A VISUALIZATION TOOL FOR THE ANALYSIS OF THE EFFECTS OF CHANGING ENERGY POLICIES ON ENERGY SECURITY IN AN ENERGY SYSTEM

by

Vinay Kumar Chatharaju

Submitted in partial fulfilment of the requirements
for the degree of Master of Applied Science

at

Dalhousie University
Halifax, Nova Scotia
October 2013

DEDICATION

I dedicate this thesis to my beloved mother, father, my sister, and my brother-in-law who continuously supported me in each step of my life. Thank you for your faith in me.

Table of Contents

LIST OF TABLES v

LIST OF FIGURES vi

ABSTRACT viii

LIST OF ABBREVIATIONS USED ix

ACKNOWLEDGEMENTS xii

CHAPTER 1. INTRODUCTION 1

1.1. Thesis Objectives: 4

1.2. Thesis Outline 4

CHAPTER 2. LITERATURE REVIEW 6

2.1. Energy Security 6

2.2. Energy Systems 8

2.3. Energy Policy 10

2.4. Modeling Tools 11

2.4.1. Eminent (Early Market Introduction of New Energy Technologies) 11

2.4.2. Balmorel 12

2.4.3. IKARUS 12

2.4.4. MESSAGE 13

2.4.5. LEAP 13

2.4.6. HOMER 14

2.4.7. GTMax 14

2.4.8. NEMS 15

2.4.9. MOSES 15

2.5. Common Limitations for Modeling Tools 16

2.6. Summary 16

CHAPTER 3. METHODS AND IMPLEMENTATION 17

3.1. Energy System Development Phase 17

3.1.1. Process Characteristics 17

3.1.2. Representing an Energy System 19

3.2. Calculation Phase 21

3.2.1. Conversion Process Energy Output (CPE_{OUT}): 22
3.2.2. Distribution Process Energy Output (DPE_{OUT}) 22
3.3. Energy Security Analysis Phase 23
3.3.1. Checking Availability Indicator 23
3.3.2. Affordability Indicator Estimation 23
3.3.3. Acceptability Indicator Estimation: 24
3.4. Implementation 26
3.4.1. Visualization Tool 26
3.4.2. Energy System Development Phase 27
3.4.2.1. Energy System Components 27
3.4.2.2. Main Screen 28
3.4.2.3. System Data 30
3.4.3. Calculation and Energy Security Analysis Phases 31
3.4.3.1. Energy Security Analysis 34
3.5. Software 36
3.6. Summary 37
CHAPTER 4. CASE STUDY AND RESULTS 38
4.1. Objectives 38
4.2. Summerside Electricity Energy Chain 39
4.3. Simulation for the year 2011 41
4.3.1. Simulation Results 42
4.4. Simulation for 2011 with Storage 50
4.4.1. Simulation Results 51
4.5. Summary 54
CHAPTER 5. DISCUSSION 55
CHAPTER 6. CONCLUSION 58
6.1. Limitations 61
6.2. Future Work 61
BIBLIOGRAPHY 62
Appendix A: Simulation Results for 2011 68

LIST OF TABLES

Table 1: Types of arrows 18

Table 2: Electricity purchase cost and sale cost.......... 46

Table 3: Simulation results for different storage capacity 52

Table 4: Total estimated Cost and Revenue monthly, weekly, and hourly for 2011 56

Table 5: 15% weekly simulation input data for 2011 68

Table 6: 15% weekly simulation output data for 2011 69

Table 7: 15% monthly simulation input data for 2011 71

Table 8: 15% monthly simulation output data for 2011 72

LIST OF FIGURES

Figure 1: A generic energy system (from (Hughes, 2011)) 8

Figure 2: A generic energy process with six flows (from (Hughes, 2011)) 9

Figure 3: Building an energy chain 20

Figure 4: A generic energy chain and a sample example (Hughes, 2011) 21

Figure 5: A primary energy source component 27

Figure 6: A primary conversion process 27

Figure 7: A distribution process 28

Figure 8: A secondary conversion process 28

Figure 9: An energy service 28

Figure 10: Front-end energy system development view 29

Figure 11: Database for the visualization tool 30

Figure 12: Back-end file showing input and output data 31

Figure 13: Flowchart showing the tool calculation phase 32

Figure 14: A process failure shown visually 34

Figure 15: Graphical representation of the tool analysing availability indicator 35

Figure 16: Graphical representation of the tool analysing affordability indicator 35

Figure 17: Graphical representation of the tool analysing acceptability indicator 36

Figure 18: Summerside's electricity energy chain 40

Figure 19: Summerside electricity energy chain showing failure for hourly simulation 42

Figure 20: Availability indicator monthly result for Summerside electricity energy chain for 2011 44

Figure 21: Availability indicator weekly result for Summerside electricity energy chain for 2011 44

Figure 22: Availability indicator hourly simulation for Summerside electricity energy chain for 2011 45

Figure 23: Affordability indicator monthly result for Summerside electricity energy chain for 2011 47

Figure 24: Affordability indicator weekly result for Summerside electricity energy chain for 2011 47

Figure 25: Affordability indicator hourly result for Summerside electricity energy chain for 2011 48

Figure 26: Acceptability indicator hourly result for Summerside electricity energy chain for 2011 49

Figure 27: Summerside electricity energy chain with storage 51

Figure 28: Availability indicator hourly simulation with storage for Summerside electricity energy chain for 2011 53

Figure 29: Affordability indicator hourly simulation with storage for Summerside electricity energy chain for 2011 54

ABSTRACT

All jurisdictions have an energy system consisting of processes responsible for the conversion and transportation of supplies of energy from various sources to meet the end-use energy demands. Energy systems are dynamic as they respond to uncertainties such as higher energy costs, new energy technologies, public concern over the environmental impacts of energy production, evolving consumption patterns, and the aging of existing infrastructure; these changes can affect the energy suppliers, the end users, and those responsible for operating the energy system. To reduce possible adverse effects and improve the energy security of the system, energy policies are often designed by those responsible for the processes. However, changes to the energy policies can also impact the system's energy security. Therefore, it is critical to study the possible effects of changing energy policies before they are deployed.

To address this problem, a visualization tool has been developed to represent a jurisdiction's energy system. The tool allows the effects of changing energy policies on energy security to be analysed. A case study using real-time wind data from the City of Summerside has been implemented to demonstrate the capabilities of the tool.

This presentation will elaborate on the methods and implementation of the visualization tool and explain the results obtained from the analysis of the Summerside project.

LIST OF ABBREVIATIONS USED

AEO	Annual Energy Outlook
BBC	British Broadcasting Corporation
CO2	Carbon dioxide
CO2e	Carbon dioxide Equivalent
CH4	Methane
CCA	Climate Change Agreement
CCS	Carbon Capture and Storage
COMPOSE	Compare Options for Sustainable Energy
DOE	Department of Energy
EIA	Energy Information Administration
EST	Early Stage Technologies
ECN	Energy Research Centre of the Netherland
EMINENT	Early Market Introduction of New Energy Technologies
GHG	Greenhouse Gas
GTMax	Generation and Transmission Maximization
GUI	Graphical User Interface
IEA	International Energy Agency
IAEA	International Atomic Energy Agency
INFORSE	International Network for Sustainable Energy
IIASA	International Institute for Applied Systems Analysis
LEAP	Long range Energy Alternatives Planning system
MOSES	Model of Short-Term Energy Security

N2O	Nitrous Oxide
NB	New Brunswick
NEMS	National Energy Modeling System
NOx	Oxides of Nitrogen
P.E.I	Prince Edward Island
STE	System Analysis and Technology Evaluation
SO2	Sulfur Oxide
VBA	Visual Basic for Applications
WEO	World Energy Outlook
WASP	Wien Automatic System Planning

CPE_{OUT}	Conversion Process Energy Output
CO2EMM	Carbon dioxide Emissions
CH4EMM	Methane Emissions
CO2EF	Carbon dioxide Emission Factor
CH4EF	Methane Emission Factor
DPEOUT	Distribution Process Energy Output
DPEFF	Distribution Process Efficiency
EC	Energy Constant
N2OEMM	Nitrous oxide Emissions
N2OEF	Nitrous Oxide Emission Factor
NBEMM	New Brunswick Emissions
PEIN	Primary Energy Input
PEFF	Primary Conversion Process Efficiency
PS	Primary Source
SCEOUT	Secondary Conversion Process Energy Output
SCPEFF	Secondary Conversion Process Efficiency

TOTEMM	Total Emissions
TOTEOUT	Total Energy Output

KW	Kilowatt
MW	Megawatt
KWh	Kilowatt-hour
MWh	Megawatt-hour
KgCO2e	Kilogram of Carbon dioxide equivalent
Mtoe	Million tonnes of Oil equivalent
Gt	Gigatonne

ACKNOWLEDGEMENTS

A major research project like this is never the work of anyone alone. The contributions of many different people, in their different ways, have made this possible. I would like to extend my appreciation especially to the following.

First and foremost, I thank my supervisor Dr. Larry Hughes for making this research possible. His support, guidance, advice throughout the research project, as well as his pain-staking effort in proof reading the drafts, is greatly appreciated. Indeed, without his guidance, I would not be able to put the topic together. Thanks Sir.

I would like to thank my committee members Dr. Timothy Little and Dr. William Phillips for their time, interest, and helpful comments on this thesis.

To all my friends, thank you for your understanding and encouragement in my many, many moments of crisis. Your friendship makes my life a wonderful experience. I cannot list all the names here, but you are always on my mind. I would also like to acknowledge the selfless contribution of the Energy Research Group members for providing their valuable feedback on my work.

Above all, I would like to thank my parents, Ravinder Chatharaju & Sujatha Kuna, receive my deepest gratitude and love for their dedication and the many years of support during my undergraduate studies that provided the foundation for this work. I would also thank my sister and brother-in-law, Madhuri Chatharaju & Ravi Pula, who always made me feel at home.

CHAPTER 1. INTRODUCTION

From the Stone Age to the Modern Age, the world has undergone drastic changes in terms of energy usage. We use energy to satisfy our needs, such as: heating and cooling our homes, lighting buildings, driving cars, manufacturing the products, and all functions that require energy. Energy is now an important part of our lives more than ever before (SKRECC, 2009). Energy can play a key role in the social, economic or environmental development of any nation (World Bank, 2005). Over the past decade, primary energy demand has increased exponentially (Suganthia, et al., 2011)— be it by the world's increasing population or upgrading living standards. Modelling lifestyle can show the effects on energy demand and leads to an increase in usage of primary energy sources and in GHG emissions (Christoph, et al., 1998). The primary energy sources—mainly fossil fuels, in the form of coal, petroleum, and natural gas, have served as the major primary energy sources, meeting 81% of the world energy demand (IEA, 2012; Inter Academies Council, 2007).

Volatile energy markets, rising energy costs and production challenges faced by many producers makes energy security an important issue. Although energy security has high importance, several authors have pointed out that there is no common definition, see (Winzer, 2011) and (Checch, et al., 2009). The definition of energy security developed by International Energy Agency (IEA) is "the uninterrupted physical availability of energy at a price that is affordable, while respecting environment concerns" and is globally representative (IEA, 2010; Hughes, 2011).

In the next few decades, the concern for energy security is expected to increase with increasing worldwide energy demands and greenhouse gas emissions (Eunju, et al., 2009). For example, the IEA's World Energy Outlook 2012, indicates that world primary energy demand will increase by 35% between 2010 and 2035, from around 13,000 million tonnes of oil equivalent (Mtoe) to around 17,000 Mtoe, or on average 1.6% per year in the time period 2010 to 2020 to 1.0% per year in 2020 to 2035 (IEA, 2012a). Also, International Energy Outlook 2010 from the U.S *Energy Information Administration (EIA)* mentioned that the world's energy-related carbon dioxide emissions will rise from 29.7 billion metric tons in 2007 to 33.8 billion metric tons in 2020 and 42.4 billion metric tons in 2035, an increase of 43 percent over the projection period (EIA, 2010).

All jurisdictions have an energy system responsible for meeting its service energy demands. An energy system is a combination of one or more energy chains composed of interconnected conversion and transportation processes (Hughes, 2011). Each process within the chain is associated with six flows: $\text{Energy}_{\text{IN}}$, $\text{Energy}_{\text{OUT}}$, $\text{Demand}_{\text{IN}}$, $\text{Demand}_{\text{OUT}}$, $\text{Policy}_{\text{IN}}$, $\text{Environment}_{\text{OUT}}$ (Hughes, 2011). These flows are logically connected between the processes or the processes and energy sources or services (Hughes, 2011). The jurisdiction's energy security can be impacted by anything affecting the flows of energy through a process within the system. Energy systems are dynamic; they experience changes (sudden or anticipated) over time, as they respond to uncertainties such as higher energy costs, new energy technologies, public concerns over the environmental impacts of energy production, evolving consumption patterns, and the aging of existing infrastructure. These changes can affect the energy suppliers, the end users, and those responsible for operating the energy system. In order to challenge those changes in the energy system and maintain energy security, energy policies are developed (Hughes, 2011). Energy policies may be adopted by governments to meet goals such as economic growth, the distribution of income, industrial diversification and the protection of the environment (BREGHA, 2012).

An important goal of energy policy in many countries around the world is to increase security of supply for energy and to decrease emissions (Winzer, 2011). These policies encourage the use of technologies and new energy sources, which are more efficient and low in carbon. The question, however, is what effects are caused by making changes to an energy system based on energy polices? Changes to energy policies can impact a system's energy security, which can include adding a new policy, removing, or modifying an existing policy. For example; the Nigerian government declares the end of subsidy on fuel price in early January 2012. As a result petrol rates increase from 65 Naira ($0.40) per litre to at least 140 Naira ($0.86) at filling stations, and from 100 Naira to at least 200 Naira on the black market (BBC, 2012). Also, most of Nigeria's power comes from privately owned diesel generators, resulting in an 88% increase in electricity tariffs (Financial Times, 2012).

It is critical to study the possible effects of changing energy polices before they are deployed. A method, known as the three 'R's — Reduce (using less energy), Replace (shifting to secure sources), and Restrict (limiting demand to secure sources), can be used to explain the state of a jurisdiction's energy security and how it can be improved (Hughes, 2011). This method can also be employed for developing a jurisdiction's energy policy (Hughes, 2011). By classifying energy policies into one of 3R's in terms of time (i.e. policy versus the policy's time-period), it is possible to see the effects of energy policies (Hughes, 2009).

Since changes to energy policy can have impact on energy security of a jurisdiction it is important to know the jurisdiction's level of energy security. The state of energy security can be explained by three energy security indicators called the 3A's: **availability** ("the uninterrupted physical availability"), **affordability** ("a price which is affordable"), and **acceptability** ("respecting environment concerns") (Hughes, 2011). These indicators can be used to analyse the changes in energy security for a jurisdiction when the 3R's are applied. Policies are not considered to be measurable. However, one or more output flows of the process can be measurable. This means if a flow experiences a short- or long-term change, it can either have a positive or negative effect on the jurisdiction's energy security (Hughes, 2011). A policy is said to have successfully improved a system's energy security when any of the indicators have improved (Hughes, 2011).

Policies should improve energy security but might not in all cases. The "*Rebound effect*" is one such case. For example, Gonzalez states that, "energy efficiency improvements do not ultimately produce the expected results in terms of energy saving". This means improvement of efficiency reduces the cost of the energy service, which leads to an increase in the energy consumption (Gonzalez, 2011). This makes it important to study the effects of energy policies before they are applied to a system. Different energy modeling tools are available today which can analyse the effects of energy policies on energy security. Tools like LEAP (Long range Energy Alternatives Planning System), NEMS (National Energy Modeling System), EnergyPLAN, Balmoral, EMINENT (Early Market Introduction of New Energy Technologies), have been developed to analyse energy security. However, all of the aforementioned tools have limitations which range from tools developed for specific jurisdiction to tools developed to analyse specific types of energy (Connolly, et al., 2009). Limitations can also include lack of visualization tools to indicate the current energy security status of a jurisdiction and indicating pathways for improved energy security. Energy systems are very complex to understand with respect to the mix of primary sources, energy storage facilities, transmission system mechanisms, and avenues to market (Stuart, et al., 2010). These complex energy systems can be more easily understood by computer-based visualization tool.

Although there are many tools available in the market, including those mentioned above, their limitations suggest that there is a need for a generic visualization tool for the complete analysis of the effects of changing energy policies on energy security. A detailed description of the thesis objectives are elaborated in the following section.

1.1. Thesis Objectives:

The primary objective of this work is to create a visualization tool to show the impacts of energy security for any jurisdiction when new policies are introduced, or existing policies are changed. This tool will have flexibility to run the software multiple times (by applying different policies) to develop efficient and effective policies by applying 3R's and analysing the changes on energy security indicators.

While accomplishing the primary objective, the main goals of this work are to:

- Develop a visualization tool that can be used to design an energy system (combination of one or more energy chains)
- Analyse the effects of changing energy policies on a jurisdiction's energy system.
- Identify the impact on energy security of changes to a jurisdiction's energy policies.
- Investigate the output of every process in the energy system and analyse it to see whether or not it satisfies the demand.

It is important to understand that changes to energy policies can influence a system's energy security. It is critical to study the possible effects of changes to energy polices before they are deployed. This research will develop a tool to visualize the effect of changing energy policies on energy security.

1.2. Thesis Outline

The thesis consists of six chapters. Brief details of each chapter are provided here.

Chapter 2 provides an outline of energy security importance and methods to analyse a jurisdiction's energy security. It also discusses the energy systems and their functions, followed by an introduction to energy policies and how they impact energy systems. It also presents a brief review on energy modeling tools and how modeling tools can be used to solve energy policy issues on energy security. Limitations of these modeling tools are also discussed in this chapter.

Chapter 3 discuss in detail the development of visualization tool and how it can be used to analyse the potential of energy policy on energy security. It also discusses the implementation and steps required to run the software.

Chapter 4 provides a brief description about the case study data chosen in this research to validate the visualization tool.

Chapter 5 presents a discussion and significance of the case study results.

Chapter 6 draws the conclusion of this thesis. The main contributions of the work are elaborated, and the issues that are outstanding in the research work are suggested for future work.

CHAPTER 2. LITERATURE REVIEW

2.1. Energy Security

Access to adequate supplies of flammable material, such as wood; security for heat and light energy has been conceptually used since in the early period of Stone Age (Victor, 2011). Over centuries, energy has become a key resource to economic and welfare growth for any jurisdiction (UN-Energy, 2008; Adil, et al., 2004; World Bank, 2005). Energy supply for any jurisdiction is expected to be secured, affordable and environmental friendly (Blum, et al., 2012). Now, energy security is globally a complex issue because of its multi-dimensional nature. Many significant factors can have an effect on energy security, such as dependence on fossil fuels, energy market deregulation, financial market unrest, nuclear energy development, obstacles to energy technology development, increasing energy demands of developing countries, instability of international politics and large-scale natural disasters (Chuang, et al., 2012).

Most jurisdictions in the world meet their energy demand from the primary energy sources, mainly from fossil fuels in the form of coal, petroleum, and natural gas. According to the IEA's New Policies Scenario, world population is assumed to grow from 6.8 billion in 2010 to 8.6 billion in 2035. An additional 2 billion people means growing mobility requirements, rising electricity needs, and increasing energy supplies to power industry. Population growth can have a direct impact on the size and composition of energy demand. World energy demand is expected to rise from 13,000 million tonnes of oil equivalent (Mtoe) to around 17,000 Mtoe, rising by approximately 35% from 2010 to 2035 (IEA, 2012a). Based on IEA's projections for 2035, demand for fossil fuels still remains high, coal demand rise by 21%, natural gas by 50% and oil demand rise from 87.4 MBD (million barrels per day) in 2011 to 99.7 MBD in 2035 (IEA, 2012a).

Changes in the climate have been associated with the rising concentrations of greenhouse gases (GHGs) in the atmosphere. This phenomenon has resulted in adverse effects, such as an increase of global surface temperature, serious change to the climatic systems, and environmental damage (Nakata, et al., 2011). The rising global demand for energy and excessive use of fossil fuels is estimated to rise in energy related CO_2 emissions from 31.2 gigatonnes (Gt) in 2011 to 37 Gt in 2035 and average temperature increase of 3.6°C (IEA, 2012a). Fossil fuel combustion contributes to over 80% of the worldwide emissions of CO_2 (Taseska, et al., 2011). The increase in the global energy demand and rise in fossil fuel energy prices has played an important role in the current global financial crisis (Shahriar, et al., 2010).

Maintaining and improving energy security in the face of these problems will be one of the major challenges facing policy makers, politicians, and the public (IEA, 2011b). Also, challenges like global warming, energy scarcity and energy price fluctuations faced by many countries makes energy security as one of the main agenda in policy making (Chuang, et al., 2012). However, several authors have pointed out that there is no common definition to explain energy security, see (Winzer, 2011; Checch, et al., 2009). The one developed by IEA, "the uninterrupted physical availability at a price which is affordable, while respecting environment concerns", is universally accepted by many of them (IEA, 2010; Hughes, 2011).

