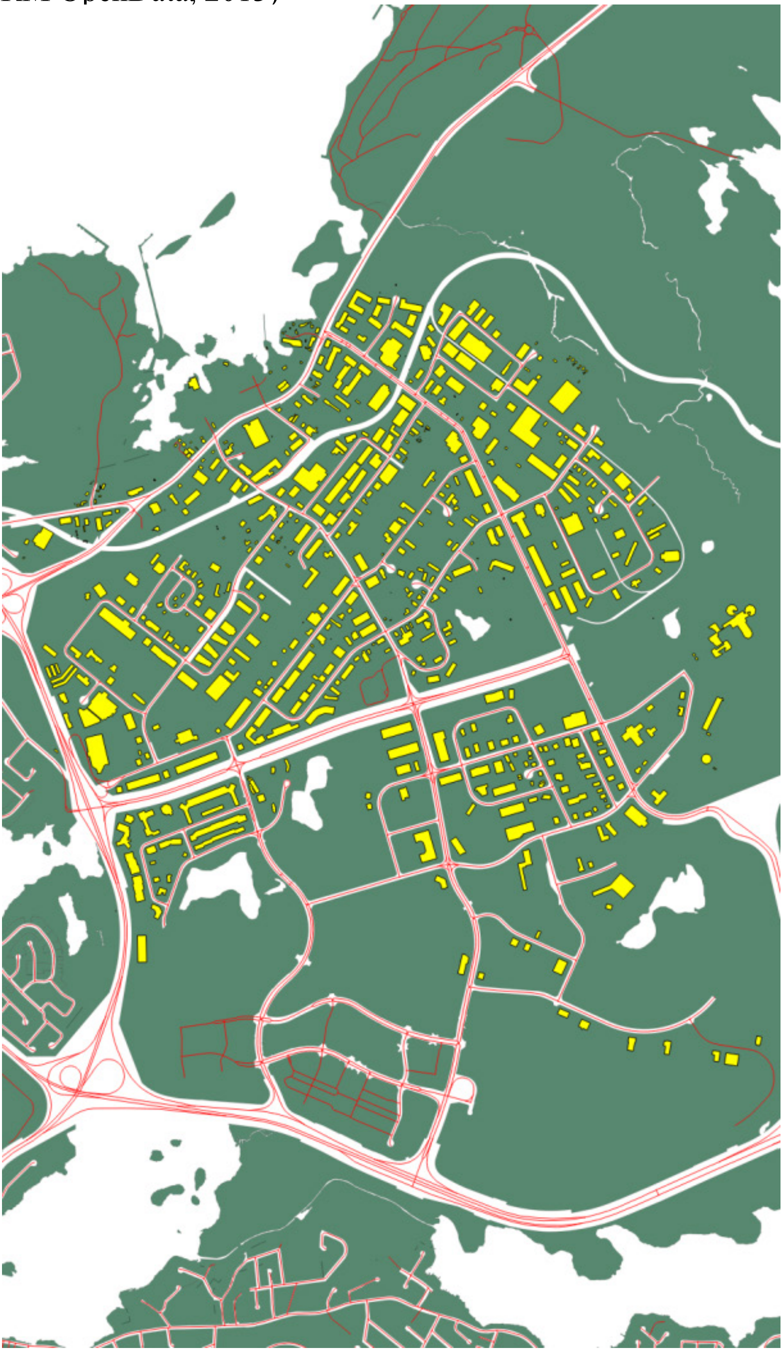


Figure 105: Burnside Solar PV Potential

Appendix B: Feature Timeline

				ESTIMATE	ACTUAL	BEGIN	DEADLINE
ID	**Current/Fix/Update/Remove/New Features:**	**STATUS**	**DAYS**	**HRS**	**HRs**	**DATE**	**DATE**
1	Renewable Resource Maps: Wind (30,50,80 meters), Solar, Tidal	100%					Prior
2	FCEV powered annually calculations	100%					2014
3	Wind Farm Maps (any wind farm greater than 4 units)	100%					Prior
4	Hydropower, Tidal, Wind, Biomass, Combustion, Coal, Planned Plants	100%					30/12/2015
5	Pie Chart of power plant categories and shaded by units	100%					Prior
6	Interactive Line Chart of personal power use estimator	100%					Prior
7	Calculator of energy use and cost	100%					prior
8	HRM Zoom in map Building polygons image, road networks, power lines	100%			Unk		01/01/2014
17	Biomass broken! 26.2MW should be 3.2MW in HRM zoom: PieChart Newglasgow and middlemusquodoboit? OR brooklyn/sackville/MM?	100%			1		01/01/2014
14	FCEV wind calculation curve for ideal turbine	100%	2.25	18	35	06/05/2014	21/08/2014
24	Latitude-Longitude Dynamic PowerPlant Population -With database	100%	3	24	28	09/05/2014	22/08/2014
25	Green planned units will dynamically update to normal colour once current computer/server date is met	100%	0.5	4	8	05/08/2014	23/08/2014
26	User added Plants	100%	5	40	28	13/05/2014	30/12/2015
38	Maritime Link Transmission Line	100%	1	8		15/10/2014	16/10/2014
23	Database of products? Wind, Solar, Tidal	100%	10	48	80	14/02/2015	09/03/2015

Table 26: Only includes completed Features Timeline (any significant features are in Future Plans)

Appendix C: Wind Farm Data

Units	Model	makeN	num N	Unit RC N	Output	Name	Built/ Added	turb_id	Company	Lat	Long	hub
17	Vestas	V80		1.8	30.6	Pubnico Point	2004	229	FPL ENERGY	43.603	65.804	78
1	Turbowinds	T-600-48		0.6	0.6	Little Brook	2002	202	NSP	44.298	66.097	50
1	EWT	DW52		0.9	0.9	Tiverton	2006	73	Renewable Energy Developers Inc	44.407	66.189	50
20	General Electric	GE 1.5 sle		1.5	30	Digby Neck	2010	94	NSP	44.597	65.949	80
1	Enercon	E48		0.8	0.8	Digby	2006	58	RESL	44.649	65.799	50
1	Turbowinds	T-600-48		0.6	0.6	Goodwood	2005	202	RESL	44.607	63.678	50
1	Turbowinds	T-600-48		0.6	0.6	Brookfield	2005	202	RESL	45.267	63.252	50
3	Vensys	V62		1.2	3.6	Higgins Mtn	2007	208	Renewable Energy Developers Inc	45.576	63.617	69
2	Vensys; EWT	V62; DW52	1;1	1.2; 0.9	2.1	Springhill	2005; 2006	208; 73	Renewable Energy Developers Inc	45.611	64.024	69; 50
15	Suzlon Energy	S97		2.1	31.5	Amherst	2012	199	Renewable Energy Developers Inc	45.828	64.248	90
1	Enercon	E48		0.8	0.8	Tatamagouche-RiverJohn/ Marshville	2006	58	RESL	45.757	63.102	50
22	Enercon	E82		2.3	50.6	Nuttby Mtn	2010	63	NSP	45.561	63.225	78
34	General Electric	GE 1.5 sle		1.5	51	Dalhousie Mtn	2009	94	RMS Energy	45.577	62.971	80
1	Enercon	E48		0.8	0.8	Spiddle Hill	2011	58	Colchester-Cumberland Wind Field Inc	45.616	63.192	50
2	Enercon	E48		0.8	1.6	Fitzpatrick Mtn	2006	58	Shear Wind	45.627	62.898	50
1	Vensys	V77		1.5	1.5	Watt Section	2011	210	Watts Wind Energy Inc	44.899	62.471	85
27	Enercon	E82		2.3	62.1	Glen Dhu	2011	63	Shear Wind Inc.	45.667	62.229	78
4	Vensys	V77		1.5	6	Maryvale	2010	210	Maryvale Wind	45.729	62.065	85

12	Enercon	E48,E82	1;11	0.8;2.05	23.4	Point Tupper	2006; 2010	58;63	RESL/NSP	45.571	61.311	50; 78
1	Vestas	V-47 660		0.66	0.66	Grand Etang	2002	224	NSP	46.549	61.038	50
8	Enercon	E70,E70; E82;E82	4,1; 2;1	2.3,2.03; 2.3;2.3	18.19	Lingan	2006; 2007 ;2012	61; 60; 63; 63	Renewable Energy Developers Inc	46.241	60.039	64, 64; 78; 78
1	Enercon	E48		0.8	0.8	Glace Bay	2005	58	Renewable Energy Developers Inc	46.218	59.981	50
1	Enercon	E48		0.8	0.8	Donkin	2005	58	Renewable Energy Developers Inc	46.185	59.897	50
1	Vestas	V100		2	2	Parker Mountain	2014	241	Scotian Windfields	44.795	65.498	100
12	Suzlon Energy	S95		2.1	25.2	Hampton Mtn-GranvilleFerry	2012	263	Renewable Energy Developers Inc	44.884	65.299	80
34	Acciona	AW3000-116		3	102	South Canoe	2015	13	Oxford Frozen Foods +Minas Basin Pulp/ NSP	44.768	64.345	92
12	Siemens	SWT 2.3 113		2.3	27.6	Pugwash	2014	264	Atlantic Wind Power Corp	45.857	63.619	99.5
30	General Electric	GE 1.68 - 80.5		1.68	50.4	Clydesdale Ridge	2014	265	Clydesdale Ridge Wind LP	45.562	63.046	80
1	Enercon	E82		2.3	2.3	Irish Mtn	2014	63	Black River Wind	45.493	62.624	78
2	Enercon	E82		2.3	4.6	Fairmont	2014	63	Wind Prospect Inc.	45.682	61.987	78
6	Enercon	E82		2.3	13.8	Sable Wind	2015	63	Municipality of Guysborough	45.318	60.997	78
1	Enercon	E82		2.3	2.3	Creignish Rear	2014	63	Black River Wind	45.726	61.42	78
1	Enercon	E82		2.3	2.3	South Cape Mabou	2014	63	Black River Wind	46.126	61.399	78

Table 27: Wind Farm Data for Nova Scotia (not including 41 ComFIT projects)