Many of the existing definitions of energy security mainly focus on maintaining energy supplies-particularly supply of oil (David, et al., 2011). Energy security is not only the long-term security of supply for primary energy sources but it should also consider a long term energy service security (Jansen, et al., 2010). For example, electricity supply is one the important energy service, yet 1.3 billion people, around 19% of the world population, lack electricity (ExxonMobil, 2012).

Energy security has become a global security issue and it needs to be interpreted in its broadest sense. Therefore, energy security is not advisable to be just security of energy supply (mainly Oil) (Nagy, 2009). One of the ways to understand the energy security is by using energy security indicators (Augutis, et al., 2012). There are different energy security indicators discussed in literature which can be considered to analyse energy security; for example, the supply/demand indicator and crisis capability indicator developed by Energy Research Centre of the Netherlands (ECN) (Scheepers, et al., 2006).

According to (Hughes, 2011), any changes in the energy system can be measured using three indicators (Availability, Affordability, and Acceptability) called the 3A's. These indicators can be parsed into IEA's definition of energy security: availability ("the uninterrupted physical availability"), affordability ("a price which is affordable"), and acceptability ("respecting environment concerns"). As with the IEA's definition of energy security being representative of many other definitions, the three indicators are found in most energy security indicator sets (Hughes, 2011).

2.2. Energy Systems

Energy systems are representations of the relationships existing between production and consumption of energy services (Nakata, et al., 2011). The energy system is responsible for meeting its end service energy demands by converting and transporting energy flows from energy suppliers or producers (Hughes, 2011; Nakata, et al., 2011). Energy systems are dynamic and they change overtime; change can be sudden or anticipated which can lead to deteriorate of energy security. In (Hughes, 2011), a generic framework has been developed by using system analysis techniques. This framework can be employed to capture the evolution of energy security in an energy system. Three energy security indicators (Availability, Affordability, and Acceptability) have been used to analyse the level of energy security (Hughes, 2011).

A generic energy system is shown in Figure 1. The energy system (a labeled circle) consists of terminators (rectangle boxes) and flows (arrows). This system will try to satisfy the demand (converted energy) coming from end-uses from energy sources (unconverted energy). No conversion and distribution of energy is done 100% efficiently; few losses and emissions are included and released into the environment. The behaviour of the energy system will change based on the policy regulations, which can affect one or more of the system's flows (Hughes, 2011).

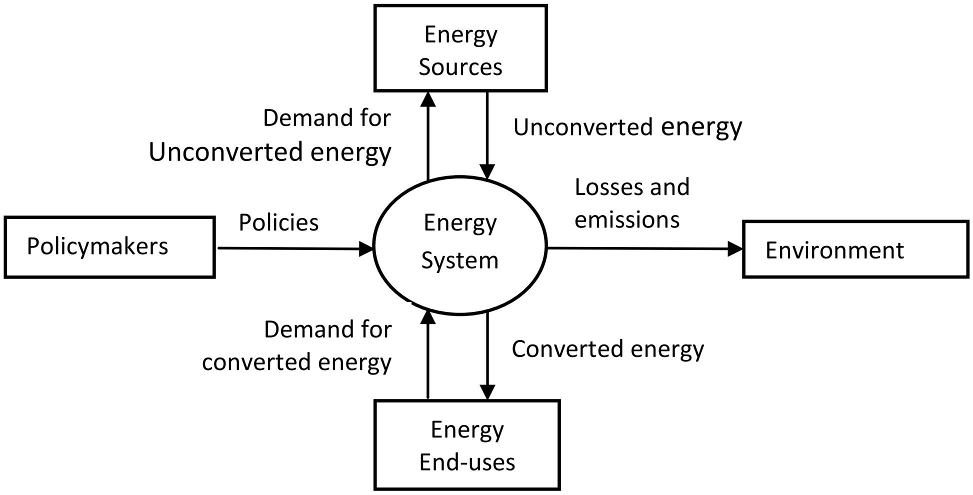


Figure 1: A generic energy system (from (Hughes, 2011))

All jurisdictions have an energy system with combinations of one or more energy chains composed of conversion or transportation processes. Each chain can be interconnected as a series of processes connected by flows. Each process is neither responsible for converting energy from one form to another nor transporting energy between one process to another process or between process and terminators. Each process (conversion or transportation) within the energy chain has six different flows, as shown in Figure 2.

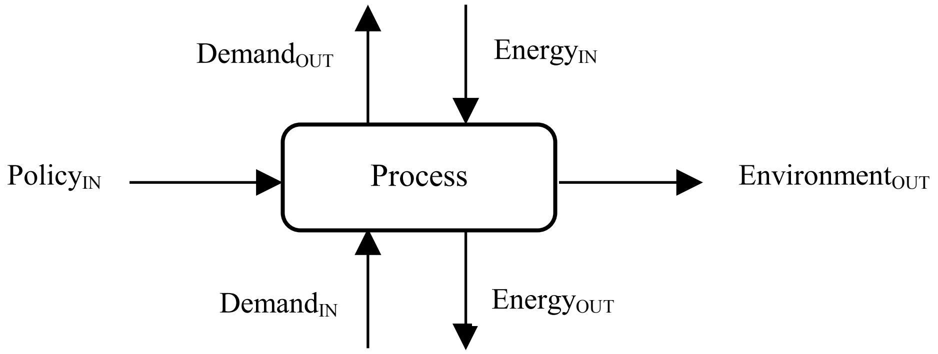


Figure 2: A generic energy process with six flows (from (Hughes, 2011))

The characteristics of each flow are defined as follows (Hughes, 2011):

- *Demand*$_{IN}$: The amount of energy required for the downstream process or energy service; the process receives demand from downstream entities.
- *Energy*$_{OUT}$: The amount of energy produced by the process upon receiving the amount of energy required by $\text{Demand}_{\text{IN}}$.
- *Demand*$_{OUT}$: The amount of energy required to process in order to meet the $\text{Demand}_{\text{IN}}$ is specified in $\text{Demand}_{\text{OUT}}$; this amount of energy is supplied by an upstream process.
- *Energy*$_{IN}$: The amount of energy requested by the process (in terms of $\text{Demand}_{\text{OUT}}$) to the upstream processes and the amount of energy received by upstream process is specified as $\text{Energy}_{\text{IN}}$. Also, $\text{Energy}_{\text{IN}}$ is always greater than the $\text{Energy}_{\text{OUT}}$.
- *Environment*$_{OUT}$*:* Converting energy from one form into another within the process or transporting the energy between the processes is not done 100% efficiently, as a result, some losses or emissions, or both, are let-off into environment specified in this flow.
- *Policy*$_{IN}$: This flow specifies the regulations intended to control the behaviour of the process; specified by an individual or organisation (such as institutional, corporate, or governmental).

Every process within a chain is responsible to meet the energy demand flow, however, the loss of an energy supply or failure of any process within a chain may lead to deterioration of energy security. As shown earlier, the state or level of energy security can be described by three indicators, described as follows (Hughes, 2011):

- **Availability**
  The availability defines a continuous supply of an energy flow between processes or processes and terminators. When process energy out flow ($\text{Energy}_{\text{OUT}}$) matches demand input flow ($\text{Demand}_{\text{IN}}$), the flow can be considered secured. However, if it fails, the flow is said to be unsecured and can lead to deterioration in energy security.
- **Affordability**
  The affordability of a process is simply the cost of the $\text{Energy}_{\text{IN}}$ flow (the costs associated with the upstream conversion or transportation process). Cost of a flow can be inversely proportional to an affordability indicator. As the cost of a flow increases, it can be less affordable; if cost of a flow decreases, it can be more affordable.
- **Acceptability**
  Converting or transporting energy with in the process or between the processes involves emission and losses ($\text{Environment}_{\text{OUT}}$ Flow). The acceptability indicator refers to the environmental acceptability of an energy flow.

Any changes to the flows of energy can be measured using these three indicators; flows can be between the processes, within a chain, or within the system (Hughes, 2011). Based on the outcome of the level of energy security, energy policies can be developed to improve the energy security for a process ($\text{Policy}_{\text{IN}}$ Flow).

2.3. Energy Policy

Most jurisdictions around the globe are facing issues such as resource depletion, environmental hazards, price instability, decline in energy security, and an increase in economic and social difficulties (IEA, 2011b). In the face of these problems, energy policies and their regulations are developed and implemented. Policies are intended to develop the jurisdictions energy security, but implementing energy policies with an incomplete analysis may have possible unintended consequence (Hughes, 2011) and (Hodge, et al., 2011); the "*rebound effect*" is one such example (Hughes, 2011). In (Barker, et al., 2007), it was shown that the UK Climate Change Agreements

(CCAs) and energy efficiency policies for industrial sector had a 19% rebound effect between years 2000-2010. Another issue is that inefficient policies will not reach the policy targets. Example, UK policy programme for electricity generation from renewable energy since 1990 targets for low carbon have not been achieved (Geoffrey, et al., 2011).

To prevent the adverse effects of energy policies, it is important to analyse them before they are applied to the processes. In (Hughes, 2011; Hughes, 2009), a method called the 3R's has been discussed to improve the energy security and develop energy policies for a jurisdiction. The method consists of 3R's: Reduce (use less energy), Replace (shifting to secure sources) and Restrict (limiting new demand to secure sources) and energy policies could be discussed in terms of these R's. However, energy policies are not considered to be measurable, but when the policies are applied to a process ($\text{Policy}_{\text{IN}}$ flow) the outcomes are influenced in one or more of a process' output flows (Hughes, 2011).

Due to the highly complex level in the modern world, energy system and inefficient energy policies may have unintended consequence on energy security (Hodge, et al., 2011). This means modeling and analysis tools can be effectively used to develop energy system and composing policies for a better secured energy system (Hodge, et al., 2011). These modeling tools can also be called energy system analysis models (Lund, 2010).

2.4. Modeling Tools

Due to the complexity of energy systems and interest in energy security, many countries compose their own national-level models (IEA, 2011; Nakata, et al., 2011). Models should be built as tools to simulate or control the behaviour of these systems (Nakata, et al., 2011). A large number of different computer energy modeling tools exist globally that make calculations or simulations related to the analysis of energy system (Lund, 2010).

Few selected modeling tools have been discussed to see how they work based on the energy system modeling, how many energy security indicators they satisfy, and their limitations.

2.4.1. Eminent (Early Market Introduction of New Energy Technologies)

Eminent was created as part of EMINENT project by Netherlands Organisation for Applied Scientific Research (TNO) in Netherlands. This tool helps in the introduction of new energy technologies and new energy solutions into the market (Klemeš, et al., 2005). It evaluates the performance and potential impact of early stage technologies (ESTs) in a pre-defined energy supply chain, over a year time-period.

Eminent is used to evaluate the impact of ESTs (Early Stage Technology). The tool is divided into three different sections: Resource manager (has the information of seven different primary energy resources which includes renewable); Demand manager (deals with the five demand types: Electricity, Fuels, Heating, Mechanical work, and Transportation); and EST manager (stores all the technical information about the technologies) (Peter, et al., 2004; Eminent, 2003). Some of the limitations of *Eminent* tool are as follows:

- Economic nor Affordability dimension of energy security are examined
- No distribution or transportation process is considered in the development of an energy system
- Not a generic tool, it can simulate Europe countries only
- Does not provide any energy security index to evaluate over all energy security

2.4.2. Balmorel

The purpose of the *Balmorel* tool is to analyse the electricity and combined heat and power sectors (Lund, 2010). *Balmorel* tool can simulate the electricity and heat sector and can be used by energy system experts, energy producing and transmission companies, and researchers for the future development of the energy sector.

Few countries have been chosen for analyses of security of electricity supply, the role of flexible electricity demand, hydrogen technologies, wind power development, and the role of natural gas (Connolly, et al., 2009; Balmorel). Some of the limitations of *Balmorel* tool are as follows:

- Can simulate only electricity and heating sectors; transportation sector is not considered
- Does not provide any energy security index to evaluate over all energy security

2.4.3. IKARUS

IKARUS tool is a classical bottom-up energy optimization model describing the energy system on a national level (Markewitz, et al., 1996). This energy model has been developed by the Programme Group Systems Analysis and Technology Evaluation (STE). In (Markewitz, et al., 1996), it was shown that the main purpose of this software is to investigate the role of carbon capture and storage (CCS) in reducing carbon emissions. The model offers a cost-minimizing solution for the energy system and effects of stochastic energy prices on long-term energy scenarios. Some of the limitations of *IKARUS* tool are as follows:

- Sudden changes in energy system cannot be handled since the overall focus is on long term issues such as cost minimization and reducing carbon emissions,
- Does not provide any energy security index to evaluate over all energy security.
- Security of supply or availability dimensions of energy security is not captured

2.4.4. MESSAGE

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environment Impact) is a dynamic linear programming model designed for the optimization of energy supply and utilization (Sabine, et al., 1995). The model was originally developed at the International Institute for Applied Systems Analysis (IIASA) and the International Atomic Energy Agency (IAEA). It is a systems engineering optimization model used for medium- to long-term energy system planning, energy policy analysis, and scenario development (Hainoun, et al., 2010). The underlying principle of this tool is optimization of energy supply and to evaluate the alternative energy supply strategies to minimize the GHG emissions (Hainoun, et al., 2010). Limitations of *MESSAGE* tool are as follows:

- Since the main focus of this tool is on reducing GHG emissions, it cannot be a generic energy policy evaluator
- Economic impacts on long run are not discussed
- Cannot be used to evaluate the overall energy security

2.4.5. LEAP

LEAP (Long range Energy Alternatives Planning System), is a widely used modeling tool for energy policy analysis and climate change mitigation assessment. This tool is designed to help assist energy planners and decision makers to evaluate the future energy demand and problems associated with the energy consumption (Amit, et al., 2003). This model can be useful for tracking down the long-term energy demand, supply situations and GHG emissions levels, and also the likely impacts of different policies. The main purpose of this tool is to estimate the future mitigation potential and costs of CO_2 reduction technology options to the electricity generation (Seungmoon, et al., 2007). Some limitations of *LEAP* tool are as follows:

- Economic dimensions are not captured
- Security of energy supply are not analysed since the overall focus is on energy sector,
- Cannot be used to compare overall energy security

2.4.6. HOMER

HOMER is a micro-power optimization model, used to evaluate designs of both off-grid and grid-connected power systems for a variety of applications (NREL, 2011). The user should provide the model with inputs, such as renewable energy resource availability, technology options, and component costs. Using these inputs, *HOMER* simulates different configurations energy chains, and generates the net cost for every combination (NREL, 2011). The system cost calculations account for costs such as capital, replacement, operation and maintenance, and fuel. Some of the limitations of *HOMER* are as follows:

- Works only for renewable energy simulation; non-renewable energy resources are considered,
- Security of energy supply are not analysed since the overall focus is on cost or affordability dimension,
- Cannot be used to analyse overall energy security
- Long-term issues are not included. Such as, environmental impacts or acceptability indicator

2.4.7. GTMax

Generation and Transmission Maximization (GTMax) Model was developed by Argonne National Laboratory in 1999.The *GTMax* tool is used by utility operators and managers to find solutions for the generation and transmission of electricity that increases income while keeping expenses at a minimum (Foley, et al., 2010). The *GTMax* model produces financial reports, which help dispatchers identify operational strategies to optimize the value of the system's resources as well as estimates regional economic clearing price of energy (Argonne, 2004). *GTMax* tool can also be used for improving company revenues, optimizing hydro and thermal generation, estimating regional economic clearing price of energy, and simulating spot market transactions (Argonne, 2004). Limitations for *GTMax* tool are as follows:

- Can only analyse electricity service; transportation and heating service are not included
- Security of energy supply and GHG emissions are not included
- Over all energy security cannot be analysed

2.4.8. NEMS

The National Energy Modeling System (NEMS) is a computer-based, energy-economy modeling system designed and implemented by the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE). Based on the *NEMS* tool, EIA projects the production, imports, conversion, consumption, and prices of energy, subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, and cost and performance characteristics of energy technologies (EIA, 2009). Also, this tool is used in projecting U.S. Annual Energy Outlook (AEO). *NEMS* framework represents the U.S. energy system, analyzing the results from the framework will help in alternative assumptions and policy initiatives (EIA, 2009).

It examines SO_2 and NOx penalties, environmental impacts and carbon reduction policies but fails to explain tax mechanisms and social impacts (EIA, 2009). One of the limitations of *NEMS* is as follow:

- Failed to be a generic tool since the framework is limited to analyse only the jurisdictions in U.S.

2.4.9. MOSES

Model of Short-Term Energy Security (MOSES) is a tool to evaluate security for short-term energy supply, and was developed by IEA. *MOSES* provides a generic framework based on a set of indicators that measures two aspects of energy security: Risk (deals energy supply disruptions) and Resilience (the ability of a national energy system to cope with such disruptions) (IEA, 2011).

MOSES takes an energy systems approach in analyzing energy security and does not aim to rank the countries on their basis of energy security; instead, it identifies ‘energy security profiles’ of individual countries based on their risks and resilience capacities (IEA, 2011). *MOSES* analyzes both risk and resilience connected to external factors as well as domestic factors. Thus, including indicators related to external risks, external resilience, domestic risks and domestic resilience (IEA, 2011). Some limitations of *MOSES* tool are as follows:

- Long term issues such as environmental impact are not assessed
- Economic dimensions of energy security are not considered
- Focuses only on short-term (refers to disruptions of days to weeks) physical security of energy supply
- Security of energy service cannot be analysed
- Since the overall energy security index does not provided, overall energy security cannot be compared.

2.5. Common Limitations for Modeling Tools

In this research, many other popularly used tools are also reviewed. Such as, EnergyPLAN, AEOLIUS, COMPOSE (Compare Options for Sustainable Energy), INFORSE (International Network for Sustainable Energy), RAMSES, WASP (Wien Automatic System Planning Package), and many other energy system modeling tools. Interestingly, all have limitations which range from tools developed for specific jurisdiction to tools developed to analyse specific types of energy. Also, no modeling tool available that can visualize the current energy security status of a jurisdiction and indicating pathways for improved energy security (Hughes, 2009). Modeling and simulation comprise a discipline that, when combined with visualization, looks at ways to understand the interactions of system components and the system (Argonne, 2010).

2.6. Summary

Developing a jurisdictions energy security is currently undergoing research. This chapter briefly discussed the importance of energy security and how it can be analyzed by using indicators. A brief description of energy system, energy chains, processes, and energy flows was also provided. The role of energy security indicators and energy flows in creating secured energy policies are shown. In parallel, energy system modeling tools have been reviewed; particularly the review conducted on these tools has highlighted modeling tools have the ability to develop energy secured policies and to improve energy security.

CHAPTER 3. METHODS AND IMPLEMENTATION

This chapter describes a method of representing an energy system by using generic processes and their characteristics. This method can effectively describe the effects of energy policies on energy security by using visualization technique.

This chapter discuss how:

- An energy system can be represented using generic processes and their characteristics
- Multiple generic processes can be combined together to create an energy system
- Energy flows can be calculated for a process
- The security for each process can be analysed by the energy security indicators

Following these steps, the effects of energy policies can be visually analysed for a jurisdiction's energy system. The proposed method has three phases: energy system development, energy flow calculation, and energy security analysis. A detailed discussion of each phase is now presented.

3.1. Energy System Development Phase

An energy system comprises of one or more energy chains, linking energy sources to an energy service. Each chain can be represented as a series of generic processes, with the behaviour of each process depending upon individual characteristics.

3.1.1. Process Characteristics

When multiple processes are linked together to create an energy chain, each process has different behaviour or characteristics. These characteristics are process type, efficiency, process color and flows. These characteristics are defined as follows:

Flows: A flow is a logical connection between entities (i.e., between each of the processes and between the processes and energy sources or services) (Hughes, 2011). Each energy chain can be represented as a series of processes connected by flows.

As shown in the previous chapter, each process has six different flows (i.e. $\text{Energy}_{\text{IN}}$, $\text{Energy}_{\text{OUT}}$, $\text{Demand}_{\text{IN}}$, $\text{Demand}_{\text{OUT}}$, $\text{Policy}_{\text{IN}}$, $\text{Environment}_{\text{OUT}}$). Since processes are linked together, an $\text{Energy}_{\text{OUT}}$ flow from a process will turn into an $\text{Energy}_{\text{IN}}$ flow for a downstream process or an end-service in the chain. Similarly, a $\text{Demand}_{\text{OUT}}$ flow from a process will turn into a Demand$_{\text{IN}}$ flow for the upstream processes or to an energy sources which supply unconverted energy.

In this method, each flow is represented by arrows. Both unidirectional and bidirectional arrows can be used to connect different processes within the chain or between the chains. Table 1shows the both arrows that can be drawn in different direction.

Table 1: Types of arrows

Arrow	**Arrow type**
↓ ↑ ← →	Unidirectional
↕ ↔	Bidirectional

Unidirectional arrows represent one way flow of energy heading towards the arrow point. Similarly, Bidirectional arrows represent a flow of energy but in both the directions. Example, a unidirectional arrow connecting two processes that represents the upstream process supplying energy to the downstream process (i.e., one way communication) Similarly, if two processes are connected with a bidirectional arrow that represents the upstream process supplying energy and the downstream process sending demand for energy (i.e., two-way communication).

Process Type: In (Hughes, 2011), it was shown that a generic process can convert or transport energy flows in order to meet the demand.

Conversion Process: A conversion process represents a technology that can be used to convert one form of energy (Energy$_{\text{IN}}$ flow) into another (Energy$_{\text{OUT}}$ flow) in order to meet the demand (Demand$_{\text{IN}}$ flow) from other processes or energy services. While the conversion process emissions or losses are released into the environment (Environment$_{\text{OUT}}$ flow) in the form of GHG and heat.

Example: a thermal plant takes energy input as coal (Energy$_{\text{IN}}$) and produce energy output in the form of electricity (Energy$_{\text{OUT}}$ flow). In this process it releases heat and GHG emissions into the air. The mathematical equations for conversion process are discussed in the calculation phase.

Transportation Process: A transportation process represents a technology where a process moves or carries an energy flow ($\text{Energy}_{\text{IN}}$ flow) from one or more processes or energy sources to meet the demand ($\text{Demand}_{\text{IN}}$ flow) of another processes or energy services ($\text{Energy}_{\text{OUT}}$ flow). Since some form of energy is required to transport the energy, the transportation process releases the losses or emissions into the environment ($\text{Environment}_{\text{OUT}}$ flow) (Hughes, 2011).

Example: electricity generated from a power plant is distributed through the transmission lines to the substations and customers. The energy required to move electricity comes from the electricity itself; the emissions are in the form of heat. The mathematical equation for transportation process is discussed in the calculation phase.

Efficiency: The amount of energy flow converted or transported in order to meet the demand will depend upon the process efficiency.

3.1.2. Representing an Energy System

An energy system is a combination of single or multiple energy chains, each consisting of interconnected conversion and transportation processes. In this method, a single generic process can be used to represent any jurisdiction's energy chains. A series of generic process are selected between the energy sources and energy services responsible for converting or transporting the energy flow, the behaviour for each process will indicate by process characteristics. Figure 3 is a flowchart representing how this method can be used to build any jurisdiction's energy chain with a single generic process. To build an energy chain using this method, initially select the primary energy sources followed by inserting a series of generic processes which can be a combination of primary conversion, transportation, and secondary conversion process. The behaviour of a process and the energy flows between the processes can be selected by process characteristics. Finally, the chain will end by selecting energy services.

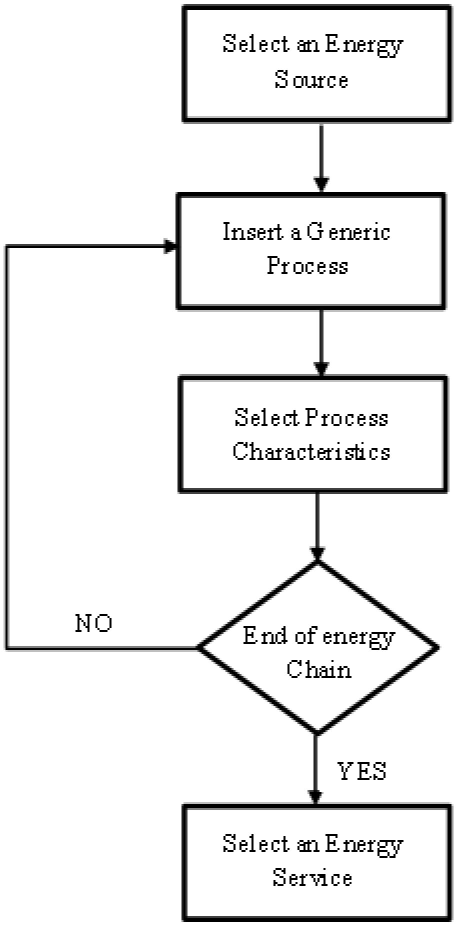


Figure 3: Building an energy chain

For better understanding to the Figure 3, the generic energy chain, shown in Figure 4, consists of three processes and process characteristics used to set the each process behaviour (i.e., primary conversion, transportation, and secondary conversion). The first process, the conversion process, takes a flow of primary energy and converts it into a secondary energy flow. The next process in the chain is responsible for transporting the secondary energy flow to the secondary conversion process that then converts it into the tertiary energy flow to meet the end service energy demand. Each process in an energy chain is typically subject to some form of policy and these will also be associated with losses and emissions. In an energy chain, the combination of conversion and transportation process as may not be the same in all cases. For example, energy chains using variable energy sources will connect directly to the transportation process.

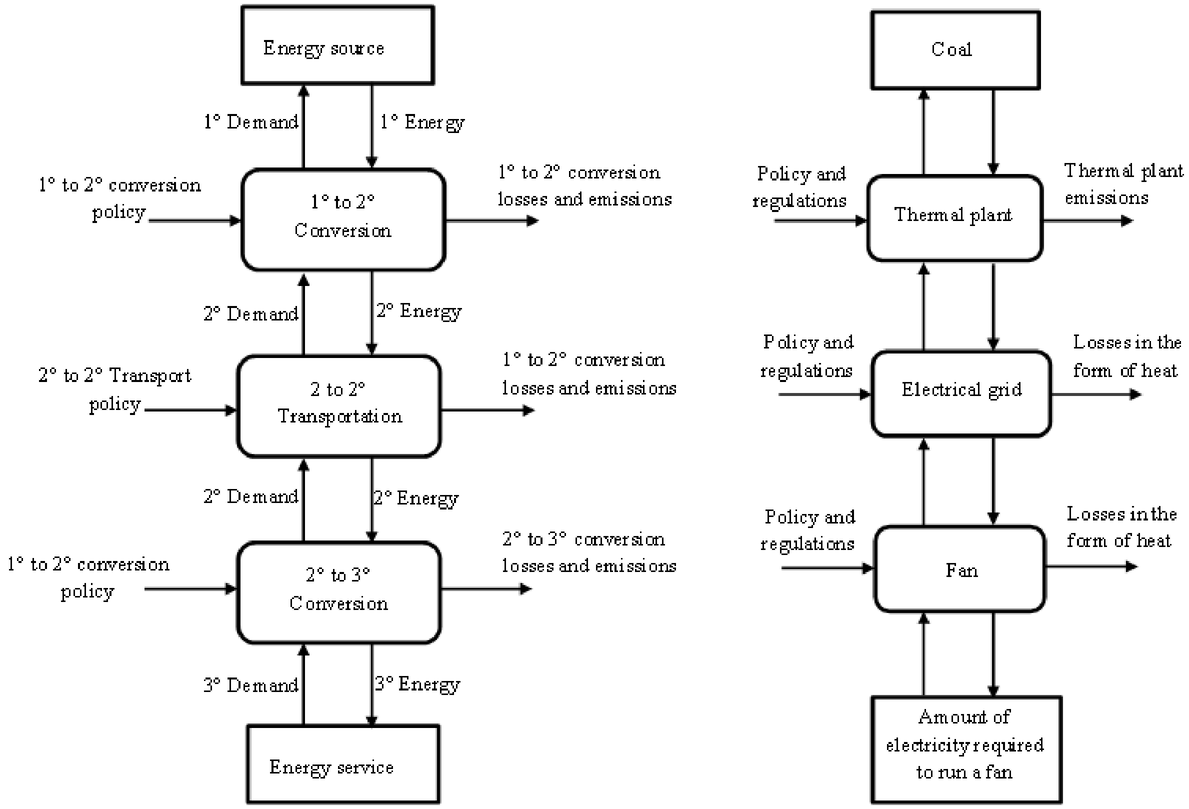


Figure 4: A generic energy chain and a sample example (Hughes, 2011)

Figure 4 also show a sample energy chain. The Primary conversion process, thermal generation station, takes energy input as coal and generates energy output as electricity. This primary conversion process is associated with air emissions as carbon dioxide as well as thermal losses. The transportation process, electrical grid, transports the electricity in to the buildings, while the electric grid experiences resistance and reactive power losses. Finally secondary conversion process, a fan, uses the electricity to blow air. A fan consuming the electricity will have inherent inefficiencies that result in losses in the form of heat. The amount of electricity required to run a fan is supplied from upper level processes. An energy service cannot meet the demand if anyone of the process failed in an energy chain.

3.2. Calculation Phase

Every process in an energy system will take a flow of energy ($Energy_{IN}$) from the upstream process or energy source and convert or transport the flow into an output flow ($Energy_{OUT}$) for downstream processes or energy services. The $\text{Demand}_{\text{IN}}$ flow is the result of a downstream process or energy service calling for energy from this process and indicates the quantity of energy required. The process requires a supply of energy to meet $\text{Demand}_{\text{IN}}$; this energy is supplied by an upstream process and the amount of energy required is specified in $\text{Demand}_{\text{OUT}}$. In order to satisfy the demand, the amount of energy converted or transported is estimated as follows.

3.2.1. Conversion Process Energy Output ($\mathbf{CPE_{OUT}}$):

The primary conversion process takes a flow of primary energy and converts it into secondary energy flow (CPE_{OUT}).

Primary conversion process, $Energy_{OUT}$ flow, can be calculated as shown in equation (1).

$$\boldsymbol{CPE_{OUT} = (PE_{IN} * EC) * P_{EFF}} \tag{1}$$

Where CPE_{OUT} is the primary energy conversion process output, PE_{IN} is the amount of primary energy input, EC is the energy content for the selected primary energy source, and P_{EFF} *(%)* is the primary conversion process efficiency.

Each energy chain converts the primary energy into secondary energy flow. With the exception of processes that converts variable energy sources. The variable energy sources directly supply secondary energy flow to distribution process and further secondary energy is converted into the tertiary energy flow.

Secondary Conversion process, $Energy_{OUT}$ flow, can be calculated as shown in equation (3). To derive SCE_{OUT} equation (3) have been used.

$$\boldsymbol{SCE_{OUT} = DPE_{OUT} * SCP_{EFF}} \tag{2}$$

Where SCE_{OUT} is the energy output from the Secondary conversion process, SCP_{EFF} is the percent of efficiency for the secondary conversion process, and DPE_{OUT} is the distribution process energy output.

3.2.2. Distribution Process Energy Output ($\mathbf{DPE_{OUT}}$)

Distribution process, $Energy_{OUT}$ flow, can be calculated as shown in equation (3). To derive DPE_{OUT} equation (1) has been used.

$$\boldsymbol{DPE_{OUT} = CPE_{OUT} * DP_{EFF}} \tag{3}$$

Where DPE_{OUT} is the energy output for the distribution process, and DP_{EFF} (%) is the efficiency for the distribution process.

3.3. Energy Security Analysis Phase

Most jurisdictions, or organizations responsible for the process, have regulations intended to control the actions of the process; these regulations are specified in the $Policy_{IN}$ flow. As mentioned in the earlier chapter, these policies can be discussed in terms of the 3R's.while such policies can affect the process output flows ($Energy_{OUT}$ and $Environment_{OUT}$).

In this method, energy policies are discussed in terms of 3R's and the impacts of the policies are captured by energy security indicators (availability, affordability, and acceptability). As discussed in the previous chapter, these indicators can be parsed from the IEA's definition of energy security. The method will check if each indicator is satisfying the criteria for IEA definition of energy security (i.e., the uninterrupted physical availability of energy at a price that is affordable, while respecting environment concerns).

3.3.1. Checking Availability Indicator

Each process converting or transporting the energy should always satisfy the demand coming from the downstream processes or energy services. A process is said to be secure when the $Energy_{OUT}$ flow for a process is greater than the $Demand_{IN}$ flow (i.e., $Demand_{IN} > Energy_{OUT}$). In this method, when a process fails to satisfy the $Demand_{IN} > Energy_{OUT}$ condition, the process will be visually notified by the tool. This condition determines whether the IEA's definition for a secured supply of energy is satisfied (i.e., the uninterrupted supply of energy). Every process within the energy system is checked with this condition. This indicates visually where the energy system has failed.

3.3.2. Affordability Indicator Estimation

Regardless of conversion or transportation process, each process energy flow is associated with a cost which has the potential to impact the energy security. As the cost of a flow increases, it can become less affordable and hence less secure; on the other hand, if the cost declines, it can become more affordable and therefore more secure. Affordability can be referring to the price paid for a unit of energy.

The affordability of an energy flow varies between the customers; the lower the costumer's income, the larger the percentage required covering the cost of energy. This interpretation of affordability refers to the ability-to-pay for a unit of energy.

In this method, affordability is estimated from the supplier's perspective. It estimates the cost at which the suppliers are supplying the energy. A jurisdiction can supply energy either by producing energy from primary energy sources in their own jurisdiction or by purchasing secondary energy from other jurisdictions. The cost of an energy flow has been estimated by using equation (4).

$$\boldsymbol{Cost} = (\boldsymbol{Number\ of\ units\ produced\ or\ purchased} * \boldsymbol{Cost\ per\ unit\ energy}) \qquad \textbf{(4)}$$

Where, *cost per unit energy* can be stated as the cost per unit energy produced and distributed or the cost per unit energy purchased and distributed.

This method also estimates the sale cost or the revenue generated in order to determine whether the supplier supplied the energy at profit or loss. The revenue generated by an energy flow is estimated using equation (5).

$$\boldsymbol{Charge} = (\boldsymbol{Number\ of\ units\ supplied} * \boldsymbol{Charge\ per\ unit\ energy}) \qquad \textbf{(5)}$$

Where *charge per unit energy* is the sale cost per unit energy charged by the suppliers to the customers for supplying the energy.

A process is said to be more affordable when the cost of an $\text{Energy}_{\text{OUT}}$ flow is less than the revenue (i.e., Cost < Charge). This is from the suppliers view. In this method, when a process fails to satisfy the Cost < Charge condition, the tool indicates the failure by changing the colour of the process.

3.3.3. Acceptability Indicator Estimation:

Acceptability, the third indicator based on the IEA's definition of energy security, refers to the need for energy that respects environmental concerns. This definition of acceptability is applied to the $\text{Environment}_{\text{OUT}}$ flow of a process (i.e., impacts caused by the process such as annual green-house gas or SOx emissions). The acceptability indicator needs not to be restricted to emissions or losses other factors like political and social issues can also be included. In (Hughes, 2011), it was mentioned that political and social metrics can be based upon opinion rather than evidence. In this method, acceptability indicator will refer to emissions or losses made by the process.

Each process will always exhibit some degree of inefficiency and, as a result, is associated with emissions or losses, or both, that are released to the environment. In this method, the total emissions are estimated by using equation (6) (DCCE, 2010).

$$TOT_{EMM} = CO2_{EMM} + CH4_{EMM} + N2O_{EMM} \tag{6}$$

Where TOT_{EMM} is the total emission level (CO2-e tonnes), $CO2EMM$ is the emissions of carbon dioxide, $CH4_{EMM}$ is the emissions of methane, and $N2O_{EMM}$ is the emissions of nitrous oxide.

$$CO2_{EMM} = (E_{IN} * EC * CO2_{EF}) \tag{7}$$

$$CH4_{EMM} = (E_{IN} * EC * CH4_{EF}) \tag{8}$$

$$N2O_{EMM} = (E_{IN} * EC * N2O_{EF}) \tag{9}$$

Where E_{IN} is the amount of primary energy used, EC is the Energy content factor, $CO2_{EF}$ is the emission factor for CO_2, CH_{4EF} is the emission factor for CH_4, and N_2O_{EF} is the emission factor for N_2O.

A process is said to be acceptable if the emissions of an energy flow is less than the emission target level set by a jurisdiction (i.e., Emissions generated < Emission target level). The emission target level is the target of emissions that need to be reduced and this emission target will vary depending upon jurisdiction. In this method, when a process fails to satisfy the acceptability condition (i.e., Emissions generated < Emission target level), the tool will change the process's colour.

By the methods in the three phases, any jurisdiction's energy system can be represented, each process output flows can be estimated. As shown in the previous chapters, every jurisdiction incorporates energy policies to improve the energy security but a few policies may show adverse effects on the energy system. Policies cannot be analysed but the outcome of the policy can show impact on the process output flow. This method analyses the changes in the output flow for each process by analysing the energy security indicators to show the effects of policies and regulation.

A software tool has been developed incorporating the methods to analyse the effects of energy policies on energy security in an energy system. The effects of energy policies are shown visually by the tool by analysing the energy security indicators.

3.4. Implementation

Energy systems can be complex, given the mix of primary sources, energy storage facilities, transmission system mechanisms, and avenues to market. These energy systems can be more easily understood with a computer-based visualization tool. Also, no existing modeling tool can represent graphically the current energy security status of a jurisdiction and indicate pathways for improved energy security. Modeling and simulation comprise a discipline that, when combined with visualization, looks at ways to understand the interactions of system components and the system.

This section describes the functionality of the software tool and demonstrates how a jurisdiction's energy chains can be represented. The energy security indicators are incorporated into the tool for analysing the changes in the energy flow.

3.4.1. Visualization Tool

A software tool has been developed based on the method proposed for the analysis of the effects of energy policies on energy security. This software tool visually shows the energy system components and their activity; this can help to reduce the complexity of an energy system and understand easily. This tool implements the three phases (Energy system development, Calculation, and Energy security analysis) discussed in the above section.

The visualization tool consists of two parts, a front-end and a back-end. The front-end is responsible for energy system development (i.e., applying different energy policies), while back-end handles the data that is required by the front-end to model the energy system. For example, to set a process behaviour different process characteristics are stored in the back-end allowing the user to select a particular process characteristics through the front-end. Also, for a simulation, the input data is provided to the tool by the back-end. This is because, simulations can have multiple number of time steps. For example, if a user wants to run a simulation each hour for about a year, the number of input data points is 8760 time steps. The back-end of the tool can handle multiple numbers of input data and the multiple numbers of output data that is generated by the front-end. The simulation results for the tool is shown in both the front-end and back-end, The process failure and the indicators failure is shown visually on the front-end, while the energy output for each process and energy security analysis is graphically shown on the back-end.

The software's used to develop the visualization tool are Microsoft VB.NET and Microsoft Excel. VB.NET coding is used to develop the front-end, while an excel file is used as back-end. All the proposed methods are coded in the front-end; this also includes operating the back-end file (i.e., opening the back-end file, graphs and outputs estimation) is done through the front-end.

3.4.2. Energy System Development Phase

When creating an energy system, in order to differentiate or for a better analysis, processes, energy sources, and energy services are indicated with different colors. For example, generic process is used to create an energy chain but different process colors are used to indicate the difference between conversion and transportation processes. Also, each component is represented with a specific shape. Energy sources and services are represented with a squared rectangle shape and processes are represented with a rounded rectangle shape.

3.4.2.1. Energy System Components

Five different energy system components are displayed as labels which can be used to select the different components of an energy system. Descriptions of each component are as follows:

Primary source**:** A primary source is an energy source found in nature. This includes both renewable and non-renewable sources. Figure 5 shows the shape and color used to represent the primary energy components.

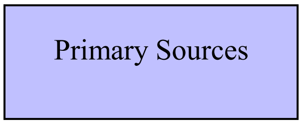


Figure 5: A primary energy source component

Primary conversion**:** A process that converts primary energy to secondary energy. Example, a process converting coal to electricity. Figure 6 shows the shape and color used to represent the primary conversion process.

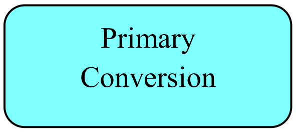


Figure 6: A primary conversion process

***Distribution Process*:** A process that transports the secondary energy. For example, distribution of electricity for different units. Figure 7 shows the shape and color used to represent the distribution process.

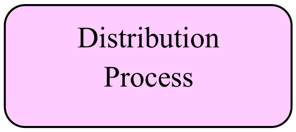


Figure 7: A distribution process

***Secondary conversion*:** A process that converts secondary energy to tertiary energy that can satisfy the end service needs. For example, distributed electricity is converted into different forms of energy to run household appliance. Figure 8 shows the color and shape used to represent the secondary conversion process.