Appendix D: Personal Transport CanESS

Units in PJ		Average 25%		
Oil Domestic Use	Conversion Losses	Useful Energy: Avg 9.42		Year
37	28	9	24.32%	2010
36	27	9	25.00%	2009
40	30	10	25.00%	2008
38	29	10	26.32%	2007
40	30	10	25.00%	2006
40	30	10	25.00%	2005
40	30	10	25.00%	2004
39	30	10	25.64%	2003
39	29	10	25.64%	2002
38	28	9	23.68%	2001
39	29	10	25.64%	2000
40	30	10	25.00%	1999
39	29	10	25.64%	1998
38	28	9	23.68%	1997
38	28	9	23.68%	1996
38	28	9	23.68%	1995
37	27	9	24.32%	1994
36	27	9	25.00%	1993
35	26	9	25.71%	1992
34	26	9	26.47%	1991
37	28	9	24.32%	1990
36	27	9	25.00%	1989
37	28	9	24.32%	1988
36	27	9	25.00%	1987
35	27	9	25.71%	1986
36	27	9	25.00%	1985
36	27	9	25.00%	1984
35	26	9	25.71%	1983
37	28	9	24.32%	1982
39	29	10	25.64%	1981
40	30	10	25.00%	1980
40	30	10	25.00%	1979
39	29	10	25.64%	1978

Table 28: Personal Transport Primary Energy in PJ CanESS 2010

Appendix E: H_2 Fuel Cell Power Plants and EROI

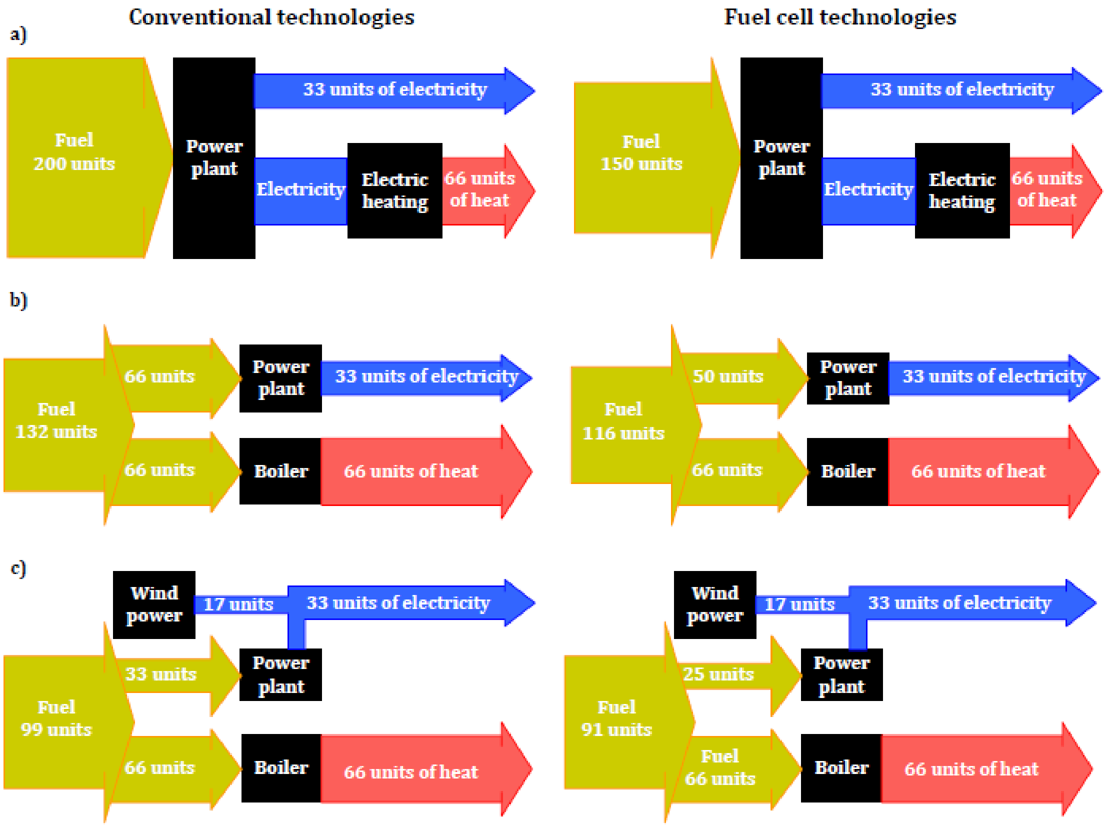


Fig. 2, Schema of energy systems with and without wind power, in which the electricity and heat supplies are met by electricity from power plants alone or from power plants and fuel boilers.

Figure 106: Fuel cells and electrolysers in future energy systems: (Mathiesen, 2008) page 24

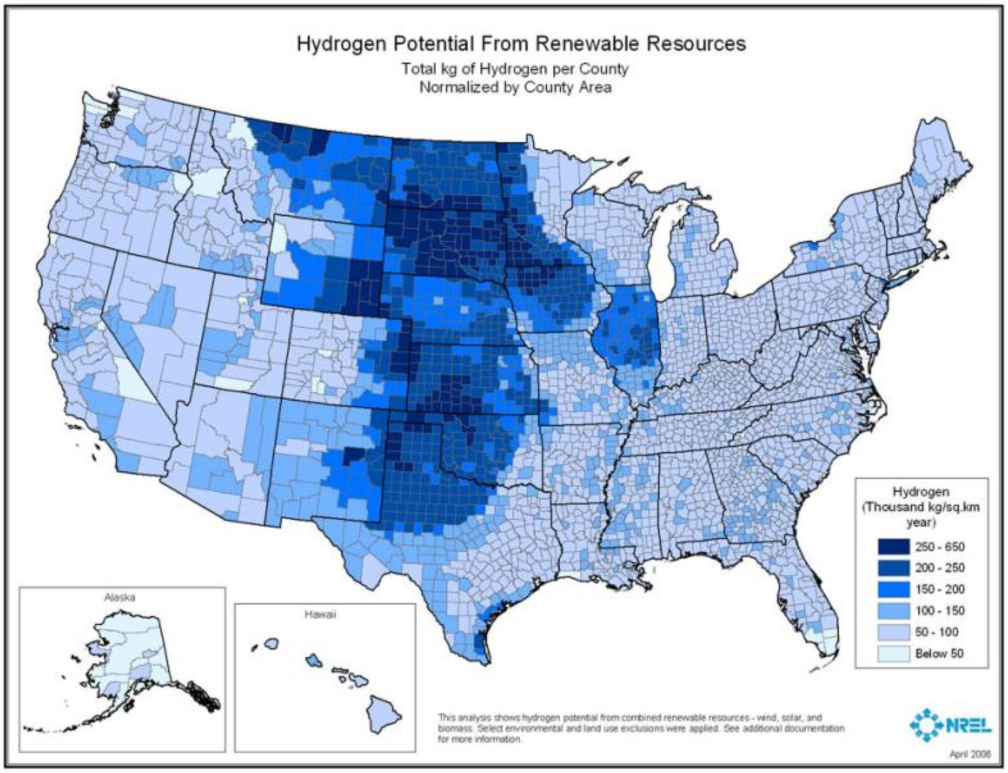
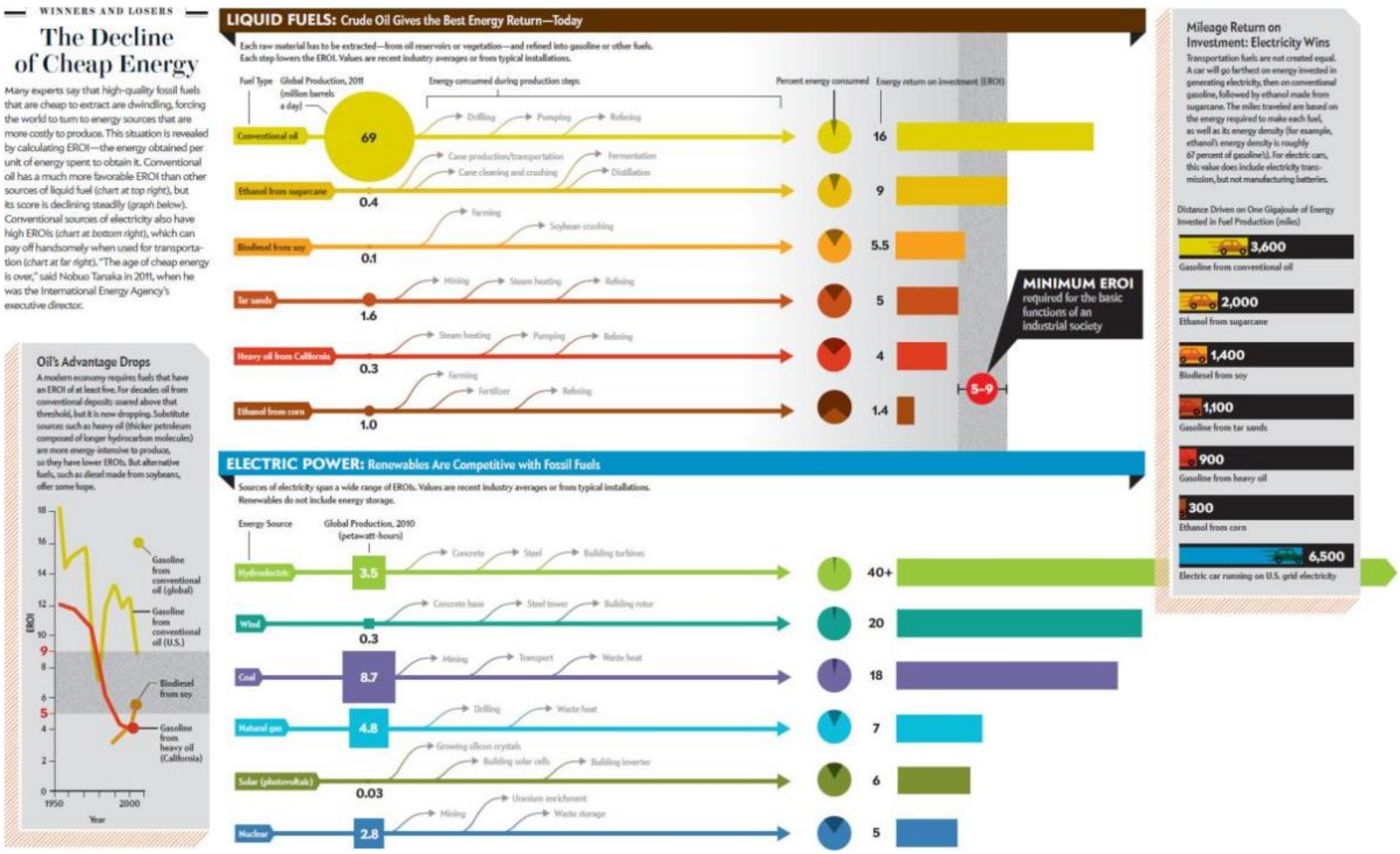


Figure 107: Hydrogen Potential from WSB Renewable Resources USA – NREL

https://maps.nrel.gov/hydra/

This is a tool used to view Wind, Solar, and Biomass resource potential in the production capacity maps with multiple layered options that can be selected.