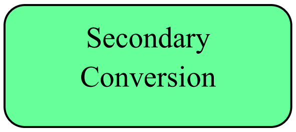


Figure 8: A secondary conversion process

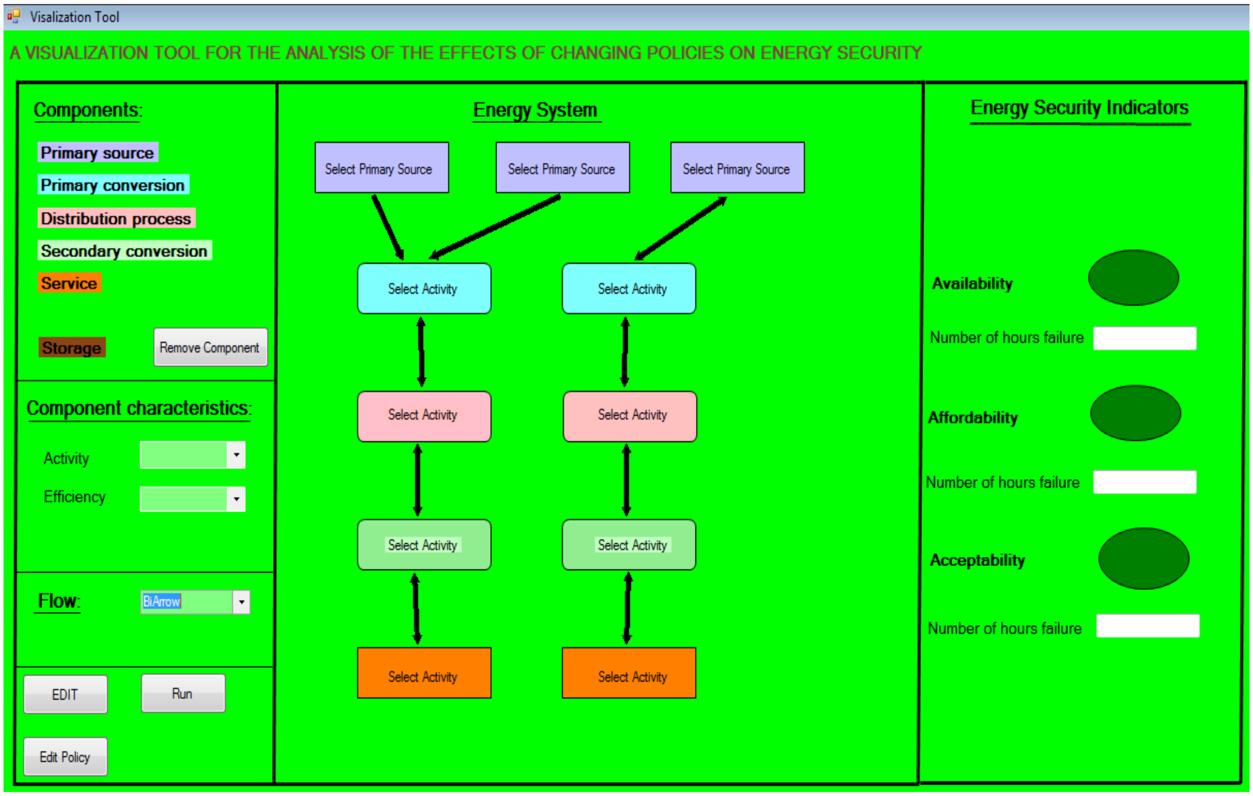
***Service*:** An end point where the secondary converted energy is used. Figure 9 shows the color and shape used to represent the end-use energy service.

Figure 9: An energy service

These components visually help to build a jurisdiction energy system. The characteristics of each component and energy flows between the components can be activated by the component characteristics.

3.4.2.2. Main Screen

The main screen of this tool (i.e., energy system development) is divided into two parts: Toolbox menu and graphical view. Toolbox menu contains the inputs for energy chain components whereas graphical view shows energy system development upon using toolbox menus and energy security indicators. Figure 10 shows the two parts of the software tool and a sample energy system.



Flow: BiArrow

Figure 10: Front-end energy system development view

The energy system components located on the left side of the tool will help to add or delete the components in the development view. For example, by a click on primary source component label a squared rectangle shape will display on development view, which represents the primary energy source. Likewise, clicking on each component label will display designated colored shape rectangle on the development view. The components on the front-end can be removed anytime by selecting the “Remove component” button. Using the component characteristics and flows from the toolbox each component behaviour and energy flows between components can be selected. The component characteristics have two pull down menus, Activity and Efficiency, for choosing the behaviour and efficiency for each process. The activity menu contains different primary energy sources, primary conversion technologies, distribution systems, secondary conversion technologies, and energy services. The activity menu will filter the names by clicking the component labels from the component section. For example, by clicking on the primary source component label the activity pull down menu will filter the items only with primary energy sources, same way it filters for each component label. In order to filter these different component names a back-end file (i.e., database file) is required. As discussed in the previous section, an excel file is used as the back-end file for the tool. Adding or deleting the components can be helpful when different kinds of energy policies are applied to the chain.

Each energy security indicator is represented with an oval shape in green. It shows indicate which indicator has failed by changing the color to red and recording the number of time steps that it has failed (see Figure 10).

3.4.2.3. System Data

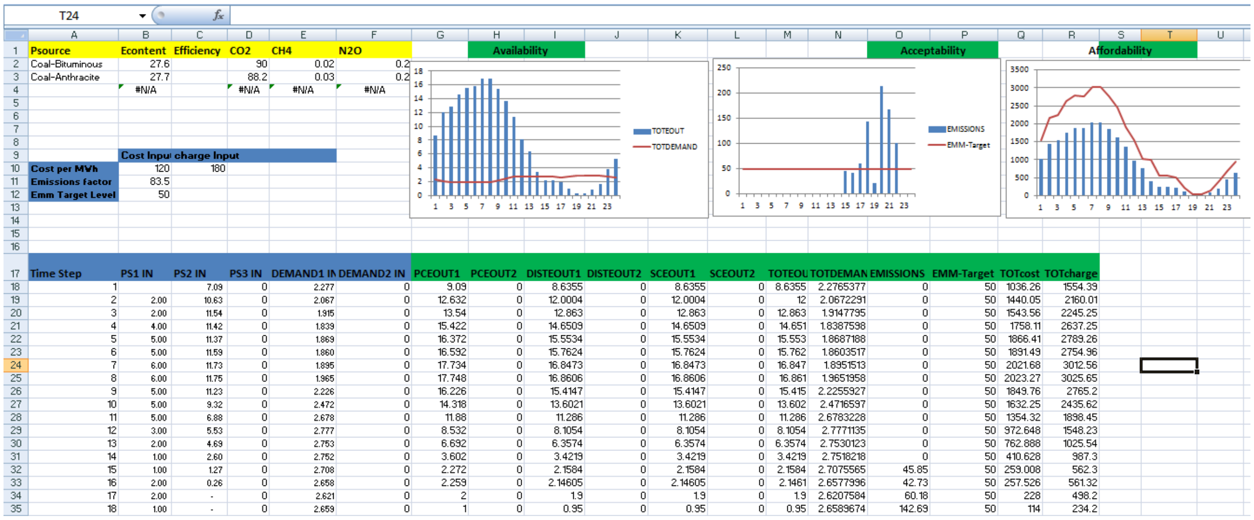
An excel file is used as the back-end file, containing data on the energy content and emission factor for each primary energy source which is used in the calculation phase (see Figure 11). As discussed in the previous section, the different sources, primary conversion (PC), transportation (Trans), secondary conversion (SC), and service are displayed in the activity pull down menu on the front-end to select the behaviour of the process. Front-end has the flexibility to accept any changes (i.e., adding or deleting the items) in the back-end file. For example, adding the new conversion technologies on the back-end the activity pull down menu on the front-end has the ability to filter the new items added.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	**Source**	**PC**		**Efficiency**		**Service**	**Trans**		**SC**	**Source**	**EnergyContent**		**Source**	**CO2**		**CH4**		**N2O**
2	Crudeoil	Refinery		Select one		Transportation	Tank farms		Gasoline and Desil Engines	Coal-Anthrac	27.7		Coal-Anth	88.2	Coal-Anth	0.03	Coal-Anth	0.2
3	Naturalga	Thermal plant		5		On-demand electricity	Natural gas network		Furnace	Coal-Bitumir	27.6		Coal-Bitur	90	Coal-Bitur	0.02	Coal-Bitur	0.2
4	Nuclear	Nuclear plant		10		Heating	Electricity Grid		Electricity load	Coal-Subbitu	18.8		Coal-Subb	93.3	Coal-Subb	0.06	Coal-Subb	0.3
5	Solar	HydroElectric Generation		15						Coal-Lignite	14.4		Coal-Ligni	92.7	Coal-Ligni	0.1	Coal-Ligni	0.4
6	wind	Solar panel		20						Crude Oil	38.51		Crude Oil	68.9	Crude Oil	0.06	Crude Oil	0.2
7	Coal	Wind turbine		25						Natural gas	40.9		Natural ga	51.2	Natural ga	0.1	Natural ga	0.03
8				30						Nuclear	34.66		Nuclear	93.3	Nuclear	0.06	Nuclear	0.3
9				35						Solar	1		Solar	0	Solar	0	Solar	0
10				40						Sside Wind	1		Wind	0	Wind	0	Wind	0
11				45						West Cape	12.2		Biomass	0	Biomass	0.6	Biomass	1.2
12				50						Hydro	1		Hydro	0	Hydro	0	Hydro	0
13				55						NB Power	1							
14				60						Sside Wind								
15				65						West Cape								
16				70														
17				75														
18				80														
19				85														
20				90														
21				95														
22				100														
23																		

Figure 11: Database for the visualization tool

3.4.3. Calculation and Energy Security Analysis Phases

Once the energy chains are created, the calculation phase in the tool will simulate the energy output for each process by using energy input and demand input data. This input data can be supplied by clicking on the "Edit" button. This button will open the back-end file where the input data for each time step is provided. Figure 12 shows the back-end file. The yellow labels are automatically filled upon selecting the components names on the front-end. The blue labels indicate the input data that is required by the tool for the calculation phase.



Psource	Econtent	Efficiency	CO2	CH4	N2O
Coal-Bituminous	27.6		90	0.02	0.2
Coal-Anthracite	27.7		88.2	0.03	0.2
	#N/A		#N/A	#N/A	#N/A

	Cost Input	charge Input
Cost per MWh	120	180
Emissions factor	83.5	
Emm Target Level	50	

Time Step	PS1 IN	PS2 IN	PS3 IN	DEMAND1 IN	DEMAND2 IN	PCEOUT1	PCEOUT2	DISTEOUT1	DISTEOUT2	SCEOUT1	SCEOUT2	TOTEOU	TOTDEMAN	EMISSIONS	EMM-Target	TOTcost	TOTcharge
1		7.09	0	2.277	0	9.09	0	8.6355	0	8.6355	0	8.6355	2.2765377	0	50	1036.26	1554.39
2	2.00	10.63	0	2.067	0	12.632	0	12.0004	0	12.0004	0	12	2.0672291	0	50	1440.05	2160.01
3	2.00	11.54	0	1.915	0	13.54	0	12.863	0	12.863	0	12.863	1.9147795	0	50	1543.56	2245.25
4	4.00	11.42	0	1.839	0	15.422	0	14.6509	0	14.6509	0	14.651	1.8387598	0	50	1758.11	2637.25
5	5.00	11.37	0	1.869	0	16.372	0	15.5534	0	15.5534	0	15.553	1.8687188	0	50	1866.41	2789.26
6	5.00	11.59	0	1.860	0	16.592	0	15.7624	0	15.7624	0	15.762	1.8603517	0	50	1891.49	2754.96
7	6.00	11.73	0	1.895	0	17.734	0	16.8473	0	16.8473	0	16.847	1.8951513	0	50	2021.68	3012.56
8	6.00	11.75	0	1.965	0	17.748	0	16.8606	0	16.8606	0	16.861	1.9651958	0	50	2023.27	3025.65
9	5.00	11.23	0	2.226	0	16.226	0	15.4147	0	15.4147	0	15.415	2.2255927	0	50	1849.76	2765.2
10	5.00	9.32	0	2.472	0	14.318	0	13.6021	0	13.6021	0	13.602	2.4716597	0	50	1632.25	2435.62
11	5.00	6.88	0	2.678	0	11.88	0	11.286	0	11.286	0	11.286	2.6783228	0	50	1354.32	1898.45
12	3.00	5.53	0	2.777	0	8.532	0	8.1054	0	8.1054	0	8.1054	2.7771135	0	50	972.648	1548.23
13	2.00	4.69	0	2.753	0	6.692	0	6.3574	0	6.3574	0	6.3574	2.7530123	0	50	762.888	1025.54
14	1.00	2.60	0	2.752	0	3.602	0	3.4219	0	3.4219	0	3.4219	2.7518218	0	50	410.628	987.3
15	1.00	1.27	0	2.708	0	2.272	0	2.1584	0	2.1584	0	2.1584	2.7075565	45.85	50	259.008	562.3
16	2.00	0.26	0	2.658	0	2.259	0	2.14605	0	2.14605	0	2.1461	2.6577996	42.73	50	257.526	561.32
17	2.00	-	0	2.621	0	2	0	1.9	0	1.9	0	1.9	2.6207584	60.18	50	228	498.2
18	1.00	-	0	2.659	0	1	0	0.95	0	0.95	0	0.95	2.6589674	142.69	50	114	234.2

Figure 12: Back-end file showing input and output data

When the data is provided the tool is now ready to calculate the energy output and analyse the energy security for any given energy policy. Green labels are the output data estimated by the tool for each process in an energy chain. The green labeled energy security indicators will generate the energy trends (i.e., graphs) for each indicator. The flowchart in Figure 13 shows the steps used by the software tool to analyse energy security and show the effects of energy policy visually.

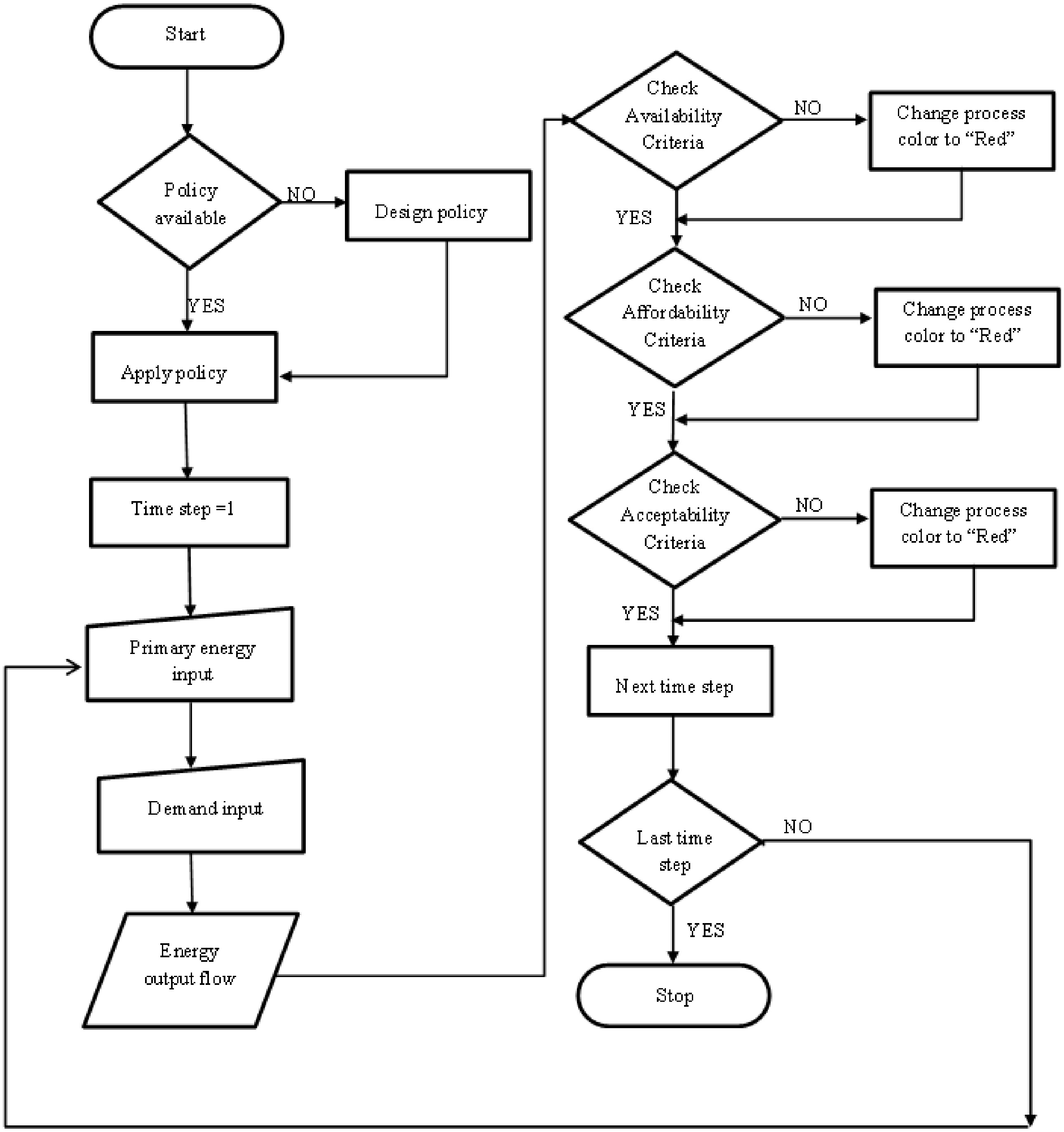
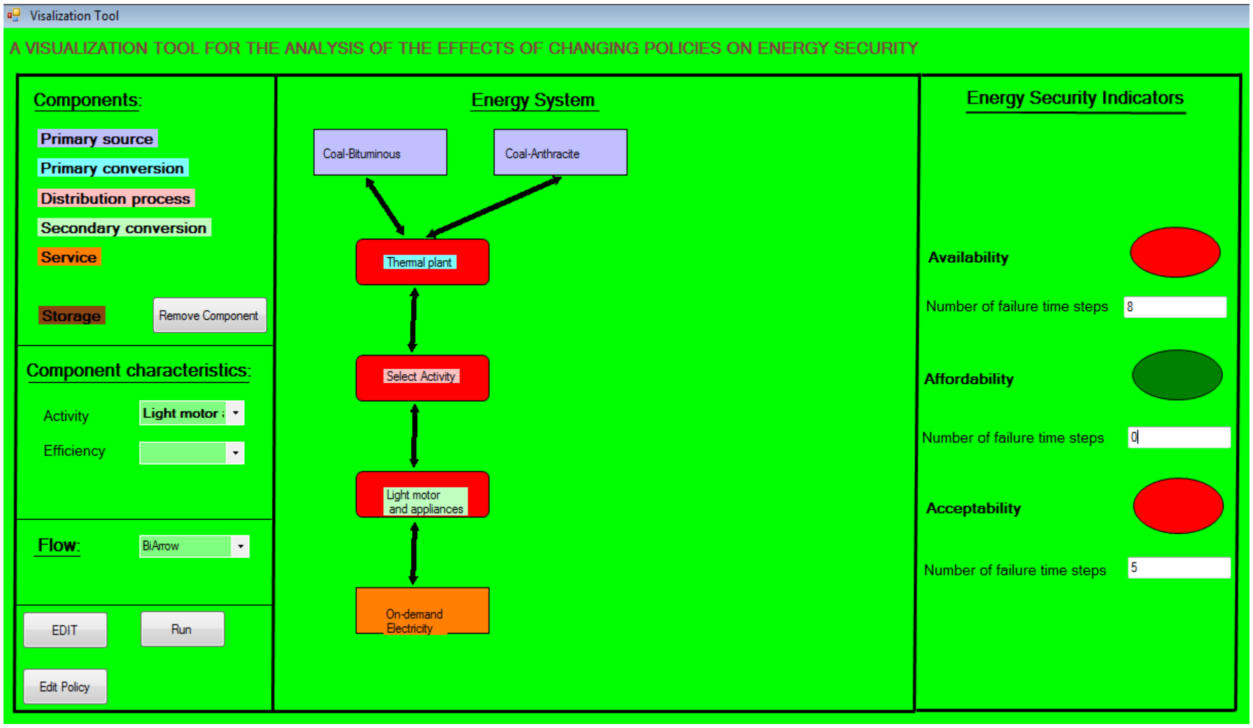


Figure 13: Flowchart showing the tool calculation phase

This tool will analyse the energy security for an energy policy applied to the energy system. If policies are not available, as mentioned in the previous chapter, new policies can be designed by using the 3R's. This tool can simulate for the specified time step (for example, an hour, a week, a month, or a year) and this can be specified by the input data. For example, if hourly data is provided, the tool will generate the hourly output and analyse the energy security for each hour.

As shown earlier in this chapter, the energy output for each process will be generated by using the equations (1), (2), and (3). Using equations (4), (5), and (6), the cost, revenue, and emissions are estimated by the tool. For each time step, upon providing energy input flow the tool will generate the energy output, cost, revenue, and emissions and check the three energy security indicators. If any indicator doesn't meet the criteria the process color will turn into red. By changing the color to red, it can be visually easy to understand at which level the energy chain has been failed. Also, which particular indicator has failed is shown in the energy security indicator section by changing its color to red. Detailed description on energy security analysis is discussed in the next section. The tool also specifies for how many time steps the indicator criteria has not been met. Displaying the number of failure time steps for each indicator will help in developing new energy policy. This means analysing the number of failure for each simulation for each indicator can tell if the level of energy security is actually increasing or decreasing for different energy policies.

A sample on-demand electricity energy chain is presented to demonstrate the tool output showing the process failure, indicators failure, and the graphical representation of what the tool performs internally (i.e., on the back-end). Figure 14 is an example of energy chain process and energy security indicator failure. For this example, on-demand electricity energy chain, if the simulation is estimated for 24 hours the tool shows the number of failure hours. In this case, availability indicator fails 8 hours and acceptability indicator fails for 5 hours. The description for the energy security analysis phase is also based on this sample on-demand electricity energy chain.