WINNERS AND LOSERS

The Decline of Cheap Energy

Many experts say that high-quality fossil fuels that are cheap to extract are dwindling, forcing the world to turn to energy sources that are more costly to produce. This situation is revealed by calculating EROI—the energy obtained per unit of energy spent to obtain it. Conventional oil has a much more favorable EROI than other sources of liquid fuel (chart at top right), but its score is declining steadily (graph below). Conventional sources of electricity also have high EROIs (chart at bottom right), which can pay off handsomely when used for transportation (chart at far right). "The age of cheap energy is over," said Nobuo Tanaka in 2011, when he was the International Energy Agency's executive director.

Oil's Advantage Drops

A modern economy requires fuels that have an EROI of at least five. For decades oil from conventional deposits soared above that threshold, but it is now dropping. Substitute sources such as heavy oil (thicker petroleum composed of longer hydrocarbon molecules) are more energy-intensive to produce, so they have lower EROIs. But alternative fuels, such as diesel made from soybeans, offer some hope.

LIQUID FUELS: Crude Oil Gives the Best Energy Return—Today

Each raw material has to be extracted—from oil reservoirs or vegetation—and refined into gasoline or other fuels. Each step lowers the EROI. Values are recent industry averages or from typical installations.

ELECTRIC POWER: Renewables Are Competitive with Fossil Fuels

Sources of electricity span a wide range of EROIs. Values are recent industry averages or from typical installations. Renewables do not include energy storage.

Mileage Return on Investment: Electricity Wins

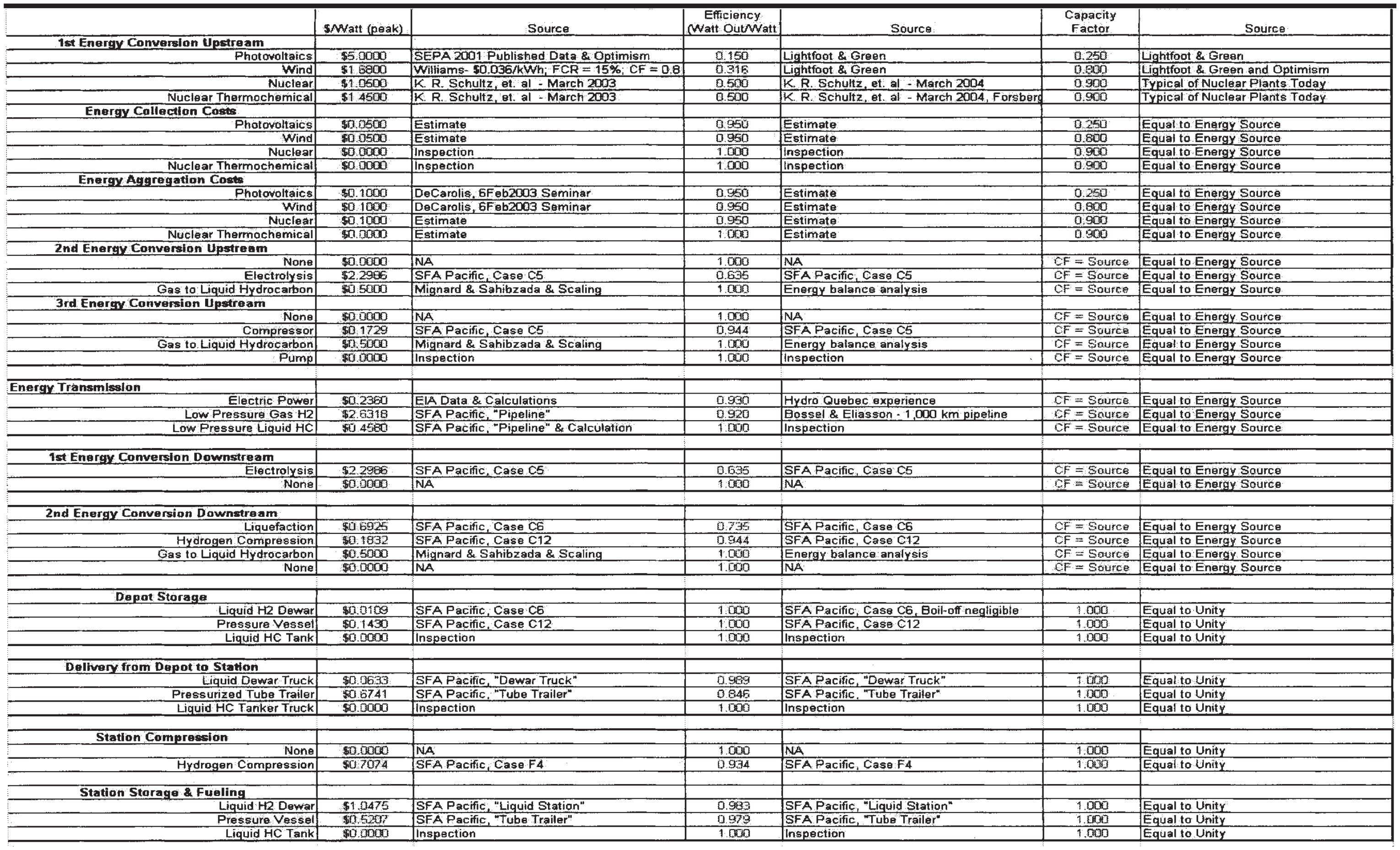
Transportation fuels are not created equal. A car will go farthest on energy invested in generating electricity, then on conventional gasoline, followed by ethanol made from sugarcane. The miles traveled are based on the energy required to make each fuel, as well as its energy density (for example, ethanol's energy density is roughly 67 percent of gasoline's). For electric cars, this value does include electricity transmission, but not manufacturing batteries.

Figure 108: Energy Return on Investment values (EROI) – wind is higher than conventional oil and coal

http://www.nature.com/scientificamerican/journal/v308/n4/box/scientificamerican0413-58_BX2.html

Appendix F: H_2 Fuel Cell Transportation

Table 1. Efficiency, Cost, and Capacity Factor Matrix



	$/Watt (peak)	Source	Efficiency (Watt Out/Watt	Source	Capacity Factor	Source
1st Energy Conversion Upstream						
Photovoltaics	$5.0000	SEPA 2001 Published Data & Optimism	0.150	Lightfoot & Green	0.250	Lightfoot & Green
Wind	$1.6800	Williams- $0.036/kWh; FCR = 15%; CF = 0.8	0.316	Lightfoot & Green	0.800	Lightfoot & Green and Optimism
Nuclear	$1.0600	K. R. Schultz, et. al - March 2003	0.500	K. R. Schultz, et. al - March 2004	0.900	Typical of Nuclear Plants Today
Nuclear Thermochemical	$1.4500	K. R. Schultz, et. al - March 2003	0.500	K. R. Schultz, et. al - March 2004, Forsberg	0.900	Typical of Nuclear Plants Today
Energy Collection Costs						
Photovoltaics	$0.0500	Estimate	0.950	Estimate	0.250	Equal to Energy Source
Wind	$0.0500	Estimate	0.950	Estimate	0.800	Equal to Energy Source
Nuclear	$0.0000	Inspection	1.000	Inspection	0.900	Equal to Energy Source
Nuclear Thermochemical	$0.0000	Inspection	1.000	Inspection	0.900	Equal to Energy Source
Energy Aggregation Costs						
Photovoltaics	$0.1000	DeCarolis, 6Feb2003 Seminar	0.950	Estimate	0.250	Equal to Energy Source
Wind	$0.1000	DeCarolis, 6Feb2003 Seminar	0.950	Estimate	0.800	Equal to Energy Source
Nuclear	$0.1000	Estimate	0.950	Estimate	0.900	Equal to Energy Source
Nuclear Thermochemical	$0.0000	Estimate	1.000	Estimate	0.900	Equal to Energy Source
2nd Energy Conversion Upstream						
None	$0.0000	NA	1.000	NA	CF = Source	Equal to Energy Source
Electrolysis	$2.2986	SFA Pacific, Case C5	0.635	SFA Pacific, Case C5	CF = Source	Equal to Energy Source
Gas to Liquid Hydrocarbon	$0.5000	Mignard & Sahibzada & Scaling	1.000	Energy balance analysis	CF = Source	Equal to Energy Source
3rd Energy Conversion Upstream						
None	$0.0000	NA	1.000	NA	CF = Source	Equal to Energy Source
Compressor	$0.1729	SFA Pacific, Case C5	0.944	SFA Pacific, Case C5	CF = Source	Equal to Energy Source
Gas to Liquid Hydrocarbon	$0.5000	Mignard & Sahibzada & Scaling	1.000	Energy balance analysis	CF = Source	Equal to Energy Source
Pump	$0.0000	Inspection	1.000	Inspection	CF = Source	Equal to Energy Source
Energy Transmission						
Electric Power	$0.2360	EIA Data & Calculations	0.930	Hydro Quebec experience	CF = Source	Equal to Energy Source
Low Pressure Gas H2	$2.6318	SFA Pacific, "Pipeline"	0.920	Bossel & Eliasson - 1,000 km pipeline	CF = Source	Equal to Energy Source
Low Pressure Liquid HC	$0.4580	SFA Pacific, "Pipeline" & Calculation	1.000	Inspection	CF = Source	Equal to Energy Source
1st Energy Conversion Downstream						
Electrolysis	$2.2986	SFA Pacific, Case C5	0.635	SFA Pacific, Case C5	CF = Source	Equal to Energy Source
None	$0.0000	NA	1.000	NA	CF = Source	Equal to Energy Source
2nd Energy Conversion Downstream						
Liquefaction	$0.6925	SFA Pacific, Case C6	0.735	SFA Pacific, Case C6	CF = Source	Equal to Energy Source
Hydrogen Compression	$0.1832	SFA Pacific, Case C12	0.944	SFA Pacific, Case C12	CF = Source	Equal to Energy Source
Gas to Liquid Hydrocarbon	$0.5000	Mignard & Sahibzada & Scaling	1.000	Energy balance analysis	CF = Source	Equal to Energy Source
None	$0.0000	NA	1.000	NA	CF = Source	Equal to Energy Source
Depot Storage						
Liquid H2 Dewar	$0.0109	SFA Pacific, Case C6	1.000	SFA Pacific, Case C6, Boil-off negligible	1.000	Equal to Unity
Pressure Vessel	$0.1430	SFA Pacific, Case C12	1.000	SFA Pacific, Case C12	1.000	Equal to Unity
Liquid HC Tank	$0.0000	Inspection	1.000	Inspection	1.000	Equal to Unity
Delivery from Depot to Station						
Liquid Dewar Truck	$0.0633	SFA Pacific, "Dewar Truck"	0.969	SFA Pacific, "Dewar Truck"	1.000	Equal to Unity
Pressurized Tube Trailer	$0.6741	SFA Pacific, "Tube Trailer"	0.846	SFA Pacific, "Tube Trailer"	1.000	Equal to Unity
Liquid HC Tanker Truck	$0.0000	Inspection	1.000	Inspection	1.000	Equal to Unity
Station Compression						
None	$0.0000	NA	1.000	NA	1.000	Equal to Unity
Hydrogen Compression	$0.7074	SFA Pacific, Case F4	0.934	SFA Pacific, Case F4	1.000	Equal to Unity
Station Storage & Fueling						
Liquid H2 Dewar	$1.0475	SFA Pacific, "Liquid Station"	0.983	SFA Pacific, "Liquid Station"	1.000	Equal to Unity
Pressure Vessel	$0.5207	SFA Pacific, "Tube Trailer"	0.979	SFA Pacific, "Tube Trailer"	1.000	Equal to Unity
Liquid HC Tank	$0.0000	Inspection	1.000	Inspection	1.000	Equal to Unity

Table 29: Hydrogen Pathway Capital Costs - Supply Chain Assessment Part I - S. Locke Bogart 2002

Vehicle Systems						
Storage						
Liquid H2 Dewar	$0.0633	SFA Pacific, "Dewar Truck"	1.000	No boil-off	1.000	Equal to Unity
Pressure Vessel	$0.0144	Ogden, Williams & Larson	1.000	Inspection	1.000	Equal to Unity
Adsorption	$0.1703	UTRC: $169/5 kg; 5 kg/week, SFA F4	1.000	Bossel & Eliasson	1.000	Equal to Unity
Hydride	$0.1703	Assumed same as Adsorption	0.600	Bossel & Eliasson	1.000	Equal to Unity
Liquid HC Tank	$0.0000	Inspection	1.000	Inspection	1.000	Equal to Unity
Vehicle Conversion 1						
Fuel Cell - Neat H2	$0.0294	74 kW FC (Ogden, Williams & Larson)	0.525	Hoffert, et. al. Science Article	1.000	Equal to Unity
Reformer	$0.0150	74 kW Methanol (Ogden, Williams & Larson)	0.775	Hoffert, et. al. Science Article	1.000	Equal to Unity
Vehicle Conversion 2						
None	$0.0000	NA	1.000	NA		
Fuel Cell - Reformate	$0.0422	74 kW FC (Ogden, Williams & Larson)	0.525	Hoffert, et. al. Science Article	1.000	Equal to Unity
Vehicle Propulsion						
Electric Motor	$0.0150	Ogden, Williams & Larson	0.825	Hoffert, et. al. Science Article	1.000	Equal to Unity

"Footnotes are in order of appearance by column."

[a] J. Judd, et al., "*The Pathway to Significant Acceleration of Grid Connected PV Markets*," (Solar Electric Power Association, 2002).

[b] R. H. Williams, *Toward Zero Emissions for Transportation Using Fossil Fuels*, Asilomar Conference Center, Monterey CA, September 11–14, 2001.

[c] K. R. Schultz, *et al.*, *Large-Scale Production of Hydrogen by Nuclear Energy for the Hydrogen Economy*, National Hydrogen Association Conference, March 4–6, 2003, Washington D.C.

[d] J. DeCarolis, *et al.*, *Wind Power*, Carnegie Mellon Electric Industry Center Seminar, February 6, 2002.

[e] D. R. Simbeck and E. Chang, *Hydrogen Supply: Cost Estimate for Hydrogen Pathways: Scoping Analysis*, NREL/SR-540-32525, July, 2002.

[f] D. Mignard *et al.*, *Methanol Synthesis form Flue-Gas CO_2 and Renewable Electricity: A Feasibility Study,* (Heriot-Watt University, circa 2002).

[g] J. M. Ogden, *et al.*, "Societal Lifecycle Costs of Cars with Alternative Fuels/Engines," (Presently a private communication September 27, 2002).

[h] D. L. Alton, "*High Density Hydrogen Storage System Demonstration Using $NaAlH_4$* Complex Compound Hydrides," DoE Project Kick-Off Meeting, UTRC, October 30, 2001.

[i] H. D. Lightfoot and C. Green, *An Assessment of IPCC Working Group III Findings in Climate Change 2001: Mitigation of the Potential Contribution of Renewable Energies to Atmospheric Carbon Dioxide Stabilization*, C^2 GCR Report No. 2002-5, November, 2002.

[j] U. Bossel and B. Eliasson, *Energy and the Hydrogen Economy*, ABB Switzerland, Internet Open Source, January 8, 2003.

[k] M. L. Hoffert, *et al.*, *Science* **298** (2002).

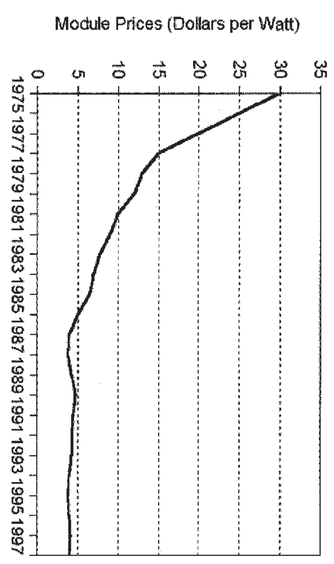


Fig. 3. History of photovoltaic cell costs.
Source: P. Maycock, The World Photovoltaic Market 1975–1998 (Warrenton, VA: PV Energy Systems, Inc., August 1999), p. A-3.

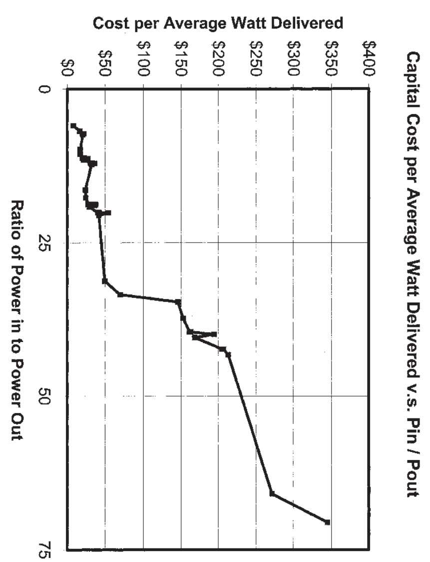


Fig. 4. Capital cost per average watt delivered versus the ratio of power in to power out.