Activity: Light motor ;

Flow: BiArrow

Availability — Number of failure time steps: 8

Affordability — Number of failure time steps: 0

Acceptability — Number of failure time steps: 5

Figure 14: A process failure shown visually

3.4.3.1. Energy Security Analysis

The analysis of the three energy security indicators for the energy chain shown in Figure 14 are analysed as follows:

Availability: As discussed in the method section, availability criteria checks the condition if energy output flow ($Energy_{OUT}$) is greater than the demand input flow ($Demand_{IN}$) for each process in an energy system. It also calculates the total energy output produced by the energy chain and the total demand input coming from the energy services. Figure 15 is a graphical representation of the tool analysing the availability indicator on the back-end. It shows total energy output versus total demand input over a 24 hour period. This tool represents the data graphically, displaying energy trends and showing the points where the system failed to supply adequate energy. The number of failures are counted and displayed by the tool on the front-end to show the number of time steps the availability indicator failed while that particular policy was applied to the system. In this example, the number of failures is estimated as 8 hours. Further simulations can be run for different policies until these 8 hours also having enough energy supply to satisfy the demand.

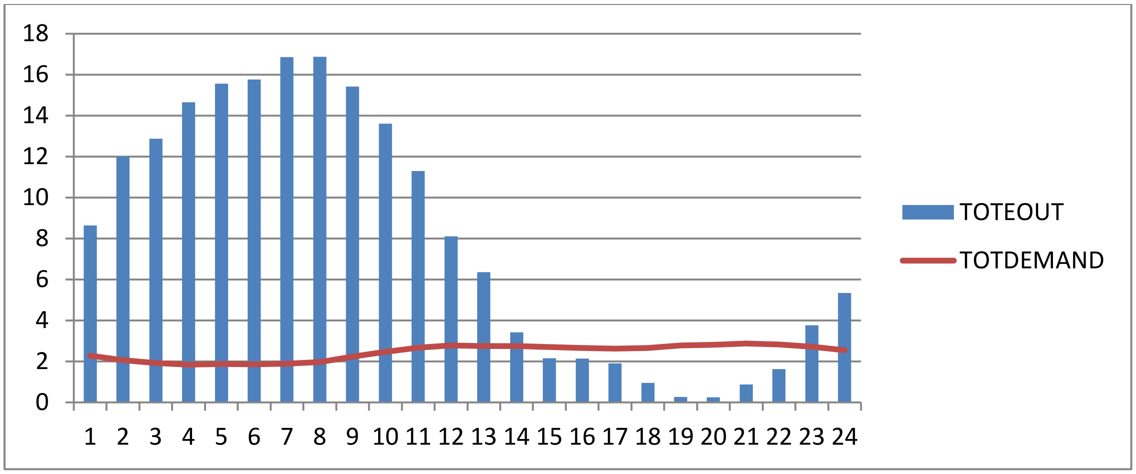


Figure 15: Graphical representation of the tool analysing availability indicator

Affordability: Each process energy flow in an energy chain is associated with a cost and the affordability of the flow depends on these costs. As mentioned in the method section, the affordability indicator is from the supplier's perspective. This indicator checks if the cost to produce and distribute energy each hour is less than the revenue generated (i.e., Cost < Revenue). If the cost is less than the revenue, the process and the affordability indicator colour will change to red and the tool will count the number of hours failed. Figure 16 is a graphical representation of the tool analysing affordability indicator for a time period of 24 hours, displaying total cost and revenue generated for each hour. In this case, the affordability criterion has failed for a total of zero hours.

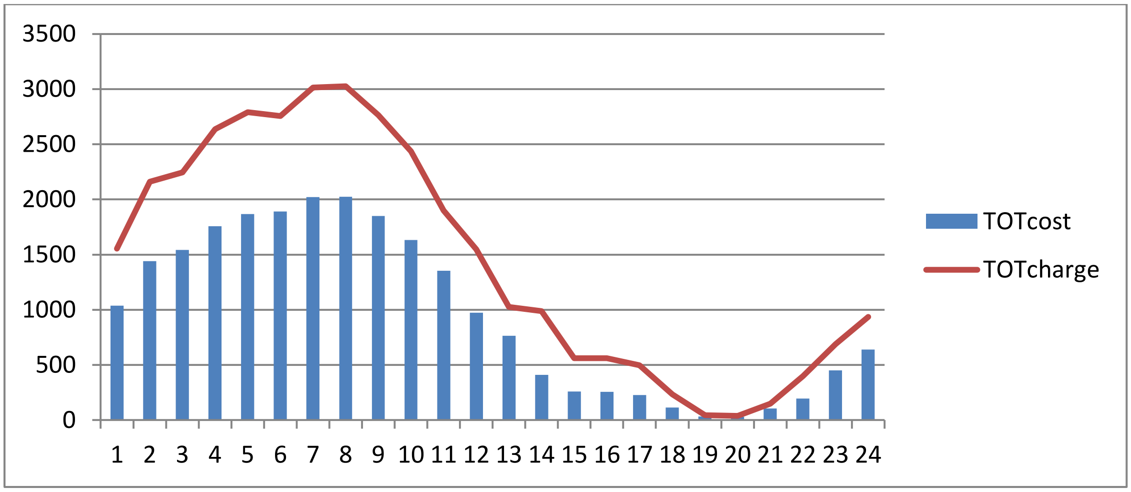


Figure 16: Graphical representation of the tool analysing affordability indicator

Acceptability: The acceptability indicator refers to the need of an energy flow that is environmentally acceptable; it can be measured by comparing $Environment_{OUT}$ flows with the emission standards specified in $Policy_{IN}$. In some jurisdictions, acceptability also pertains to the social or political acceptability of an energy flow or process. Examples of this include public perceptions regarding nuclear power and the extraction of tight natural-gas by fracking. In this method, the acceptability indicator, the total emissions made by each process in an energy chain are estimated and compared with the emission target level (i.e., Emissions generated < Emission target level). If the acceptability criterion fails then the process and acceptability indicator will turn red. The number of time steps the acceptability criteria has failed is also measured. For this example, if the emission target for each hour is set to 50t-CO2, the graphical representation of the tool analysing acceptability indicator shows as Figure 17. It shows the total emissions made by an energy chain in a 24 hour period. In this case, the acceptability criterion has failed for five hours.

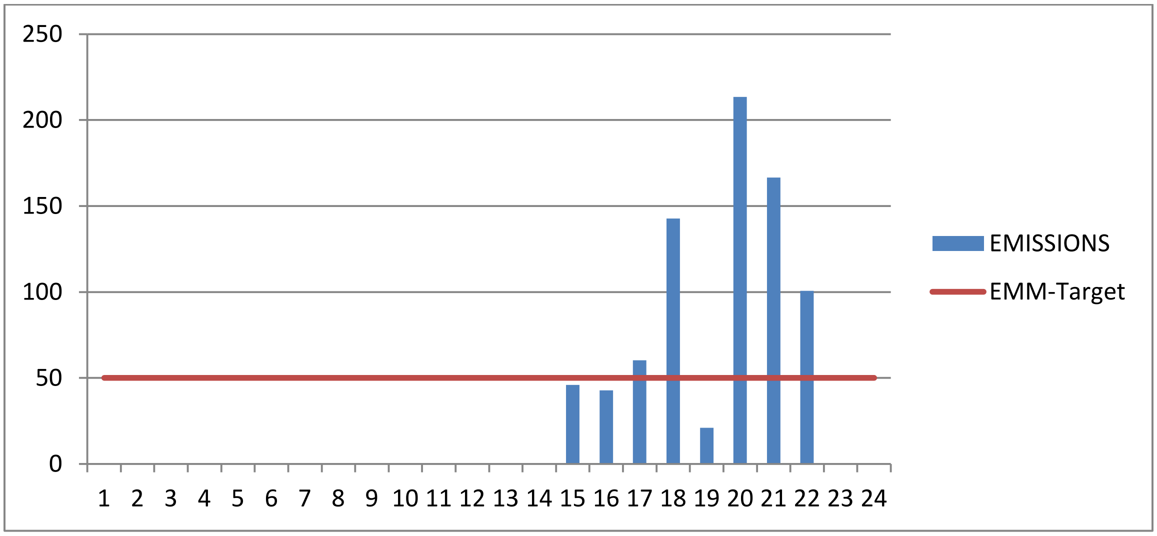


Figure 17: Graphical representation of the tool analysing acceptability indicator

3.5. Software

The following software was used to develop the analysis tool:

- Microsoft Visual Studio 2010
- Microsoft Office Excel 2007

Microsoft Visual Studio 2010 is a product from Microsoft used to develop console and graphical user interface (GUI) applications, applications include, windows forms and web development.

Visual Studio provides a language specific service, which allows supporting any programming language. The Windows forms application is used to develop this visualization tool and VB.Net programming language is used to run the form application. The Windows forms contain different controls that can display data can be bound to data sources like databases or queries. Microsoft Excel 2007 is used as database for this project.

Microsoft Office Excel 2007 is a spread sheet application which is most popular and commonly used. It features graphing tools, calculations, charts and tables, and the programming language, Visual Basic Application (VBA). Excel is able to handle a large amount of data sets using built-in functions, and can be used for detailed analyses. Using its built-in charting feature, this visualization tool shows the energy security indicators graphically.

3.6. Summary

This chapter presented a method on how to represent an energy system by using a generic process, which can effectively analyse the effects of energy policies for improving energy security. It also discussed the software tools used to implement the proposed method.

In the next chapter, a case study is presented to examine the proposed methods. The jurisdiction selected to implement the methods was the City of Summerside, P.E.I.

CHAPTER 4. CASE STUDY AND RESULTS

This chapter demonstrates the application of the methods proposed for the visualization tool through a case study, which deals with the use of wind electricity to meet part of the electricity load in the City of Summerside in Prince Edward Island, Canada. It describes Summerside's on-demand electricity energy chain, along with the input data required to analyse the effects of an energy policy.

The city purchases electricity from three sources: two wind-farms (Summerside with 12MW installed capacity and West Cape with 9MW installed capacity) and NB Power (acting as a backup source). The wind-farms are variable sources of electricity while NB Power is a stable source of electricity. Summerside entered into its new five-year energy supply contract with NB Power on September 2012, which continues until August 31, 2017 for part of its electricity supply (City of Summerside, 2012). Also, Summerside has a 20 year power purchase agreement with West Cape Energy (now in its sixth year).

In 2012, Summerside's electricity came from NB Power (56.4%), Summerside Wind Farm (23.1%) and the remainder from West Cape Energy (20.5%). Summerside Electric customers were supplied with 100% wind power for 1,355 hours or 15.5% of the demand (City of Summerside, 2012).

The data required for this case study is provided by Summerside, the wind-electricity generation data from Summerside wind farm and West Cape wind farm, and load data for the year of 2011. The required input data for the case study are as follows:

- Electricity load for Summerside
- Hourly wind production data from Summerside's wind farm and hourly wind supply data from the West Cape wind farm
- Carbon dioxide equivalent emission for grid electricity was taken from (Hughes, et al., 2012)
- Summerside's customer purchase cost (Hughes, et al., 2012)

4.1. Objectives

The visualization tool described in the previous chapter is used to simulate several scenarios to analyse the effects of above considered energy policy on the City of Summerside.

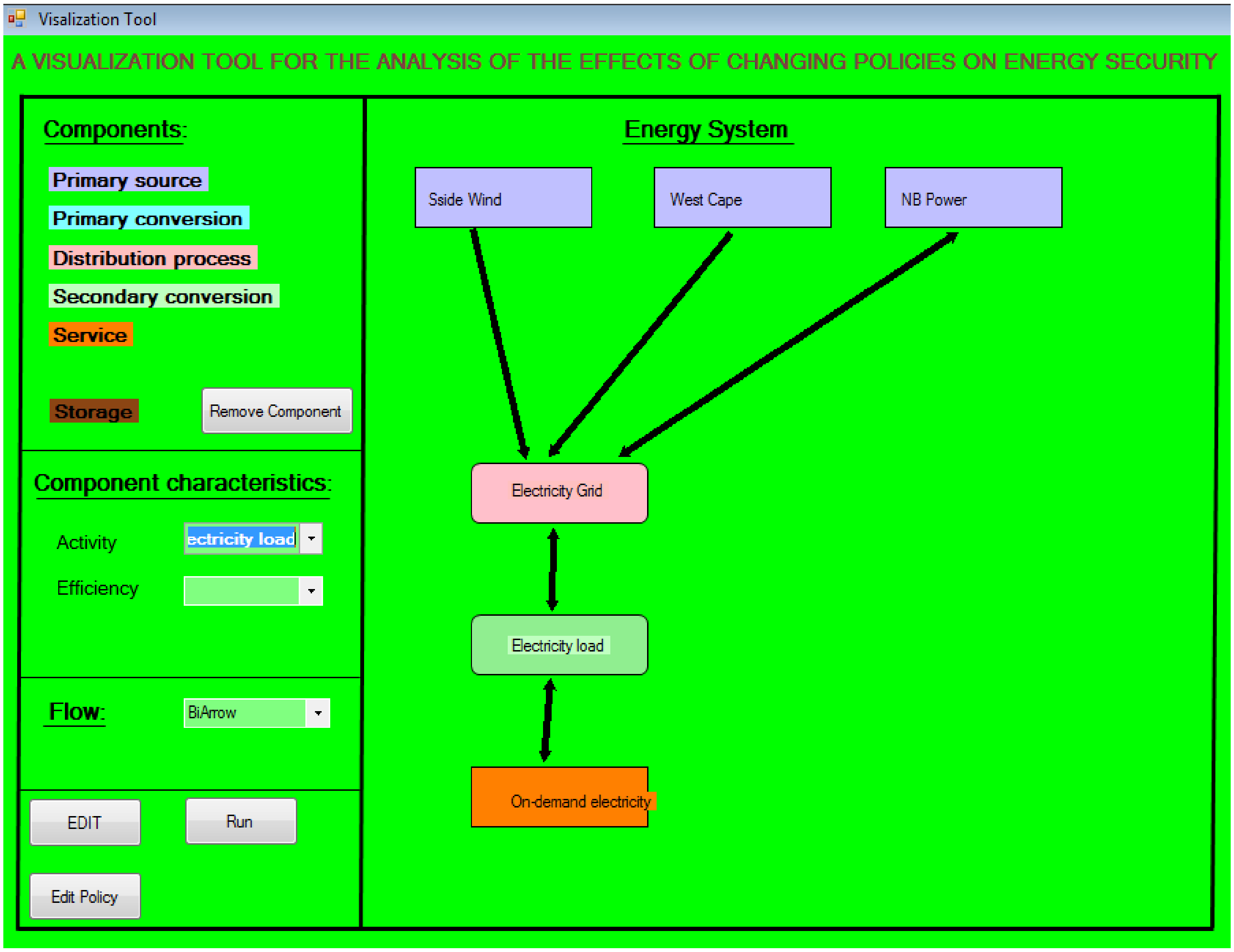
Simulations are performed with the following objectives:

- To determine if 15% of Summerside's electricity load can be satisfied by the two wind-farms for monthly, weekly, and hourly time steps
- To show the effects of Summerside electricity energy chain visually
- To analyse the energy security indicators for the electricity chain

The simulations are performed for the year 2011 to target electricity load is 15%; therefore the objective is to determine if this load is satisfied by the two wind-farms. The three steps implemented in the tool to simulate the results for 2011 include: (i) energy system development, (ii) calculation, and (iii) energy security analysis.

4.2. Summerside Electricity Energy Chain

Developing the Summerside electricity energy chain is the first phase of the tool. Summerside's electricity supply is from the two wind farms and stable supply from NB Power. Figure 18 shows Summerside on-demand electricity energy chain.



Activity ectricity load

Flow: BiArrow

Figure 18: Summerside's electricity energy chain

A shown in Figure 18, Summerside on-demand electricity energy chain is supplied electricity from the two wind-farms and NB Power. The two wind farms generate electricity and transport it to the buildings through electricity grids. Maritime Electric's grid is linked to the NB Power grid via two submarine cables; these cables enable the Company to purchase electricity from the mainland under various contracts (Maritime Electric, 2010). This electricity is used to satisfy Summerside's on-demand electricity requirements.

For the simulation, the tool has been provided with load data and the amount of electricity produced by the two wind-farms. In the tool distribution process (i.e., Maritime Electric grid) efficiency is assumed to be 95% and secondary conversion process (i.e., electricity loads) efficiency assumed to be 100%. Summerside's electricity grid Energy$_{IN}$ flow is purchased from the Summerside wind-farm, the West Cape wind-farm, and NB Power. The secondary conversion process, electricity loads, will receive the $\text{Energy}_{\text{IN}}$ flow from the electricity grid process $\text{Energy}_{\text{OUT}}$ flow. The secondary conversion process $\text{Energy}_{\text{OUT}}$ flow meets the electricity demand for Summerside.

4.3. Simulation for the year 2011

Once the electricity energy chain has been developed, the output flows and energy security analysis for each process in Summerside's energy system is performed for the year 2011. To generate results, the simulation used monthly, weekly, and hourly wind-data for the year. As mentioned in the previous chapter, equations (1), (2), and (3) are used to calculate primary conversion, distribution, and secondary conversion $\text{Energy}_{\text{OUT}}$ flows. In this case, the data used is the amount of electricity generated by the two wind-farms. This means the $\text{Energy}_{\text{IN}}$ flow to the Summerside grid is directly provided. However, equations (2) and (3) are used to calculate Summerside's grid and electricity load output flows. The City of Summerside provided the wind electricity data and load data for each hour (the finest granulation available from Summerside); for the monthly and weekly simulations, the hourly data is aggregated. For example, in the weekly simulation 168 consecutive hours of data is aggregated and considered to be one week's input.

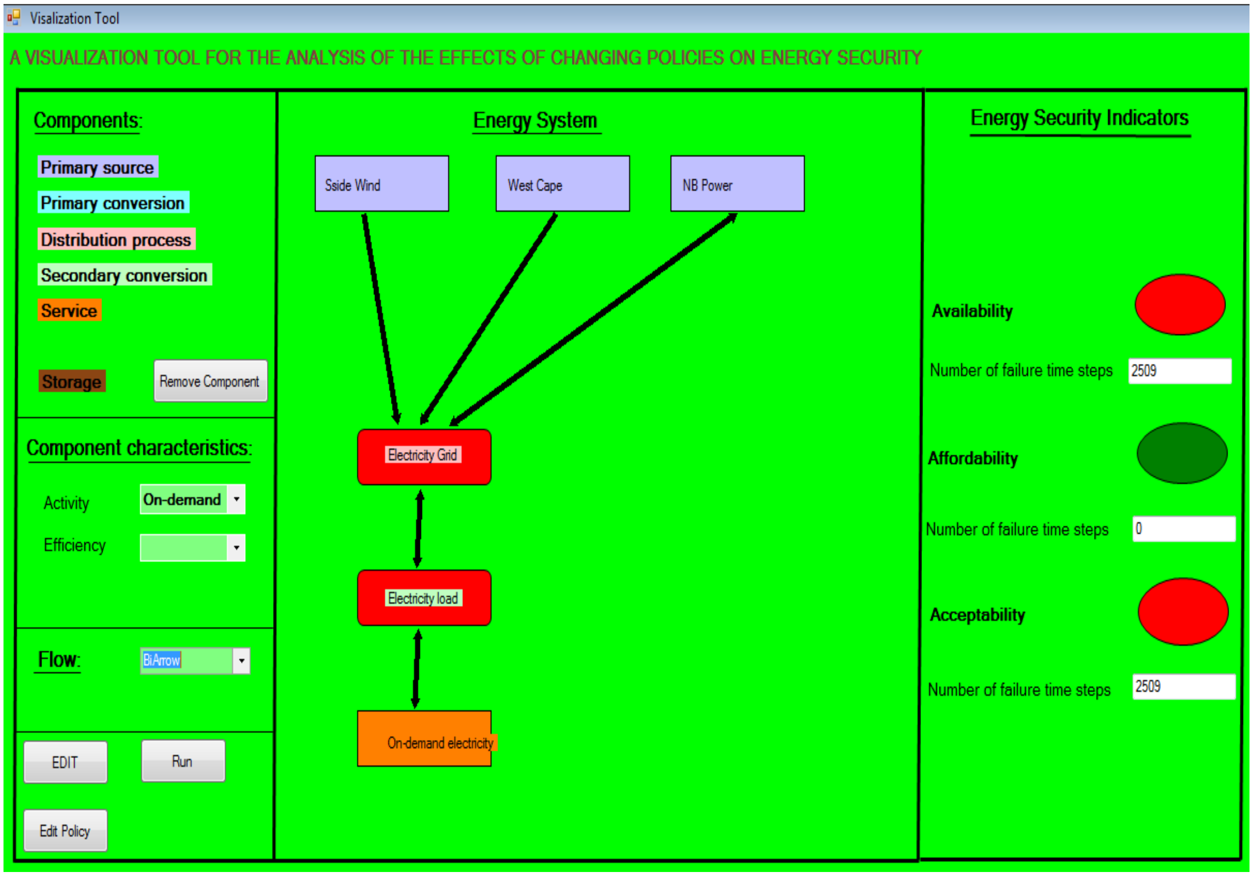
In 2011 Summerside annual report it was reported that, 15% of the Summerside electrical load has been satisfied by the two wind-farms. Simulation 2011 is performed to check if the two wind farms in fact did meet the target of 15% electrical load. Monthly, weekly, and hourly time steps are considered for simulation to check if the overall 15% electricity load is met. Simulating these three time steps are considered to show the tool has the flexibility to run for any time step. The observations for the calculation phase are as follows:

- The simulations were performed for monthly, weekly (i.e., 52 weeks), and an hourly (i.e., 8760 hours) time step for the year 2011
- The input data: amount of electricity generated from two wind farms and jurisdictions total demand for electricity can be found in Appendix A (Table 5 and Table 7).
- The output data: distribution process output (i.e., Summerside electricity grid output flow), secondary conversion process output (i.e., electricity load process output flow), total electricity generated, and total load, generated by the tool can be found in Appendix A (Table 6 and Table 8).