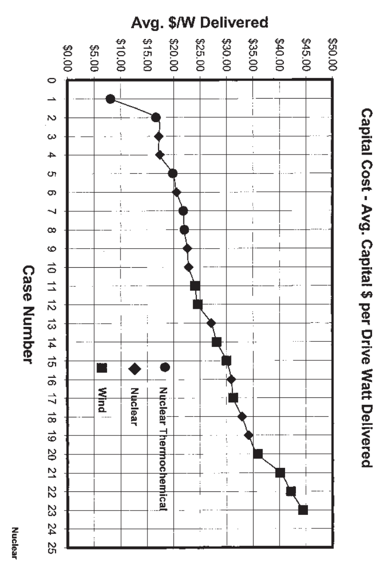
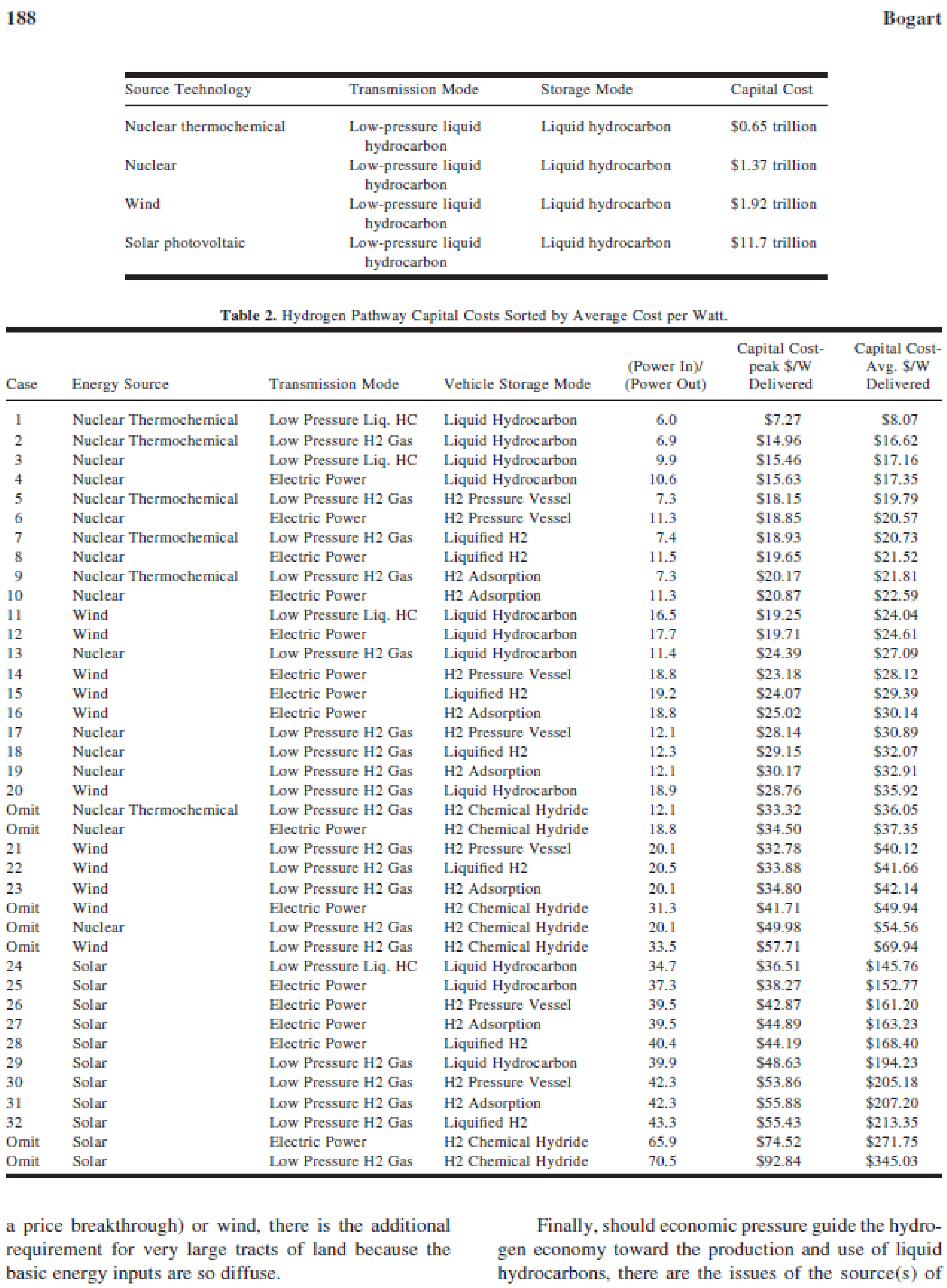


Fig. 5. Grouping of nuclear and wind technologies by average capital cost per delivered watt.

Table 30: Hydrogen Pathway Capital Costs - Supply Chain Assessment Part II - S. Locke Bogart 2002



Source Technology	Transmission Mode	Storage Mode	Capital Cost
Nuclear thermochemical	Low-pressure liquid hydrocarbon	Liquid hydrocarbon	$0.65 trillion
Nuclear	Low-pressure liquid hydrocarbon	Liquid hydrocarbon	$1.37 trillion
Wind	Low-pressure liquid hydrocarbon	Liquid hydrocarbon	$1.92 trillion
Solar photovoltaic	Low-pressure liquid hydrocarbon	Liquid hydrocarbon	$11.7 trillion

Table 2. Hydrogen Pathway Capital Costs Sorted by Average Cost per Watt.

Case	Energy Source	Transmission Mode	Vehicle Storage Mode	(Power In)/ (Power Out)	Capital Cost- peak $/W Delivered	Capital Cost- Avg. $/W Delivered
1	Nuclear Thermochemical	Low Pressure Liq. HC	Liquid Hydrocarbon	6.0	$7.27	$8.07
2	Nuclear Thermochemical	Low Pressure H2 Gas	Liquid Hydrocarbon	6.9	$14.96	$16.62
3	Nuclear	Low Pressure Liq. HC	Liquid Hydrocarbon	9.9	$15.46	$17.16
4	Nuclear	Electric Power	Liquid Hydrocarbon	10.6	$15.63	$17.35
5	Nuclear Thermochemical	Low Pressure H2 Gas	H2 Pressure Vessel	7.3	$18.15	$19.79
6	Nuclear	Electric Power	H2 Pressure Vessel	11.3	$18.85	$20.57
7	Nuclear Thermochemical	Low Pressure H2 Gas	Liquified H2	7.4	$18.93	$20.73
8	Nuclear	Electric Power	Liquified H2	11.5	$19.65	$21.52
9	Nuclear Thermochemical	Low Pressure H2 Gas	H2 Adsorption	7.3	$20.17	$21.81
10	Nuclear	Electric Power	H2 Adsorption	11.3	$20.87	$22.59
11	Wind	Low Pressure Liq. HC	Liquid Hydrocarbon	16.5	$19.25	$24.04
12	Wind	Electric Power	Liquid Hydrocarbon	17.7	$19.71	$24.61
13	Nuclear	Low Pressure H2 Gas	Liquid Hydrocarbon	11.4	$24.39	$27.09
14	Wind	Electric Power	H2 Pressure Vessel	18.8	$23.18	$28.12
15	Wind	Electric Power	Liquified H2	19.2	$24.07	$29.39
16	Wind	Electric Power	H2 Adsorption	18.8	$25.02	$30.14
17	Nuclear	Low Pressure H2 Gas	H2 Pressure Vessel	12.1	$28.14	$30.89
18	Nuclear	Low Pressure H2 Gas	Liquified H2	12.3	$29.15	$32.07
19	Nuclear	Low Pressure H2 Gas	H2 Adsorption	12.1	$30.17	$32.91
20	Wind	Low Pressure H2 Gas	Liquid Hydrocarbon	18.9	$28.76	$35.92
Omit	Nuclear Thermochemical	Low Pressure H2 Gas	H2 Chemical Hydride	12.1	$33.32	$36.05
Omit	Nuclear	Electric Power	H2 Chemical Hydride	18.8	$34.50	$37.35
21	Wind	Low Pressure H2 Gas	H2 Pressure Vessel	20.1	$32.78	$40.12
22	Wind	Low Pressure H2 Gas	Liquified H2	20.5	$33.88	$41.66
23	Wind	Low Pressure H2 Gas	H2 Adsorption	20.1	$34.80	$42.14
Omit	Wind	Electric Power	H2 Chemical Hydride	31.3	$41.71	$49.94
Omit	Nuclear	Low Pressure H2 Gas	H2 Chemical Hydride	20.1	$49.98	$54.56
Omit	Wind	Low Pressure H2 Gas	H2 Chemical Hydride	33.5	$57.71	$69.94
24	Solar	Low Pressure Liq. HC	Liquid Hydrocarbon	34.7	$36.51	$145.76
25	Solar	Electric Power	Liquid Hydrocarbon	37.3	$38.27	$152.77
26	Solar	Electric Power	H2 Pressure Vessel	39.5	$42.87	$161.20
27	Solar	Electric Power	H2 Adsorption	39.5	$44.89	$163.23
28	Solar	Electric Power	Liquified H2	40.4	$44.19	$168.40
29	Solar	Low Pressure H2 Gas	Liquid Hydrocarbon	39.9	$48.63	$194.23
30	Solar	Low Pressure H2 Gas	H2 Pressure Vessel	42.3	$53.86	$205.18
31	Solar	Low Pressure H2 Gas	H2 Adsorption	42.3	$55.88	$207.20
32	Solar	Low Pressure H2 Gas	Liquified H2	43.3	$55.43	$213.35
Omit	Solar	Electric Power	H2 Chemical Hydride	65.9	$74.52	$271.75
Omit	Solar	Low Pressure H2 Gas	H2 Chemical Hydride	70.5	$92.84	$345.03

a price breakthrough) or wind, there is the additional requirement for very large tracts of land because the basic energy inputs are so diffuse.

Finally, should economic pressure guide the hydrogen economy toward the production and use of liquid hydrocarbons, there are the issues of the source(s) of

Table 31: Hydrogen Pathway Capital Costs Average Cost per Watt - S. Locke Bogart 2002