4.3.1. Simulation Results

The results have shown that 15% load target from the Summerside jurisdiction can be met by the two wind farms for each month and week in the monthly and weekly simulation. In the case of hourly simulation, the 15% load target by the two wind-farms is not met for each hour. The total demand and total electricity generated to satisfy the demand for each week and month can be found in Appendix A (Table 6 and Table 8).

As mentioned in the previous chapter, the tool will change the process colour to red when the process fails to meet the load. The visualization tool doesn't show any process failure in the Summerside electricity energy chain for monthly and weekly because the 15% load is met by the wind supply. The energy chain remains unchanged as Figure 18. For hourly simulation the energy chain shows the failure process which doesn't meet the 15% load. Figure 19 shows Summerside electricity energy chain failure processes and indicators for hourly simulation.



Activity: On-demand

Efficiency:

Flow: BiArrow

Availability — Number of failure time steps: 2509

Affordability — Number of failure time steps: 0

Acceptability — Number of failure time steps: 2509

Figure 19: Summerside electricity energy chain showing failure for hourly simulation

The energy security indicators show that winds was unable to meet demand for a total of 2509 hours (out of 8760 hours). This means the availability criteria failed for 2509 hours (i.e., the two wind farms don't supply enough electricity for 2509 hours). The failure of availability indicator can be seen in Figure 19.

The tool also estimated that the acceptability criterion failed for 2509 hours. As mentioned in the previous section, NB Power is the backup supply of electricity for Summerside. The unsatisfied demand during the 2509 failure hours is supplied by NB Power. Since wind is considered to be a zero-emissions source of energy, the emissions should be zero for the 15% of the demand for each hour. The remaining 85% may or may not be associated with emissions; however, this is outside the scope of the case study. The failure of acceptability indicator is shown in Figure 19.

In the third phase, energy security analysis, the tool has visually shown the monthly, weekly, and hourly energy security statuses as follows:

Availability: As discussed in the previous chapter, the availability criteria checks for the energy output flow ($Energy_{OUT}$) being greater than the demand input flow ($Demand_{IN}$) for each process in an energy system. For monthly simulations, the availability condition has been checked for the monthly data and the result shows that the demand is met by the energy output flow. Figure 20 shows total monthly energy output versus total demand input for the year 2011. Again, the energy trends verifies that the Summerside electricity energy chain didn't fail to supply energy in any data point (i.e., for 12 months). The total energy output produced by the Summerside electricity energy chain and the total demand input coming from the Summerside electricity energy services can be found in Appendix A (Table 8).

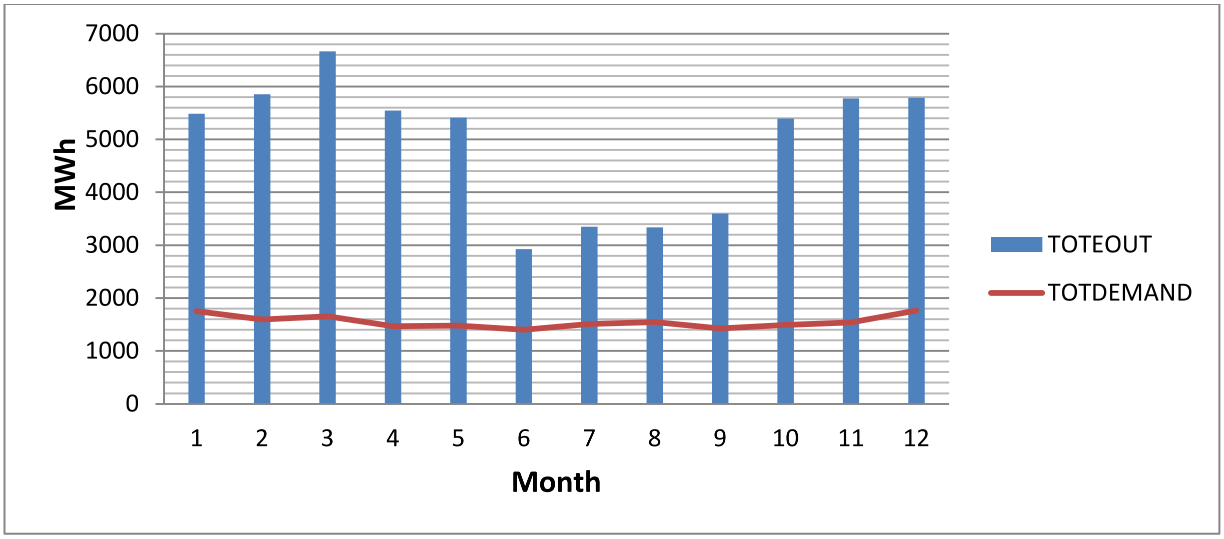


Figure 20: Availability indicator monthly result for Summerside electricity energy chain for 2011

For weekly simulation, the availability condition has been checked for the weekly data and the result shows that the demand is met by the energy output flow. Figure 21 shows total energy output versus total weekly demand input for the year 2011. Also, the energy trends have clearly shows that the Summerside electricity energy chain didn't fail to supply energy in any data point (i.e., for 52 weeks). The total energy output produced by the Summerside electricity energy chain and the total demand input coming from the Summerside electricity energy services can be found in Appendix A (Table 6).

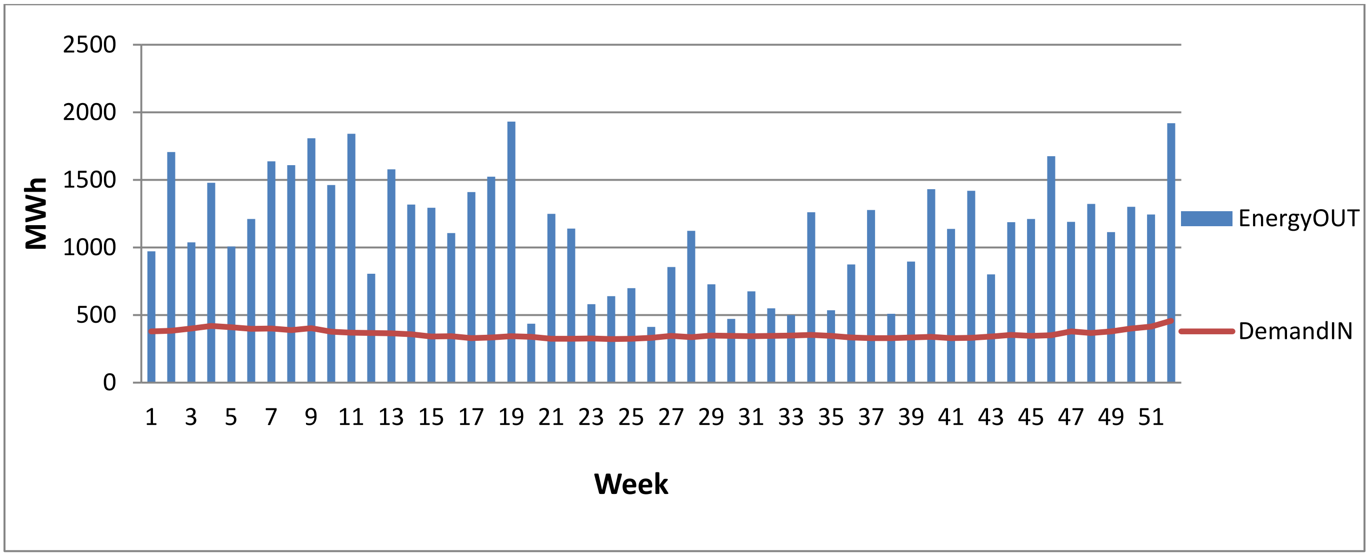


Figure 21: Availability indicator weekly result for Summerside electricity energy chain for 2011

For the hourly simulation, the tool checks the availability condition for the hourly data to determine if the 15% load is met. The simulation result shows that the 15% load is not met by wind supply for each hour. This is because wind is a variable energy supply, and there might be hours with no wind supply or wind generated electricity less than 15% load target. In the case of monthly and weekly, the 15% load target is met because the amount of energy generated by wind is added in total to satisfy the 15% load target for each month and week. For example, in the weekly simulation, the total amount of energy produced in 168 hours is considered to satisfy the 15% load target for that week. This may not be possible in the hourly case because of wind variability. This makes the case study to consider three different simulations to check if the 15% load target is actually met. Figure 22 shows a 24-hour simulation for January 6th 2011.

As discussed in the previous section, Summerside relies on NB Power as its backup source of electricity. When wind supply fails to meet the electricity demand, Summerside is supplied electricity with NB Power. Figure 22 also shows the supply from NB Power when there is no enough wind supply to meet the 15% load target. This makes to choose this particular day to demonstrate the availability indicator because it will show the different variations of supply (i.e., supply from wind and supply from NB Power). In Figure 22, blue bars indicate the total energy supplied from wind energy, the red line indicates each hour's 15% demand, and green line indicates the amount supplied by NB Power.

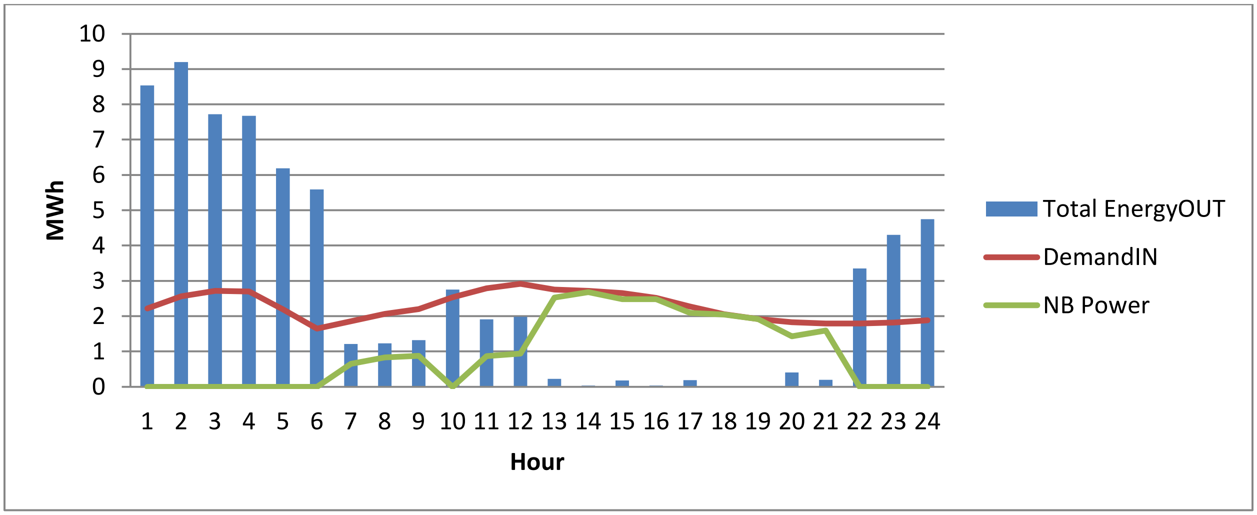


Figure 22: Availability indicator hourly simulation for Summerside electricity energy chain for 2011

Affordability: Each process energy flow in an energy chain is associated with a cost. The tool determines the affordability criteria from the supplier's point of view, cost to produce energy versus the amount of charge for the customers. Displaying energy trends will show when the cost of production is higher than the charge. To generate the cost and charge, this tool requires the cost of production per MWh and average charge per MWh. Table 2 shows the electricity purchase cost and sale cost for both wind supply and NB Power.

Table 2: Electricity purchase cost and sale cost

(Summerside Electric, 2011; Summerside Electric, 2010)

	Cost	**Charge**
West Cape	$0.075	$0.080
Summerside	$0.075	$0.080
NB Power Grid	$0.085	$0.080

Using the average cost and sale cost, the visualization tool generates the affordability criteria. For monthly simulation, the visualization tool will estimate the cost and the expected revenue from the sales based upon the retail price of the electricity. Availability indicator has shown, each month 15% load is met by the two wind-farms and remaining 85% load is met by the two wind-farms or NB Power or both. This means remaining 85% load may have the NB Power cost and charge. Since the total 15% load is met by the two wind-farms, there is no additional cost and charge from the NB Power is estimated. Figure 23 shows the monthly cost and revenue estimated for each time period. Cost and revenue estimation for each time step is shown in Appendix A (Table 8).

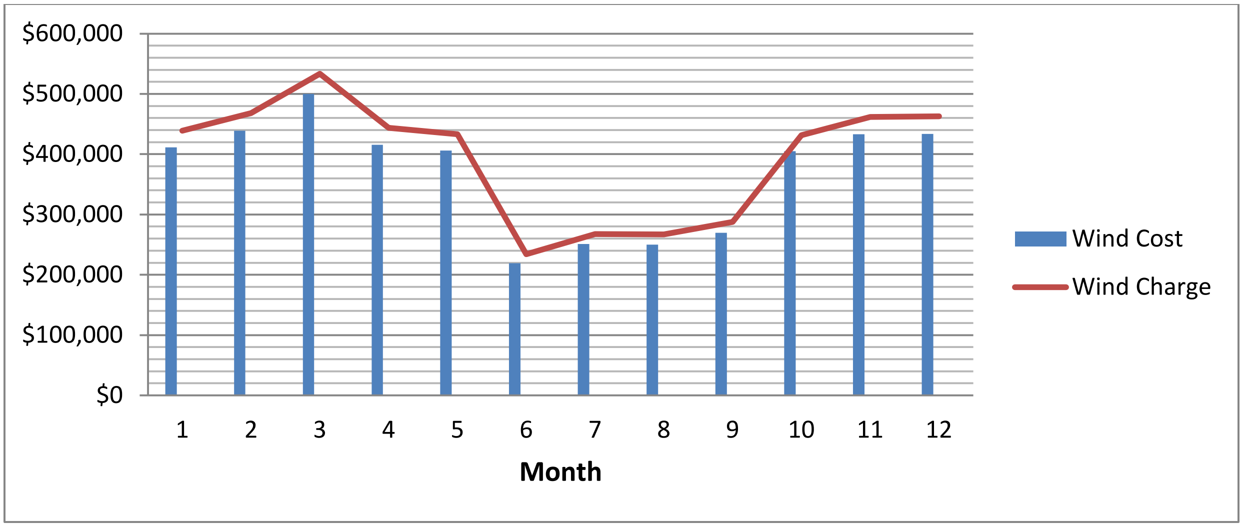


Figure 23: Affordability indicator monthly result for Summerside electricity energy chain for 2011

For the weekly simulation, the visualization tool estimates the cost and revenue for each week. Availability indicator shows each week the 15% load is met by the two wind farms for 2011. This means there is no additional cost or revenue estimated from NB Power for the 15% load. Figure 24 shows weekly wind purchase cost and expected revenue for each time period. Cost and revenue estimation for each time step is shown in Appendix A (Table 6).

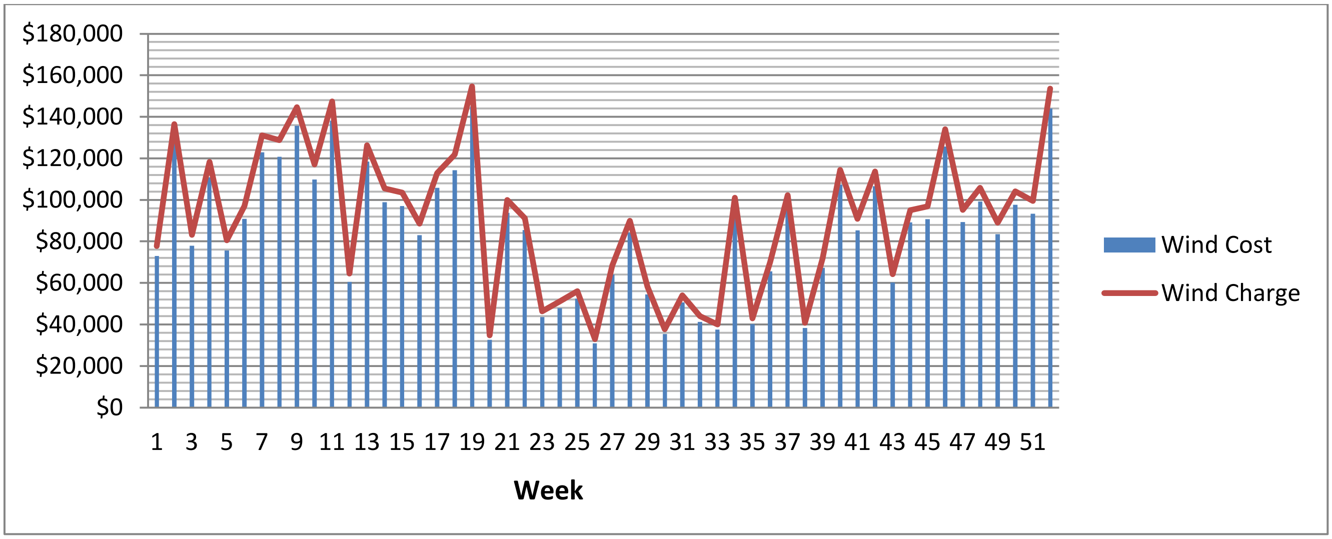


Figure 24: Affordability indicator weekly result for Summerside electricity energy chain for 2011

For the hourly simulation, the visualization tool estimates the affordability criteria. As mentioned in the previous section, the City has failed to meet the 15% load target for 2509 hour. The amount of electricity failed to supply in these hours the City is supplied the electricity with NB Power. According to the amount of electricity used from NB Power, the tool will estimate the electricity purchase cost and sale cost along with the wind cost and sale cost for each hour. The tool estimated the total cost (i.e., wind purchase cost and NB Power purchase cost) as $4,738,043 and the total revenue (i.e., wind and NB Power) as $ 5,015,734. Figure 25 shows, estimated cost and revenue on January 6th (i.e., 24 hours) for 2011.

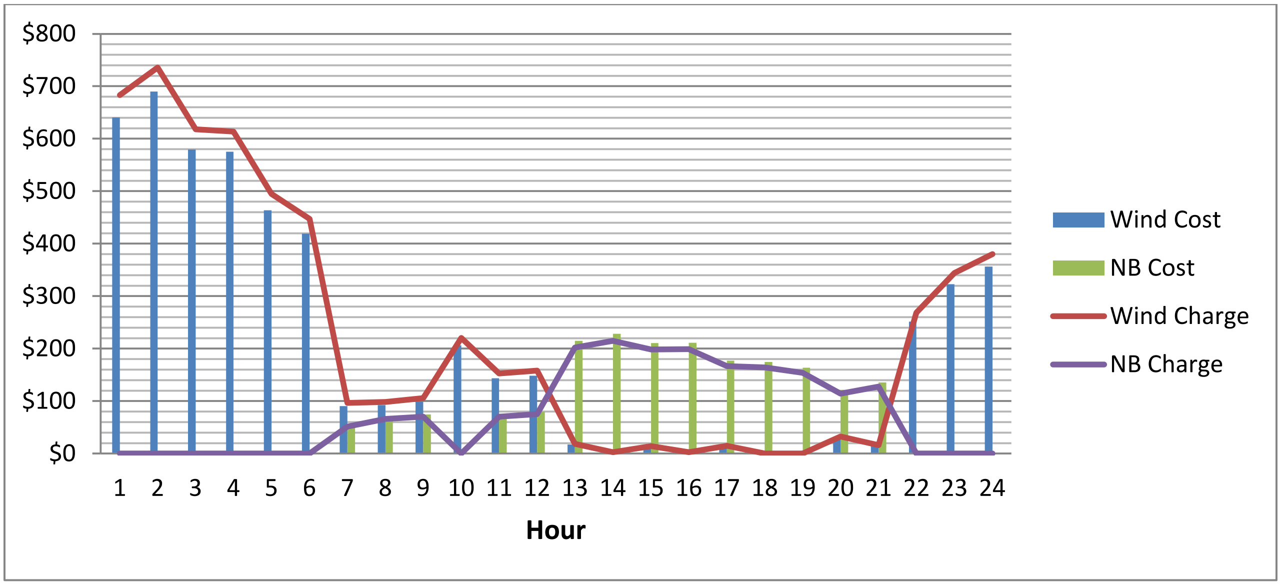


Figure 25: Affordability indicator hourly result for Summerside electricity energy chain for 2011

Acceptability: This energy security indicator shows Summerside's level of emissions for a given time period. In this study, Summerside's greenhouse gas emissions can be classified as indirect emissions, as there are no contributions to direct emissions (direct emissions include all pollution contributed directly and controlled by the producer or supplier, while indirect emissions include all emissions that result from the use or purchase of a product). This mean the amount of energy supplied to Summerside by NB Power to satisfy the 15% load is the amount of indirect emissions it generate. The emission index for indirect emissions from purchased grid electricity is 0.835 kg CO_2e/kWh (NB Power, 2009/10; Environment Canada, 2011).