Appendix G: Potential Tidal Current Energy

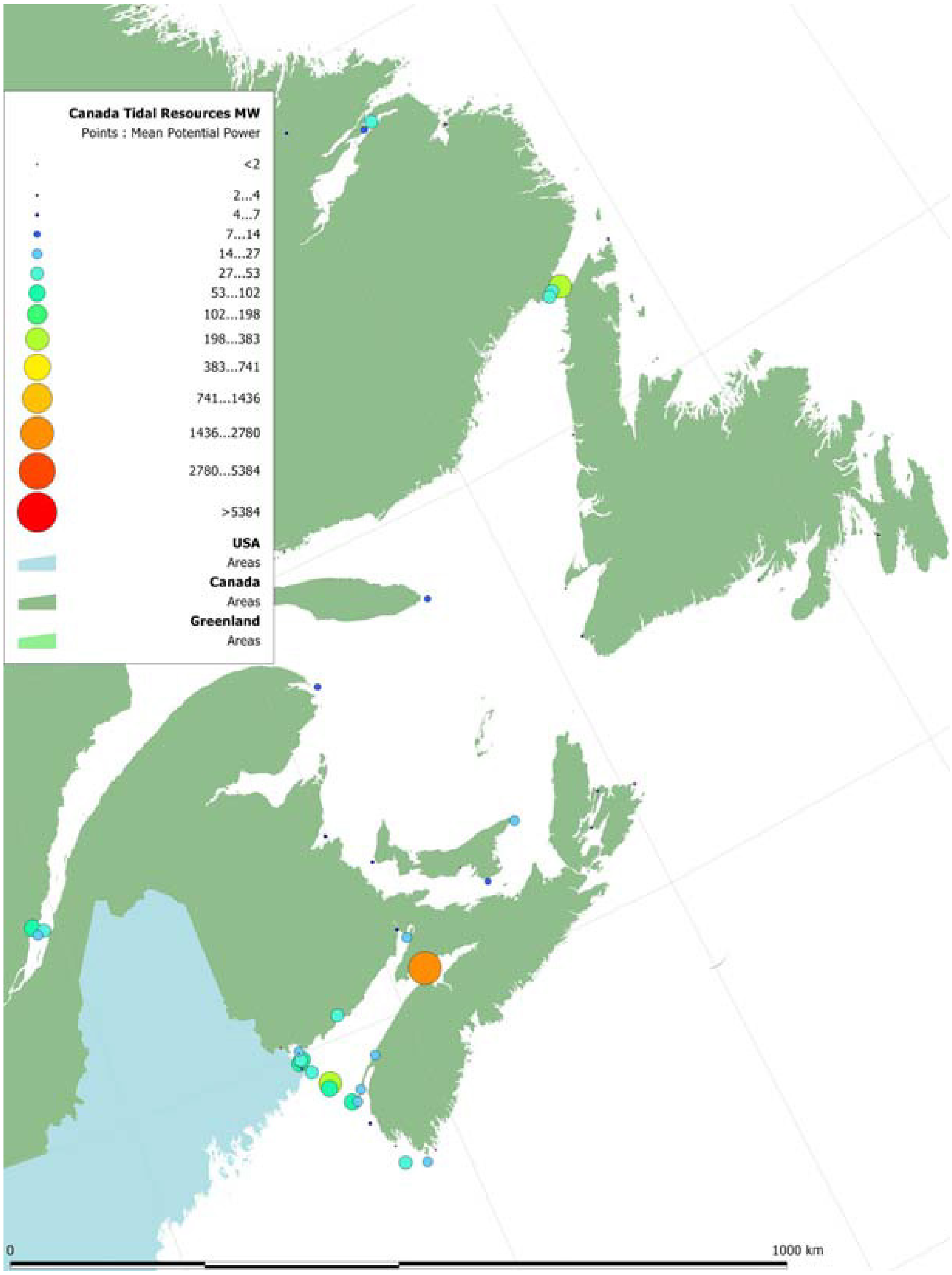


Figure 109: Map of Potential Tidal Power Resources (MW) – Triton Consultants 2006

http://www.marinerenewables.ca/wp-content/uploads/2012/11/Canada-Ocean-Energy-Atlas-Phase-1-Potential-Tidal-Current-Energy-Resources-Analysis-Background.pdf

Appendix H: ESR – NS Energy Futures

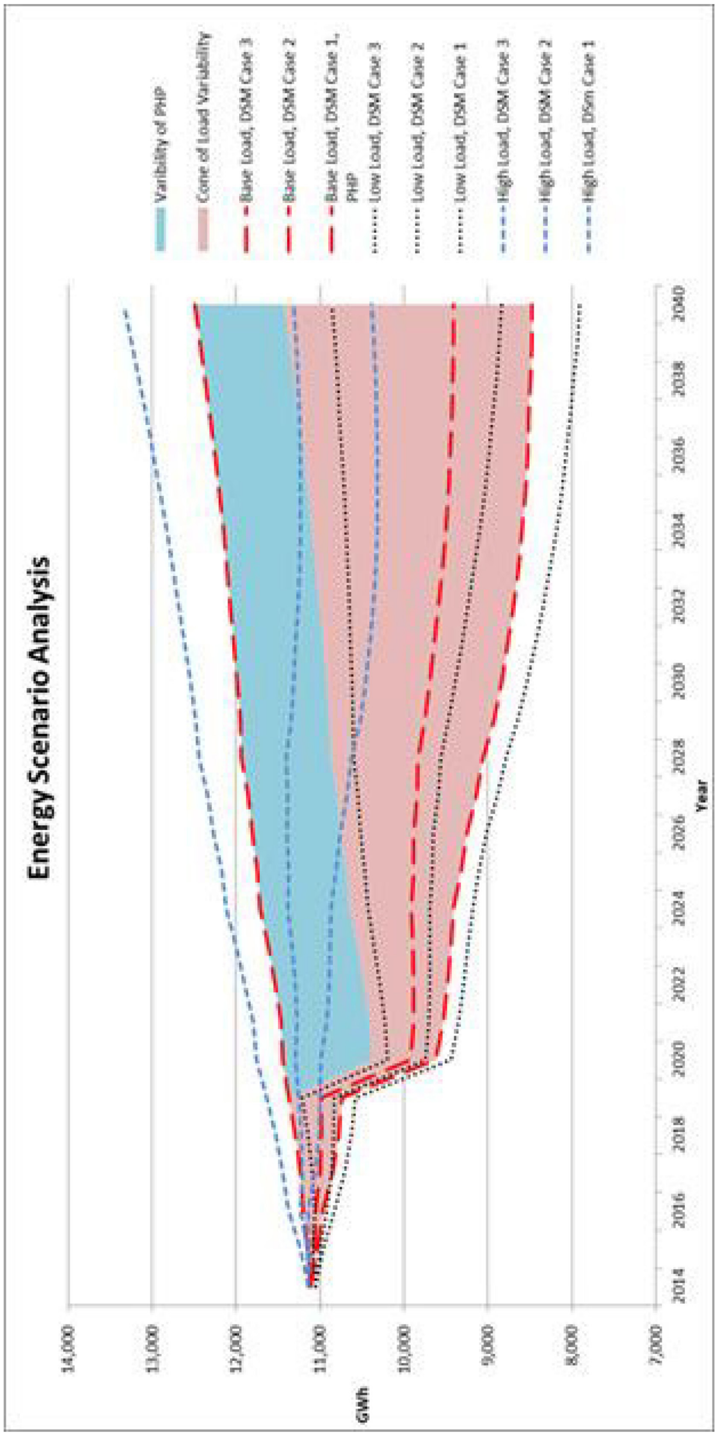


Figure 110: Electricity System Review NS Energy Futures 2014-2040

Appendix I: BEV, FCEV, and FFOV

Fuel Tank Exercise: Based on the Fuel Tank Size and Fuel Efficiency

A. What are the ranges of your assigned vehicles?

Nissan Leaf 24kWh Battery 2.0 Le/100km (115 mpg) [0.198 kWh/km] Range _________ km EPA	
Honda Civic 50 Liter (13.2 Gallon) 7.1 L/100 km (33 mpg) Range _________ km EPA	
Tesla Model S 85kWh Battery 2.64 Le/100 km (89 mpg) [0.197 kWh/km] Range _________ km EPA	
Ford F150 2.7L EcoBoost V6 136 Liter (26 Gallon) Gasoline Fuel Tank 10.7 L/100 km (22 mpg) Range _________ km EPA	
Toyota Mirai 5kg Hydrogen Fuel Tank @ 70 MPa (10,000 psi) equivalent to 19.62 L gasoline 1.6 kWh Battery 3.02 Le/100 km (60 mpg) [0.7692kg H2/100km] Range _________ km EPA	
Hyundai ix35 5.94 kg Hydrogen Fuel Tank @ 70 MPa (10,000 psi) equivalent to 23.34 L gasoline 24 kWh Battery 3.6 Le/100 km (65.3 mpg) [1 kg H2/100km] Range _________ km EPA	

Note: Le stands for Liters Equivalent (to Gasoline) in terms of energy content.

Answer Sheet:

Average Vehicle Travel: 16,600 km annually.

BEVs

Nissan Leaf
24kWh Battery
2.0 Le/100km (115 mpg) [0.198 kWh/km]
Range 121km EPA
Annual Fuel Costs: $467

Tesla Model S
85kWh Battery
2.64 Le/100 km (89 mpg) [0.197 kWh/km]
Range 431km EPA
Annual Fuel Costs: $464

Chevy Volt
17kWh Battery
2.5 Le/100 km (112 mpg) [0.279 kWh/km] all electric mode
3.9 Le/100 km (72 mpg) gasoline-electric mode
610 km Total Range: 61km Electric Range EPA
Annual Fuel Costs: Assume 80% driving uses electric, and 20% uses gasoline
$526 for electricity, and $388 for gasoline
→ Total: $914

FCEVs

Toyota Mirai
5kg Hydrogen Fuel Tank @ 70 MPa (10,000 psi) equivalent to 19.62 L gasoline
1.6 kWh Battery
3.02 Le/100 km (60 mpg) [0.7692kg H2/100km]
Range 650km EPA
Annual Fuel Costs:
128 kg H_2 @ $4/kg → $510
128 kg H_2 @ $8/kg → $1021

Hyundai ix35
5.94 kg Hydrogen Fuel Tank @ 70 MPa (10,000 psi) equivalent to 23.34 L gasoline
24 kWh Battery
3.6 Le/100 km (65.3 mpg) [1 kg H2/100km]
Range 594km
Annual Fuel Costs:
166 kg H_2 @ $4/kg → $664
166 kg H_2 @ $8/kg → $1328

FFOVs

Honda Civic
50 Liter (13.2 Gallon)
7.1 L/100 km (33 mpg)
Range 704 km, Annual Fuel Costs: 1178 L @ $1.3/L → $1533, or 1178 L @ $1.45/L → $1710

Ford F150 2.7L EcoBoost V6
136 Liter (26 Gallon) Gasoline Fuel Tank
10.7 L/100 km (22 mpg)
Range 1271 km, Annual Fuel Costs: 1776 L @ $1.3/L → $2309, or 1776 L @ $1.45/L → $2575

*Fuel Tank Exercise created by Jacob Thompson 2015.