This simulation has assumed that when the two wind farms have failed to satisfy the demand, the unsatisfied demand is met from the NB Power. Also, the target is to meet the 15% load by two wind farms the case study assumed the emission target level for acceptability indicator should be zero. This is because of wind is considered to be a zero emission source and this can be seen in Figure 26. The case study defines the acceptability indicator as the level of emissions made by Summerside whenever it uses electricity from NB Power. Since the 15% electricity load target for 2011 is met by the two wind-farms for monthly and weekly simulation, the visualization tool doesn't generate any emission. For hourly simulation, there are 298,863 kg CO_2e emissions estimated. This means the 15% electricity load is satisfied by clean energy and has emissions. Figure 26 shows the, hourly simulation for 6th January 2011. The amount of energy generated from two wind-farms and amount of energy used from NB Power for this day is shown in availability indicator.

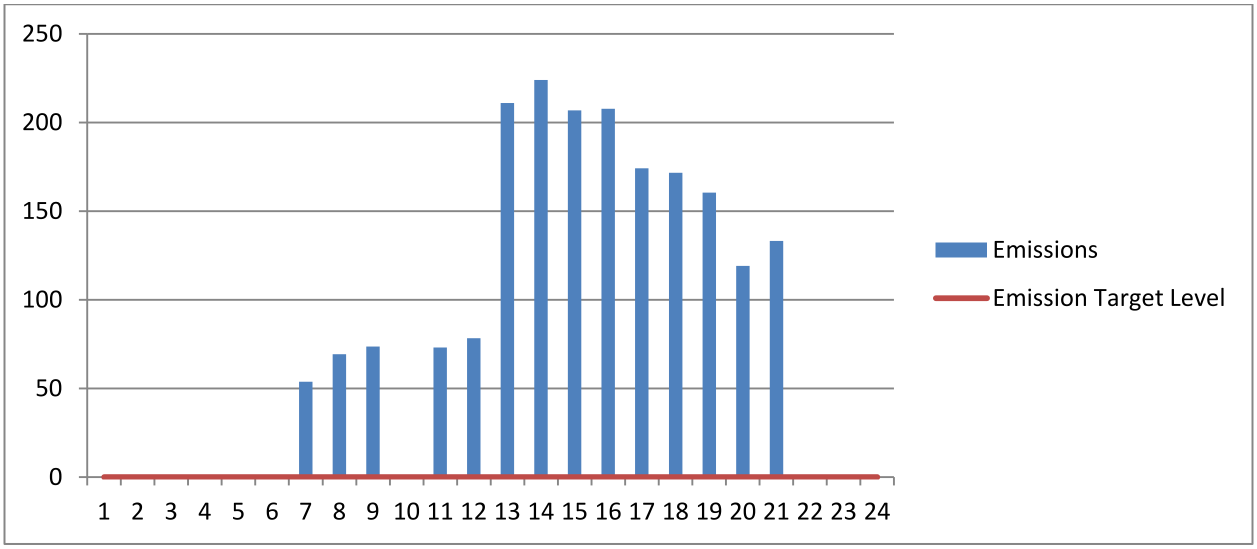


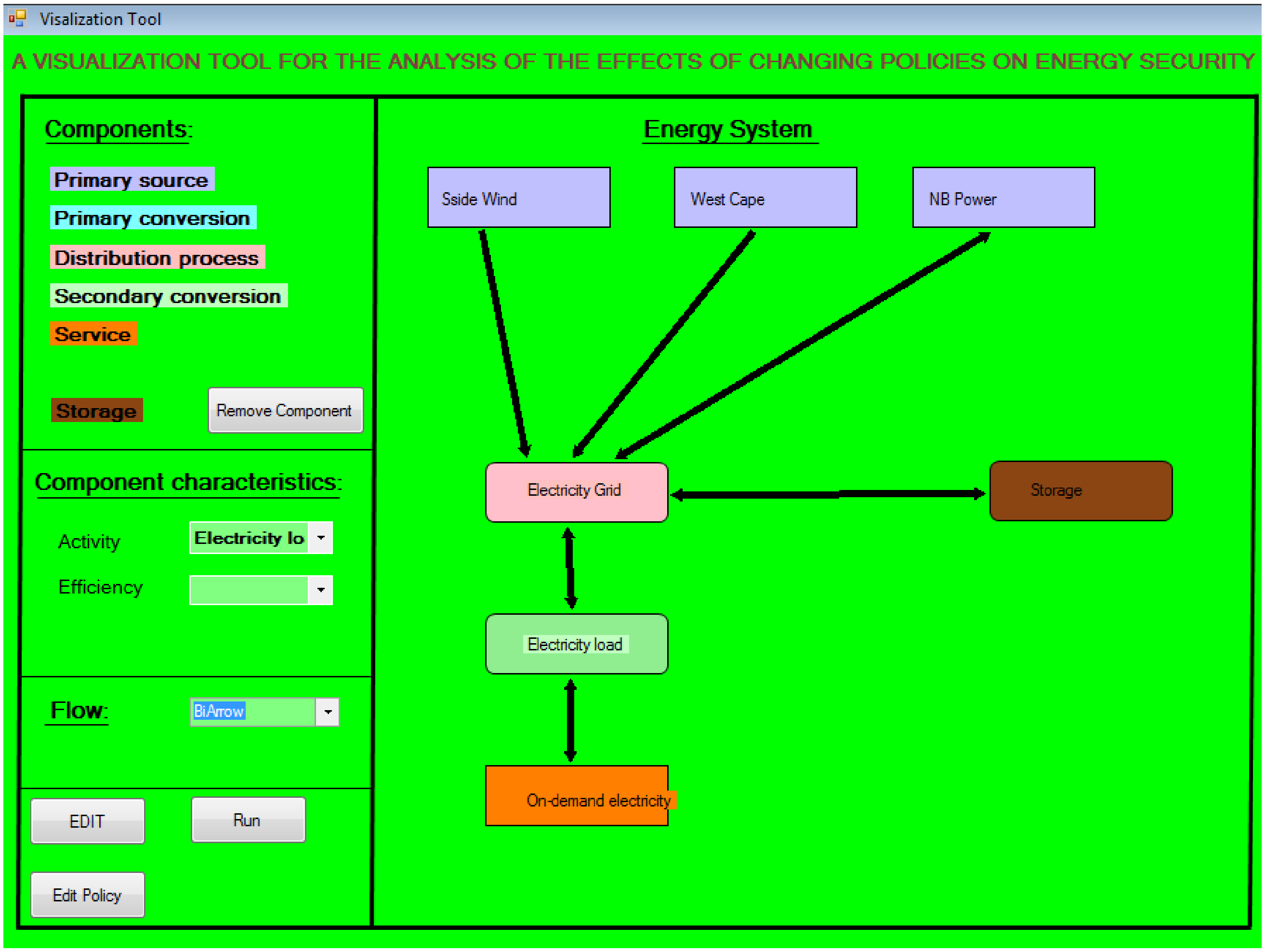
Figure 26: Acceptability indicator hourly result for Summerside electricity energy chain for 2011

The simulations for monthly, weekly, and hourly are done by using Summerside electricity data for 2011. Wind is a variable energy source which cannot meet the 15% load each hour but for monthly and weekly simulation the aggregated wind data satisfies the 15% load target. An example discussed in the availability indicator, in weekly simulation, shows the total amount of energy generated in one week (i.e., total wind supply of 168 hours) is aggregated to satisfy the total week load. Also, every hour in a week will not produce wind electricity. As a result, there are hours that do not generate electricity, hours that generate less than 15% of the load target, and hours that exceed 15% of the load target. In the case of monthly and weekly simulation, the excess amount of electricity generated is also added to meet the 15% load target for that particular month or week. This may not be possible while satisfying hourly load because of wind variability.

Currently, Summerside's electricity energy chain uses a replacement policy by replacing the electricity supply with NB Power when there is no wind supply. As mentioned in the previous chapter, the tool has the ability to run multiple simulations with different combinations of energy chains (i.e., different energy policies and regulations). For example, the tool can simulate with a reduction policy but the 15% load reduction for each hour may not be possible in all the sectors. Also, restriction policy, adding a new energy source and its process may be possible but depends on the source availability. Since the target is 15% electricity load satisfaction, this case study considered a replacement policy, adding storage. In the next section, the energy chain adds 40MW of storage to meet the 15% load target.

4.4. Simulation for 2011 with Storage

To meet the 15% hourly target, Summerside electricity energy chain is modified to include storage. This example allows the storing of excess electricity and using it for the hours when wind supply is not sufficient to satisfy the load. In all simulations (with and without storage), the wind and load data is unchanged. Figure 27 shows the Summerside On-demand electricity energy chain with storage.



Activity: Electricity lo

Efficiency:

Flow: BiArrow

Figure 27: Summerside electricity energy chain with storage

4.4.1. Simulation Results

For choosing the size of the storage, the case study is simulated for different storage capacities. Table 3 shows the simulation results for different storage capacities. With 40MWs of storage charging and discharging efficiency of 90%, the number of failure hours was zero.

Table 3: Simulation results for different storage capacity

Storage Capacity (MW)	Efficiency (%)	Number of Failure Hours
20	80	1635
30	85	1288
35	90	954
40	90	0

The cost of charging and discharging for the storage (i.e., charging the storage when excess electricity is produced and discharging the storage by supplying electricity to the City when there is no wind supply) were assumed to be \$0.05 kWh and \$0.08 kWh respectively. In this case, the maintenance cost and capital cost for the storage is not included. The simulation result shows the 15% load was supplied by wind for 8760 hours for 2011 with storage. The results are as follows:

Availability: The $\text{Demand}_{\text{IN}}$ versus $\text{Energy}_{\text{OUT}}$ condition has been checked for 8760 hours for 2011 and the result shows that the demand meets the energy output flow for 8760 hours. Figure 28 show a 24-hour simulation for 6 January, 2011. This is the same day that has been chosen from the simulation without storage. The hours that wind supply cannot meet the 15% electricity load displayed in the availability indicator without storage is now met by using storage. In the Figure 28, total energy generated by wind, demand required, storage of excess wind, and amount of energy consumed from storage are displayed. The first six hours shows when the storage has reached its limit (i.e., 40MW), it cannot store any excess energy from wind. The next hours show the charging and discharging of the storage to meet the 15% load.

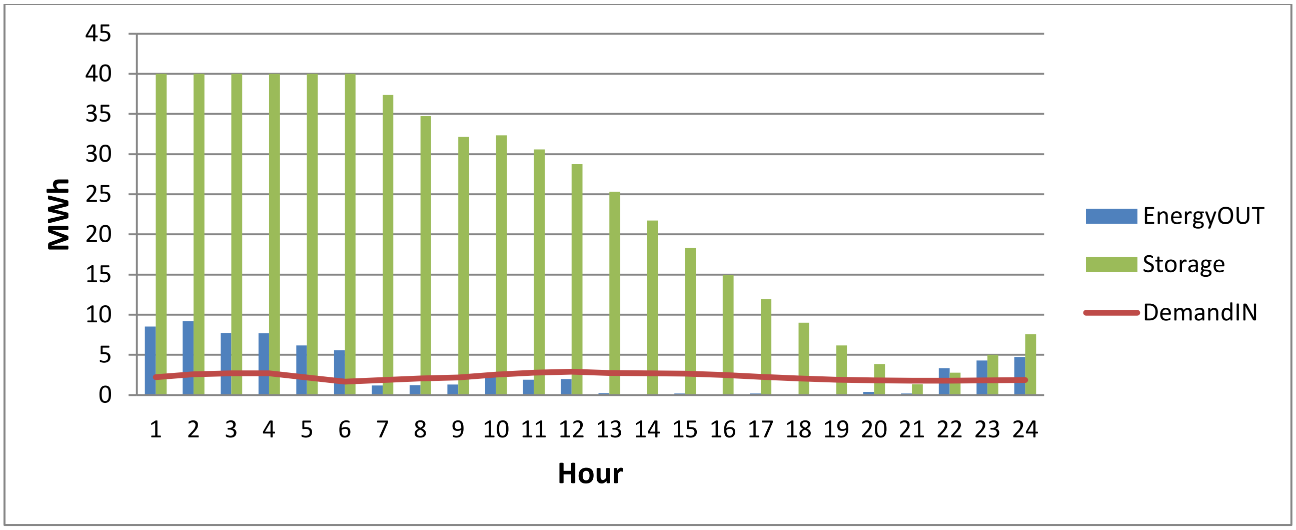


Figure 28: Availability indicator hourly simulation with storage for Summerside electricity energy chain for 2011

Affordability: For each hour the affordability indicator estimates the cost of storing excess wind and charge to use the supply from storage. The indicator also estimates the wind purchase cost and charge to use supply from wind. The amount of electricity generated from the wind and the electricity supplied from storage is estimated in the availability indicator. Whenever the excess electricity is used to charge the storage, the tool estimates the storage cost. Similarly, when electricity is supplied from the storage, the charge to the amount of electricity supplied is estimated. Figure 29 shows the result of the simulation for 6 January, 2011. For the first six hours there is no storage cost included because the storage has reached its maximum capacity; this is shown in the availability indicator. The last three hours is estimating the storage cost because the storage is charging with the excess wind available.

The tool estimates the total cost (i.e., cost to charge the storage and wind purchase cost) as $4,625,295 and revenue (i.e., electricity supplied from wind and storage) as $5,015,734. The total cost in this case is estimated lower than without storage. This is because the fuel to charge the storage is some of the excess generated wind; the cost is already included in the wind purchase cost. In the case of without storage, an additional purchase cost is included from NB Power which is higher than the cost of charging storage. Also, additional capital and maintenance costs are included to the total cost.

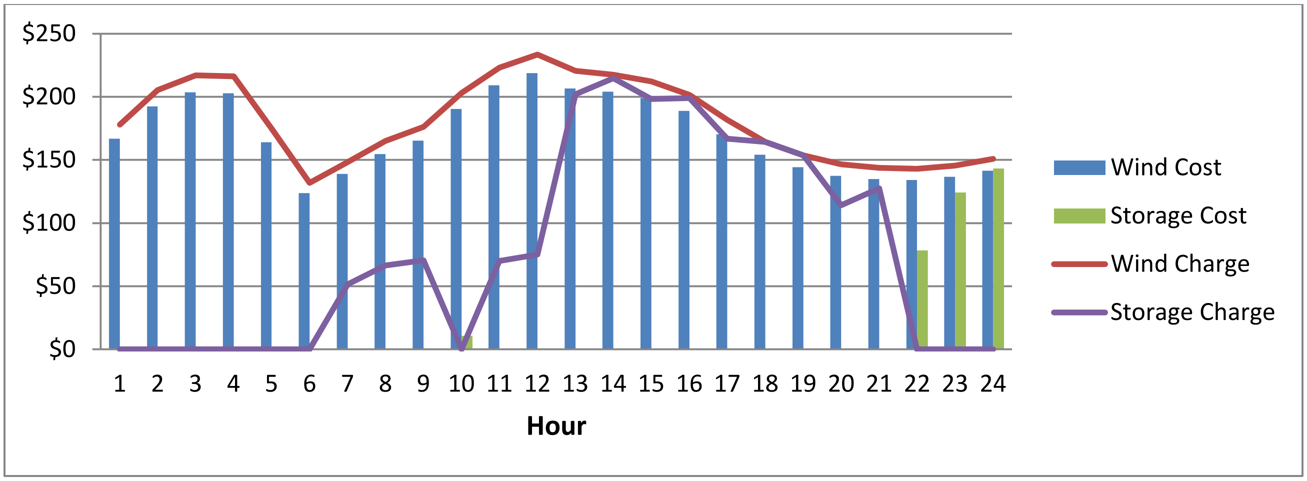


Figure 29: Affordability indicator hourly simulation with storage for Summerside electricity energy chain for 2011

Acceptability: The indirect emissions made by the Summerside jurisdiction whenever it uses the supply from NB Power are shown in the acceptability indicator. Initially, the wind supply tries to satisfy the 15% load, but if it fails, the storage energy is used along with wind supply. When wind and storage has not enough supply to meet the demand, lastly the supply from NB Power is used. In this case, the storage has enough supply for the hours that cannot meet the 15% load. Since 15% of the load is met by wind and storage, no additional replacement electricity is needed from NB Power to satisfy the 15% load and no indirect emissions are generated. This will satisfy the acceptability emission target level (i.e., zero for the 15% load).

The simulation results show Summerside can met 15% of its load each hour from wind coupled with storage. The simulation results shows that adding storage to Summerside's electricity energy chain the useage of electricity from NB Power will reduce and therefore the indirect emissions will be reduced to zero for the 15% load.

4.5. Summary

This chapter demonstrated the visualization tool by selecting the Summerside electricity energy chain as a case study. Simulations were performed for 2011. The results indicated that 15% electricity target in 2011 is not satisfied by the two wind-farms in hourly simulation. However with storage, the 15% electricity target is achieved. The chapter highlighted the flexibility of the tool, which can be used by the jurisdiction to investigate various options and choose an appropriate energy chain to improve energy security.

CHAPTER 5. DISCUSSION

The visualization tool and methods proposed have helped in finding the effects of energy policy in Summerside's 15% load target satisfied by two wind-farms. The simulation results for 2011 have clearly shown that for weekly and monthly time steps the 15% load was met but hourly simulation cannot be met. For the hourly simulation, the jurisdiction failed to meet the load for 2,509 hours (out of 8,760 hours). The tool has the capability to show at which time step the energy chain has failed to meet the target load and by what amount of energy it has failed. The tool also shows that the total energy output produced over the year is more than the total load target. The total electricity generated for the year estimated as 59,117 MWh, while the total 15% load target estimated as 18,633 MWh.

From the simulation results, it is clearly seen that the total energy produced by two wind-farms is aggregated to satisfy the overall 15% load in the case of monthly and weekly simulation. For example, in the weekly simulation, the total amount of energy produced in 168 hours is aggregated to satisfy the 15% load target for that week. This may not be possible in the hourly case because their might be hours with no wind supply or wind electricity generated less than load target. This results in the jurisdiction failing to meet the 15% load target in the hourly simulation.

Summerside purchases electricity from three sources: two wind-farms and NB Power. Initially, the wind supply tries to satisfy the electricity demand, but if it fails the supply from NB Power is used. For 2011, the hourly simulation did not meet the 15% load target for 2509 hour and these hours energy is supplied from NB Power. The rest of 85% load is satisfied by wind or NB Power or both. Summerside's greenhouse gas emissions can be classified as indirect emissions, as there are no contributions to direct emissions (direct emissions include all pollution contributed directly and controlled by the producer or supplier, while indirect emissions include all emissions that result from the use or purchase of a product).The simulation estimated energy supplied from NB Power indirect emission level is 298,863 kg CO_2e.

Energy production and supply will include production cost and customer charge. Projecting the production cost and customer charge will provide the benefit of understanding price structure for producing and consuming energy. In the case study, cost is estimated for the wind purchase cost for the monthly, weekly, and hourly simulations. Along with the wind purchase cost additional cost is added when the power is used from NB Power. For monthly and weekly simulation there is no additional electricity used from NB Power to meet the 15% load target and there is no additional cost added. For hourly simulation, the 15% load failure hours is satisfied by NB Power which added additional cost from NB Power to the wind purchase cost. The price structure from each simulation is shown in Table 4.

Table 4: Total estimated Cost and Revenue monthly, weekly, and hourly for 2011

Simulation	Total cost	Total Charge
Weekly	\$4,433,814	\$4,729,401
Monthly	\$4,433,811	\$4,729,398
Hourly	\$4,738,043	\$5,015,734

Summerside electricity energy chain uses a replacement policy by replacing the electricity supply with NB Power when there is no wind supply. According to the Summerside 2011 annual report, the target wind supply has to meet the 15% load, but the hourly simulation shows it does not. In order to meet the targets, the visualization tool can run the simulation for different combinations of energy chains (i.e., different energy policies and regulations) and the appropriate combination can be chosen based on the jurisdiction level of energy security. For example, the tool can simulate with a reduction policy but the 15% load reduction for each hour may not be possible in all the sectors. Also, restriction policy, adding a new energy source and its process, may be possible but depends on the source availability. However, the visualization tool has clearly shown that 15% of the electricity load can be successfully met from the wind if the excess energy unused from the two wind-farms can be used for the hours that cannot meet the load target. Since the target is 15% electricity load satisfaction this case study considered a replacement policy, adding storage. This means excess energy can be used for charging storage units which can provide energy on the periods that cannot meet the 15% load target.