Appendix J: NREL PV Efficiency

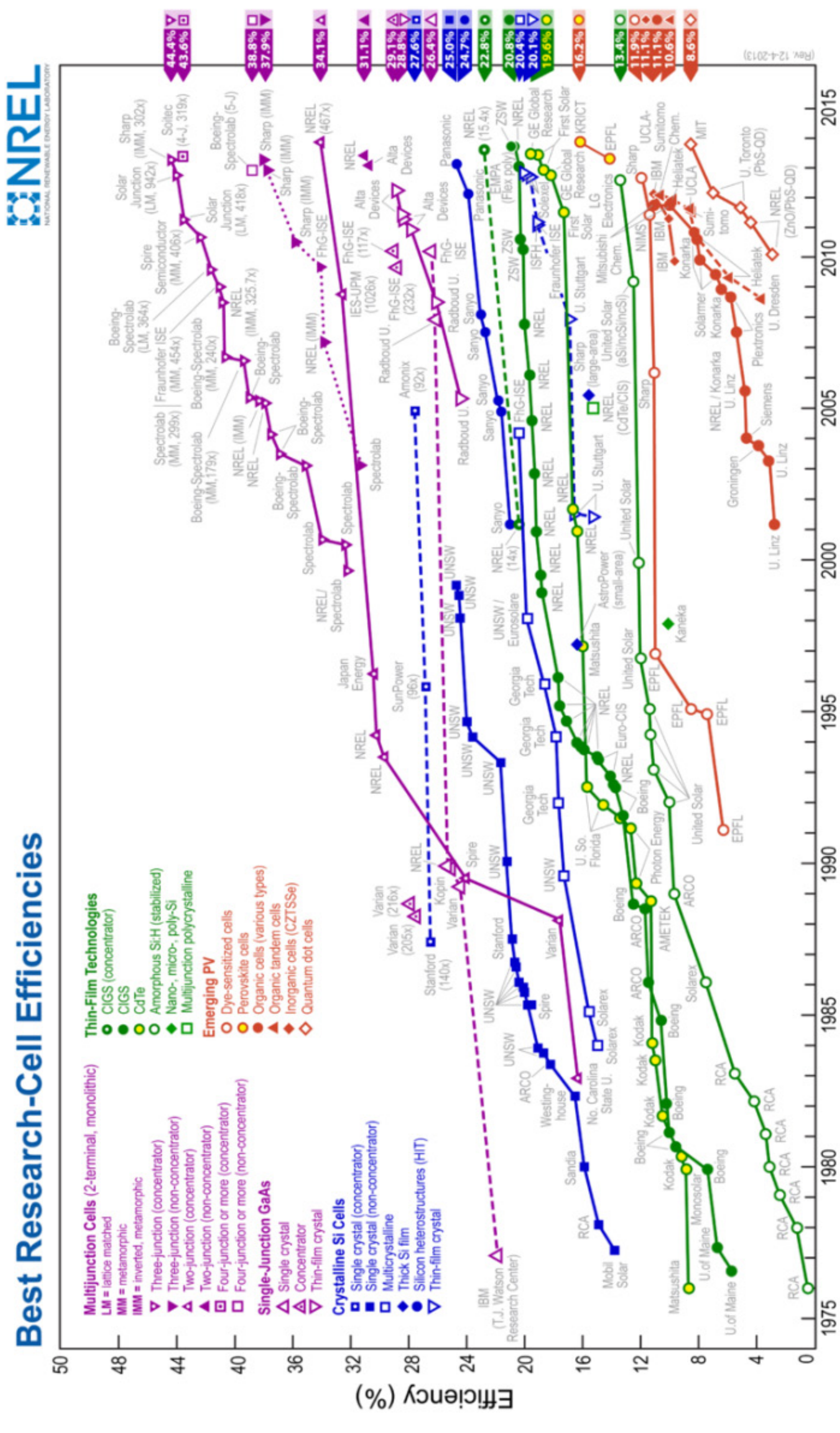


Figure 111: NREL Solar PV Efficiency Improvements from 1975 to 2015

Appendix K: eCO2 Thermal Plants NS

Year	Lingan	Point Aconi	Trenton	Point Tupper	Tufts Cove	Tusket1	Burnside	Victoria Junction	Brooklyn	Sackville	Taylor	Northern	Port Hawkesbury
1965					0.5								
1966					0.7								
1967					0.9							0.01	
1968					1.0							0.01	
1969			1.0		1.0							0.01	
1970			1.3		1.0							0.01	
1971			1.4		1.0	0.07						0.01	0.01
1972			1.9		1.0	0.14						0.01	0.01
1973			1.9		1.2	0.14						0.01	0.01
1974			2.1	0.0	1.2	0.14						0.01	0.01
1975			2.2	0.0	1.2	0.09		0.05				0.01	0.01
1976			2.2	0.0	1.2	0.02	0.01	0.05				0.01	0.01
1977			2.6	0.0	1.2	0.02	0.07	0.01				0.01	0.01
1978	1.4		3.1	0.0	0.3	0.02	0.00	0.05				0.01	0.01
1979	1.3		2.7	0.1	0.1	0.02	0.00	0.05				0.01	0.01
1980	2.3		2.3	0.1	0.1	0.02	0.00	0.05				0.01	0.01
1981	2.9		1.9	0.0	0.1	0.02	0.00	0.05				0.01	0.01
1982	3.0		2.0	0.0	0.1	0.02	0.00	0.03				0.01	0.01
1983	2.9		2.0	0.0	0.1	0.02	0.00	0.05				0.01	0.01
1984	3.3		2.2	0.0	0.1	0.02	0.00	0.05				0.01	0.01
1985	3.5		2.3	0.0	0.1	0.02	0.00	0.04				0.01	0.01
1986	3.8		2.6	0.0	0.1	0.01	0.00	0.01				0.01	0.01
1987	4.0		1.7	1.0	0.1	0.02	0.06	0.02				0.01	0.01
1988	4.1		1.7	1.0	0.1	0.02	0.09	0.05				0.01	0.01
1989	4.3		1.8	1.1	0.1	0.02	0.06	0.02				0.01	0.01
1990	4.6		1.9	1.2	0.1	0.02	0.06	0.03				0.01	0.01
1991	4.3		1.8	1.1	0.1	0.02	0.06	0.04				0.01	0.01
1992	5.0		2.1	1.2	0.1	0.02	0.06	0.03				0.01	0.01
1993	4.8		2.0	1.2	0.1	0.02	0.06	0.04				0.01	0.01
1994	3.1	1.2	2.3	1.2	0.1	0.02	0.06	0.04				0.01	0.01
1995	3.1	1.2	2.3	1.2	0.1	0.04	0.15	0.07	0.011		0.0007	0.01	0.01
1996	2.9	1.1	2.2	1.1	0.1	0.03	0.08	0.07	0.011		0.0007	0.01	0.02
1997	3.0	1.1	2.3	1.1	0.1	0.03	0.08	0.07	0.011		0.0007	0.01	0.02

1998	3.2	1.2	2.0	1.6	0.1	0.03	0.07	0.02	0.011		0.0007	0.01	0.02
1999	3.5	1.3	2.2	1.8	0.1	0.02	0.03	0.02	0.004		0.0007	0.01	0.01
2000	3.5	1.3	2.2	1.7	0.1	0.01	0.06	0.03	0.004		0.0007	0.01	0.02
2001	3.4	1.3	2.2	1.7	0.1	0.04	0.07	0.07	0.004		0.0007	0.01	0.01
2002	4.7	1.4	2.3	0.9	0.1	0.04	0.10	0.07	0.004		0.0007	0.01	0.01
2003	4.1	1.0	2.3	1.0	0.6	0.04	0.19	0.11	0.004		0.0007	0.01	0.01
2004	4.5	1.4	2.1	1.2	1.3	0.04	0.20	0.11	0.014		0.0007	0.01	0.02
2005	4.4	1.9	2.0	1.0	1.3	0.04	0.03	0.09	0.004		0.0007	0.01	0.01
2006	4.1	1.8	2.2	1.1	0.6	0.01	0.02	0.01	0.014	0.001	0.0007	0.01	0.02
2007	4.3	1.5	2.2	1.2	1.0	0.01	0.03	0.02	0.003	0.001	0.0007	0.01	0.02
2008	4.1	1.4	2.2	1.0	1.0	0.01	0.03	0.01	0.014	0.001	0.0007	0.01	0.03
2009	3.9	1.4	1.8	1.0	1.1	0.02	0.04	0.02	0.010	0.001	0.0007	0.00	0.01
2010	3.7	1.5	1.7	1.1	1.3	0.01	0.03	0.01	0.011	0.001	0.0007	0.01	0.02
2011	3.5	1.4	1.7	0.6	1.4	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2012	2.8	1.4	1.4	0.8	1.2	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2013	3.3	1.4	1.6	0.8	0.8	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2014	3.6	1.5	1.8	0.9	1.0	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2015	3.6	1.5	1.8	0.9	1.0	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2016	3.6	1.5	1.8	0.9	1.0	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2017	3.3	1.3	1.6	0.8	0.9	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2018	3.3	1.3	1.6	0.8	0.9	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2019	3.3	1.3	1.6	0.8	0.9	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03
2020	3.1	1.2	1.5	0.8	0.9	0.00	0.00	0.00	0.011	0.001	0.0007	0.01	0.03

Table 32: GHG emissions from Thermal Plants in NS from 1965-2020 (Tonnes)

Appendix L: World Wind-only Energy Supply

The American Wind Energy Association states that: "Over the past five years, U.S. wind energy capacity grew from 25,000 MW to over 61,000 MW, a 140 percent growth rate" (http://www.awea.org/generationrecords). The onshore wind energy trend will undoubtedly continue to grow, while they specify offshore forecasts: "In fact, the U.S. Department of Energy analyzed the future of offshore wind in the recent Wind Vision Report and described an 'ambitious but credible' scenario in which offshore wind provides 22GW of electricity by 2030 and 86 GW by 2050" (www.aweablog.org/steel-going-in-the-water-for-americas-first-offshore-wind-farm/). The Wind Vision Report (http://energy.gov/eere/wind/maps/wind-vision) estimates that by 2050 the USA will have installed 344GW, which can be estimated as 104,000 3.3 MW wind turbines (WT). Assuming 20% are offshore wind farms (WF) there would be an estimated 404 WF where 85% are 400MW WFs and 15% are 40MW WFs. With the remainder 275.2GW of onshore wind, with an estimated 2795 WFs where 85% are 83.7MW WFs (current WF average size from AWEA). Based on regional policies and installation data, a percentage based on land use restrictions would be built to the ComFIT size spread with the average WF size of 10MW. The remaining 15% are 10MW WFs equal to 4128 WFs.

Of the 344GW, in total there would be 2795 + 4128 + 404 = 7327 new WFs. 344 GW of wind energy is approximately 1000 TWh of electricity in a modest wind resource of 33% capacity factor with plenty of available land meeting these criteria. Whereas the Total Primary Energy Supply (TPES), when transportation, heating and other fuels are upgraded will be near 24.89 times that amount (IEA 2014, TPES USA 24890 TWh). This translates to a US wind-only TPES of (8571 GW) if all the energy was either directly used or captured in energy storage. Normally the system will be overbuilt, which presently is the cheaper option than scaling energy storage; therefore with a conservative estimate it would require 10% more installed wind, which we can estimate as (9428 GW).

The IEA Key World Energy Statistics 2014 report states that present world TPES is 155,477 TWh. Filtering by the top ten current highest energy countries, the TPES is near 97593 TWh. The top thirty highest energy countries would be a market of 128,669 TWh. Note that this does not yet include an improvement in other nation's energy budgets, which will follow in the next paragraph. In terms of raw materials, to meet current world TPES with wind-only would amount to 7067 MT of Steel, 19.8MT of Aluminum, 107-535MT of Copper (all onshore vs all offshore), 5.9 MT of Nickel, and if 10% was offshore: 36MT of Lead, 0.663MT Neodymium, and finally 0.118MT Dysprosium (from Figure 64: Metals used in onshore and offshore wind turbines).

If all countries had the same energy affluence as Canada at 83TWh/Million people (Mpop), the global total would be 584,071 TWh, which is quite high, with ~3.75 times the material resources in paragraph three. Many advanced economy countries have 30-50TWh/Mpop. I use Germany as an example at 44TWh/Mpop, which recalculates the global TPES at 310,954 TWh (107TW). This effectively doubles the world average from 22 TWh/Mpop per country, attainably using twice the material resources. Presently 78 countries are below the world TWh/Mpop average, while 62 are above it. Of these, a total of 30 countries below the world average have wind energy policies. To recap, the world market would be 20,915TWh wind-electric-only, in contrast to the world TPES wind-only market 310,954 TWh when including all 92 countries with the economic conditions for investing in wind energy.

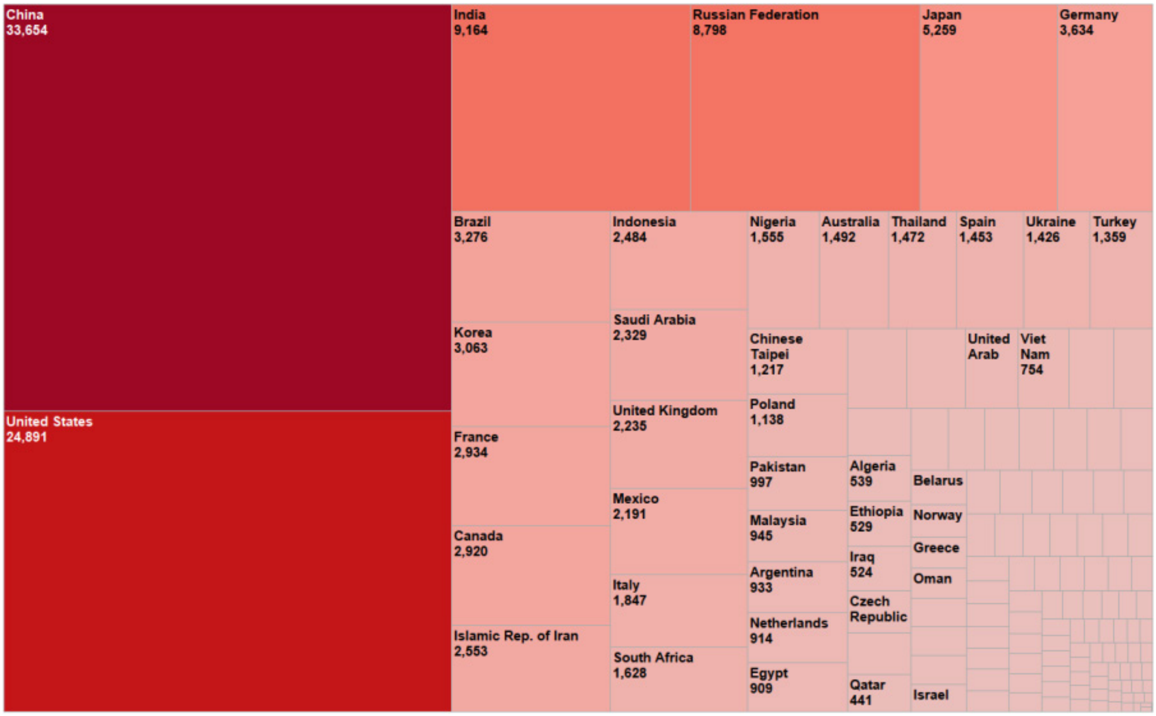


Figure 112: International TPES (TWh) IEA 2014

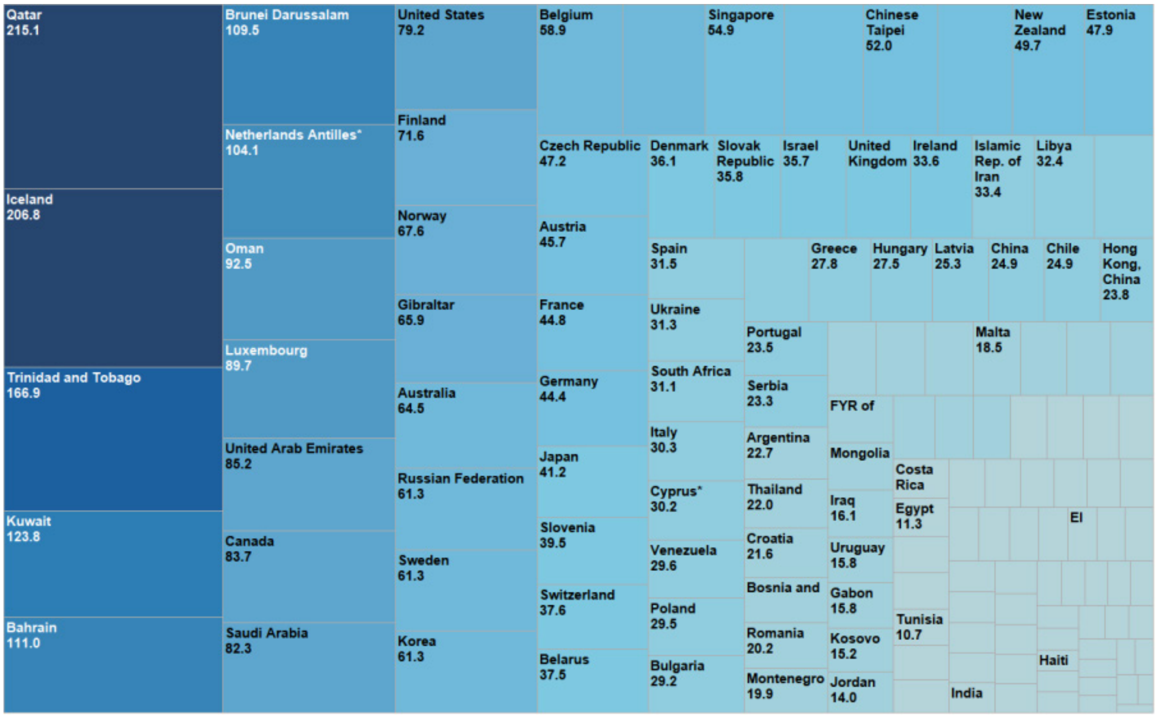


Figure 113: International TPES/Million People (TWh) IEA 2014

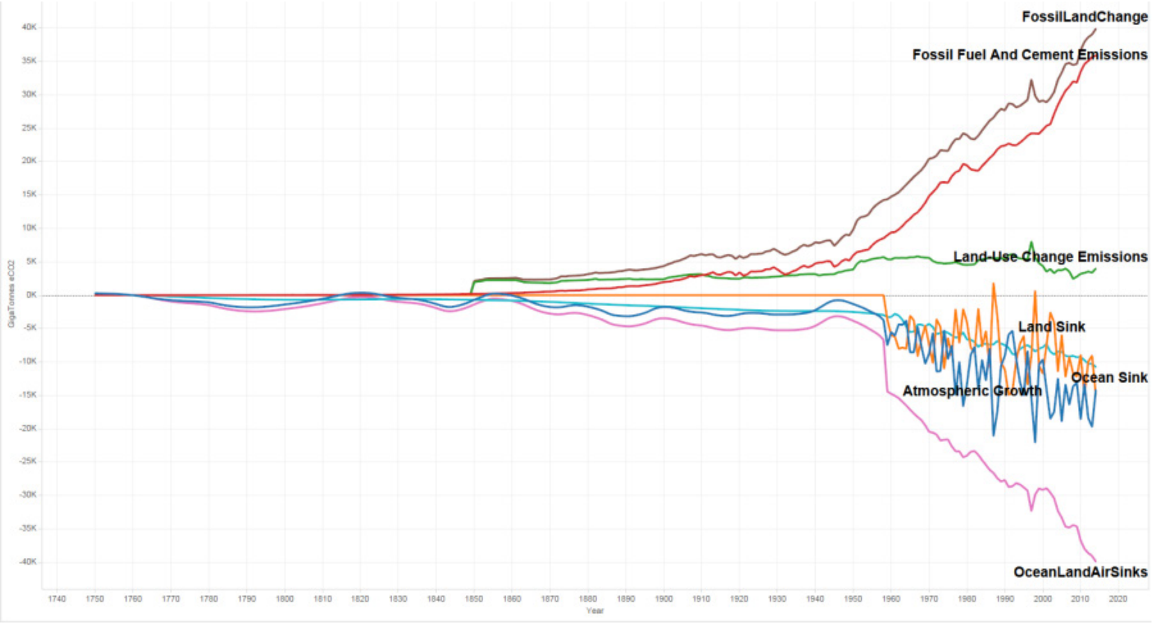


Figure 114: Global Carbon Project (Mt eCO2) (Ecofys 2015)