For the simulation that includes an energy chain with storage, the results have shown that the 15% load can be met by the two wind-farms by adding 40MW storage with 90% efficiency. Using storage, the indirect emissions for the amount of 298,863 kgCO$_2$e are eliminated and the tool estimates the total cost (i.e., wind purchase cost and cost to charge the storage) as

$4,625,295 and revenue (i.e., electricity supplied from wind and storage) as $5,015,734. The total cost in this case is estimated lower than without storage. This is because the fuel to charge the storage is some of the excess generated wind; the cost is already included in the wind purchase cost. In the case of without storage, an additional purchase cost is included from NB Power which is higher than the cost of charging storage. Also, capital cost for installing storage and maintenance cost is not included. However, the net balance is estimated as $390,439 which can be spent on capital cost of the storage and maintenance cost each year.

The visualization tool can help to run the simulations with different combinations of energy chains (i.e., different energy policies and regulations), while the effects of these combinations can be understood interactively. In this case study, the simulation has run with a replacement policy which is to store wind-electricity to meet its 15% load target. This will reduce the reliance on NB Power and significantly reduce the indirect emissions. Consequently, Summerside will improve its overall energy security by eliminating the GHG emissions and guaranteed 15% load target with cost effective.

CHAPTER 6. CONCLUSION

Energy can play a key role in the social, economic or environmental development of any nation. Over the past decade, primary energy demand has increased exponentially by both the world's increasing population and improving living standards. Primary energy sources—mainly fossil fuels, in the form of coal, petroleum, natural gas and their by-products—have served as the major primary energy source in meeting 81% of the world energy demand.

Regardless of its size or location, maintaining and improving energy security is considered an important requirement of any jurisdiction. Over the next few decades, the concern for energy security is expected to increase with increasing demand for energy worldwide and impact of energy-related GHG emissions. Although energy security is important for any jurisdiction, several authors have pointed out that there is no common definition. The one developed by International Energy Agency (IEA) "the uninterrupted physical availability of energy at a price that is affordable, while respecting environment concerns" is globally representative.

All jurisdictions have an energy system responsible for meeting its service energy demands. Energy systems are dynamic, experiencing changes (sudden or anticipated) over time: these changes can affect the energy suppliers, the end-users, and those responsible for operating the energy system. In order to address changes in the energy system and maintain energy security, energy policies are developed. By examining a jurisdiction's different energy sources and services using the three IEA-derived indicators (availability, affordability, and acceptability), the current state and possible future states of energy security can be determined. With this information, policies can be developed to reduce energy consumption (reduction policies), replace existing energy flows with ones that are more secure (replacement policies), or to find entirely new energy sources and processes to meet energy demand (restriction policies).

An important goal of energy policy in many countries around the world is to increase security of supply for energy and to decrease emissions. The question, however, is what are the effects of changing energy policies on energy security in an energy system? Changes to energy policies (i.e., adding a new policy, removing or modifying an existing policy) can impact a system's energy security. Also, energy systems are complex, which means it is essential to study the possible effects of changing energy polices before they are deployed. Computer models can help in understanding complex systems.

Given the need to address the effects of energy policies on energy security, the contribution of this thesis is the development of a visualization tool that allows a person to apply energy policy to an energy system and analyze its impact. The tool has three phases: energy system representation, calculation, and energy security analysis. In the first phase, a generic process is used to represent any jurisdiction's energy chains (an energy system is a combination of single or multiple energy chains). A series of generic processes are selected between the energy sources and energy services responsible for converting or transporting the energy flow, the behaviour for each process will indicate by process characteristics (i.e., flows, process type, and efficiency). In the second phase, every process in the modeled energy system takes a flow of energy ($Energy_{IN}$) from the upstream process or energy source and converts or transports the flow into an output flow ($Energy_{OUT}$) for downstream processes or energy services. The input and output flows of each process is estimated in this phase. In the third phase, the impacts of energy policies on each process are captured by energy security indicators (availability, affordability, and acceptability). Availability criteria checks the condition if each process energy output flow is meeting with the demand input flow, affordability indicator will estimate the cost and revenue of the flow, and acceptability indicator estimates the level of emissions produced form each process. The tool estimates the affordability indicator from the supplier's view, showing whether or not the supplier is making a profit. The tool does not consider affordability from the customer's perspective; for example, ability to pay or customer's income. Also, the acceptability indicator only estimates the emissions from each process; the tool does not consider any social or political factors of acceptability because they are more based on opinion rather than quantitative results.

Energy system can be complex to understand but a visualization tool will visually shows the energy system components and their activity, this can help to reduce the complexity of an energy system. For each time step, the tool will generate the energy output, cost, and emissions and check the three energy security indicators. If any indicator doesn't meet the criteria the process colour and the particular indicator will turn red, indicating the point at which the energy chain has failed. It also estimates the number of time steps each indicator has failed. This process is repeated until the last time step. This can also help in developing appropriate energy policies to improve and maintain energy security.

The jurisdiction selected to illustrate the tool's analysis capabilities was the City of Summerside. Simulations of one of Summerside's energy policies were carried out for the year 2011 to study methods of the tool and validate the tool by analysing the effects of an energy policy intended to meet 15% of the Summerside's electricity load met by two wind-farms in 2011 and to show how energy security in Summerside could be improved.

The visualization tool represented Summerside's on-demand electricity energy chain and analysed the effects of the city's energy policy on its energy security in terms of: availability, affordability, and acceptability of electricity. The simulation was run for monthly, weekly, and hourly time-steps and the results show that for 2011, the 15% load target could be met for monthly and weekly simulation but not for hourly. This is because of wind is a variable energy supply, there might be hours with no wind supply or wind generated electricity less than 15% load target. For the monthly simulations, the tool showed that each process in the energy chain had met the 15% load target. For weekly simulations, the tool showed that the 15% load was also met for 2011; however, for the hourly simulation, the distribution process and secondary conversion process failed to supply 15% load for 2509 hours.

For the hours that failed to meet the 15% load target energy is supplied by NB Power. The remainder of the 85% load may be satisfied by wind or NB Power, or both. The simulation estimated electricity supplied from NB Power resulted in indirect emissions of 298,863 kg CO_2e. Summerside purchased electricity from the two wind-farms (West Cape and Summerside) and NB Power. In 2011, the total electricity supply cost (i.e., wind purchase cost and NB Power purchase cost) was estimated to be $4,738,043 and the total revenue was estimated to be $5,015,734.

The tool has the ability to run multiple simulations with different combinations of energy chains (i.e., different energy policies and regulations). For the case study to achieve the objective, the tool can simulate with different energy policies. For example, the tool can simulate with a reduction policy but the load reduction for each hour may not be possible in all sectors. Also, a restriction policy, adding a new energy source and its process may be possible but depends on the new energy source availability for the jurisdiction. Since the target is 15% electricity load satisfaction, this case study considered a replacement policy involving the addition of storage. For the case study 40MWs of storage with 90% efficiency was selected. For the simulation that includes the energy chain with storage, the results have shown that, 15% load target was met by the two wind-farms by storing the excess wind generated electricity. By adding storage, the indirect emissions of 298,863 kgCO_2e, the result of using electricity from NB Power were eliminated. The tool estimated the total cost (i.e., wind purchase cost and cost to charge the storage) as $4,625,295 and revenue (i.e., electricity supplied from wind and storage) as $5,015,734. The total cost in this case was estimated lower than without storage because the fuel to charge the storage is some of the excess wind; the cost was already included in the wind-purchase cost. Without storage, an additional purchase cost is included from NB Power which is higher than the cost of charging with storage; however, the capital costs for installing the storage and its maintenance were not included. However, the net balance is estimated as $390,439 which could be spent on capital cost of the storage and maintenance cost each year.

The work presented in this thesis showed that the visualization tool can represent a jurisdiction's energy chain using a single generic process and analyse the effects of energy policy on a jurisdiction's energy system. It can visually show the impact on energy security of changes to a jurisdiction's energy policies by using energy security indicators.

6.1. Limitations

The following limitations need to be considered when using the visualization tool:

- The tool has no capability of decision making. This means the tool will not suggest the appropriate energy policies to increase the energy security.
- The tool has the ability to run different combination of energy chains but each combination should be modified manually before the simulation.
- The affordability indicator refers to the supplying rather than the consuming process.

6.2. Future Work

This thesis shows the potential of the visualization tool representing energy chains with a single generic process and analyse the effects of energy policy on energy security in an energy system. Possible future research work that can be carried out to enhance the visualization tool so that it has the capability to:

- Represent an energy system which has the ability to represent multiple energy chains at a time.
- Run the simulations for different combination automatically.
- Make decisions.

BIBLIOGRAPHY

Adil Najam, Cutler J and Cleveland World Environment Summits: The Role of Energy [Article] // Encyclopedia of Energy. - Massachusetts : [s.n.], 2004. - pp. Pages 539–548.

Amit Kumar, Bhattacharya S and Pham H Greenhouse gas mitigation potential of biomass energy technologies in Vietnam using the long range energy alternative planning system model [Article] // Energy. - Alberta : [s.n.], 2003. - 7 : Vol. 25. - pp. 627–654.

Argonne Decision and Information Sciences [Online] // Argonne. - 2013. - http://www.dis.anl.gov/exp/msv/index.html.

Argonne Generation and Transmission Maximization (GTMax) Model [Online] // Decision and Information Sciences. - Argonne National Labortary, 2004. - 2013. - http://www.dis.anl.gov/projects/Gtmax.html.

Augutis Juozas [et al.] Energy security level assessment technology [Journal]. - Kaunas : Applied Energy, 2012. - Vol. 97.

Balmorel Balmorel [Online] // Balmorel Energy system model. - 2013. - http://www.balmorel.com/.

Barker Terry, Ekins Paul and Foxon Tim Macroeconomic effects of efficiency policies for energy-intensive industries: The case of the UK Climate Change Agreements, 2000–2010 [Article] // Energy Economics. - London : [s.n.], 2007. - 4 : Vol. 29. - pp. 760–778.

BBC News Africa [Online] // BBC. - Jan 2nd, 2012. - 2012. - http://www.bbc.co.uk/news/world-africa-16382286.

Blarke M B, and H Lund The effectiveness of storage and relocation options in renewable [Article] // Renewable Energy. - July 2008. - 7 : Vol. 33. - pp. 1499-1507.

Blum Helcio and Legey Luiz The challenging economics of energy security: Ensuring energy benefits in support to sustainable development [Journal]. - [s.l.] : Energy Economics, 2012. - 6 : Vol. 34.

BREGHA FRANÇOIS Energy Policy [Online] // The Canadian Encyclopedia. - 2012. - 2012. - http://www.thecanadianencyclopedia.com/articles/energy-policy#ArticleContents.

Carlin P W, Laxson A S and Muljadi E B The History and State of the Art of Variable-Speed Wind Turbine Technology [Journal] // Wind Energy. - [s.l.] : National Renewable Energy Laboratory, 2003. - Vol. 6. - pp. 129–159.

Checch Arianna, Behrens Arno and Egenhofer Christian Long-Term Energy Security Risks For Europe [Report]. - [s.l.] : Centre for European policy studies, 2009. - 978-92-9079-849-1.

Christoph Weber and Adriaan Perrels Modelling lifestyle effects on energy demand and related emissions [Article] // Energy Policy. - Stuttgart : [s.n.], 1998.

Chuang Ming Chih and Hwong Wen An assessment of Taiwan's energy policy using multi-dimensional energy security indicators [Journal]. - [s.l.] : Renewable and Sustainable Energy Reviews, 2012.

City of Summerside 2012 Annual Report [Report]. - Summerside : [s.n.], 2012.

Connolly D [et al.] A review of computer tools for analysing the integration of renewable energy into various energy systems [Article] // Applied Energy. - Limerick : [s.n.], 2009. - 4 : Vol. 87. - pp. 1059-1082.

David Hippel [et al.] Energy security and sustainability in Northeast Asia [Article]. - San Francisco : Energy Policy, 2011. - Asian Energy Security. - 11 : Vol. 39.

DCCE National Greenhouse Accounts Factors [Report]. - [s.l.] : Department of Climate Change and Energy Efficiency, 2010.

EIA International Energy outlook 2010 [Report]. - 2010. - Report #:DOE/EIA-0484(2010).

EIA The national Energy Modeling System: An Overview 2009 [Report] / U.S Department of Energy. - 2009. - DOE/EIA-0581(2009).

Eminent Introduction [Online] // Eminent. - 2003. - Feb 5, 2011. - http://www.cpi.umist.ac.uk/eminent/Introduction2.asp.

Environment Canada Emission Factors from Canada's GHG Inventory- Fuel Combustion [Online] // Environment Canada. - 06 23, 2011. - 08 01, 2011. - http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=AC2B7641-1.

Eunju Jun, Wonjoon Kim and Heung Chang The analysis of security cost for different energy sources [Article] // Applied Energy. - 2009. - 10 : Vol. 86. - pp. Pages 1894–1901.

Exonmobil 2012 The Outlook for Energy: A View to 2040 [Report]. - 2012.

ExxonMobil 2012 The Outlook for Energy: A View to 2040 [Report]. - 2012.

Financial Times Nigeria power rates to rise up to 88% [Online]. - THE FINANCIAL TIMES LTD, 2012. - 2012. - http://www.ft.com/cms/s/0/78b805ec-5586-11e1-9d95-00144feabdc0.html#axzz2E2Qk6ORp.

Foley A [et al.] A strategic review of electricity systems models [Article] // Energy. - Cork : [s.n.], 2010. - 12 : Vol. 35.

Geoffrey Wood and Stephen Dow What lessons have been learned in reforming the Renewables Obligation? An analysis of internal and external failures in UK renewable energy policy [Article] // Energy Policy. - Dundee : [s.n.], 2011. - 5 : Vol. 39.

Goldthau Andreas and Sovacool Benjamin The uniqueness of the energy security, justice, and governance problem [Article] // Modeling Transport (Energy) Demand and Policies. - Budapest : Energy Policy, 2012. - 0 : Vol. 41.

Gonzalez Jaume-Freire Methods to empirically estimate direct and indirect rebound effect of energy-saving technological changes in households [Article] // Ecological Modelling. - 2011. - 1 : Vol. 223. - pp. 32-40.

Hainoun A, Aldin Seif and Almoustafa S Formulating an optimal long-term energy supply strategy for Syria using MESSAGE model [Article] // Energy Policy. - Damascus : [s.n.], 2010. - 4 : Vol. 38.

Hodge S [et al.] A multi-paradigm modeling framework for energy systems simulation and analysis [Article] // Computers & Chemical Engineering. - West Lafayette : [s.n.], 2011. - 9 : Vol. 35.

Hughes Larry A generic framework for the description and analysis of energy security in an energy system [Article] // Energy Policy. - 2011. - Vol. 42. - pp. 221-231.

Hughes Larry and Harisubramanian Lakshminarayanan The Summerside Smart-Grid Pilot Program: An innovative approach to improved energy security and reduced greenhouse gas emissions [Report]. - Summerside : Summerside, 2012.

Hughes Larry The four ‘R's of energy security [Article] // Energy Policy. - 2009. - 6 : Vol. 37. - pp. 2459–2461.

Hughes Larry The four ‘R's of energy security [Article] // Energy Policy. - Halifax : [s.n.], 2009. - 6 : Vol. 37. - pp. 2459–2461.

IEA Energy Security [Online] // international energy agency. - energy agency, 2010. - Oct 20, 2010. - Energy security is the availability of a source for an affordable price while respecting environmental concerns.

IEA Energy Security [Online] // International Energy Agency. - 2012. - 02 14, 2012. - http://www.iea.org/subjectqueries/keyresult.asp?KEYWORD_ID=4103.

IEA Key World Energy Statistics 2011 [Report]. - Paris : International Energy Agency, 2012.

IEA Measuring short Term Energy Security [Report]. - 2011.

IEA World Energy Outlook 2010 [Report]. - [s.l.] : International Energy Agency, 2010.

IEA World Energy Outlook 2011 [Report]. - Paris : International Energy Agency, 2011b. - ISBN: 978 92 64 12413 4.

IEA World Energy Outlook 2011 [Report]. - Paris : International Energy Agency, 2011. - ISBN: 978 92 64 12413 4.

IEA World Energy Outlook 2012 [Report]. - Paris : International Energy Agency, 2012a. - ISBN:978-92-64-18084-0.

Inter Academies Council Lighting the Way: Toward a Sustainable Energy Future [Report]. - 2007.

Jansen Jaap and Seebregts Ad Long-term energy services security: What is it and how can it be measured and valued? [Article] // Energy Security - Concepts and Indicators with regular papers. - Petten : Energy Policy, 2010. - 4 : Vol. 38.

Klemeš Jiri and al et Novel Energy Saving Technologies Evalution Tool [Report] / The University of Manchester. - Grenoble : Heat Transfer in Components and Systems for Sustainable Energy Technologies, 2005.

Lund Henrik Renewable Energy Systems [Book Section]. - 2010.

Maritime Electric Maritime electric open access tranmission tariff [Online] // Maritime Electric. - Jan 2010. - 2013.

Markewitz [et al.] IKARUS- A FUNDAMENTAL CONCEPT FOR NATIONAL GHG-MITIGATION STRATEGIES [Article]. - Juelic : Elsevier Science Ltd, 1996. - 6-8 : Vol. 37.

Nagy Karoly The additional benefits of setting up an energy security centre [Article]. - Budapest : Elsevier, 2009. - 10 : Vol. 34.

Nakata Toshihiko, Diego Silva and Mikhail Rodionov Application of energy system models for designing a low-carbon society [Article] // Progress in Energy and Combustion Science. - Aoba-Yama : [s.n.], 2011. - 4 : Vol. 37. - pp. 462–502.

NB Power Sustainability Report [Report]. - 2009/10.

NREL Documentation [Online] // HOMER Energy. - National Renewable Energy Laboratory, 2011. - 2.68. - 2013. - http://homerenergy.com/pdf/homergettingstarted268.pdf.

Peter Jansen [et al.] EMINENT accelerates market introduction of promising early stage technologies for transport and energy [Online] // University of Manchester. - 2004. - 2011. - http://www.cpi.umist.ac.uk/eminent/publicFiles/CISAP1.pdf.

Sabine Messner and Manfred Strubegger User's Guide for MESSAGE I11 [Report] / International Institute for Applied Systems Analysis. - 1995.

Scheepers martin [et al.] EU Standrads for Energy Security of Supply [Report]. - The Hague : ECN/Clingendael International Energy Programme , 2006. - ECN-C-06-039/CIEP.

Seungmoon Lee [et al.] Implication of CO2 capture technologies options in electricity generation in Korea [Journal] // Energy Policy. - [s.l.] : Elsevier, 2007. - 1 : Vol. 36.

Shahriar Shafiee and Erkan Topal A long-term view of worldwide fossil fuel prices [Journal]. - Kalgoorlie : Applied Energy, 2010. - 3 : Vol. 87.

SKRECC Electric Thermal Storage [Online] // South Kentucky Rural Electric Cooperative Corporation. - 2009. - 10 10, 2011. - http://www.skrecc.com/ets.htm.

Stuart Bridgeman [et al.] [Online] // World Energy Council. - Hatch, 2010. - 2012. - http://www.worldenergy.org/documents/congresspapers/342.pdf.

Suganthia L and Anand A Samuelb Energy models for demand forecasting—A review [Article] // Renewable and Sustainable Energy Reviews. - Vellore : [s.n.], 2011. - 2 : Vol. 16.

Summerside Electric Electric Pricing Single Heater & Water Heater Comparison [Report]. - Summerside : Summerside Electric, 2011.

Summerside Electric Energy purchase agreement (NB POWER and THE CITY OF SUMMERSIDE) [Report]. - 2010.

Summerside Electric Summerside numbers for research 2010-Aug2011 [Report]. - Summerside : [s.n.], 2011.

Taseska v [et al.] Greenhouse gases (GHG) emissions reduction in a power system predominantly based on lignite [Journal]. - Skopje : Energy, 2011. - 4 : Vol. 36.

UN-Energy Energy Development and Security [Report]. - [s.l.] : United Nations Industrial development Organization, 2008.

Victor Scott Emerging symbiosis: Renewable energy and energy security [Article]. - Hongo : Renewable and Sustainable Energy Reviews, 2011. - 9 : Vol. 15.

Winzer Christian Conceptualizing Energy Security [Article] // Energy Policy. - 2011. - Vol. 46. - pp. 36-48.

World Bank Energy Security Issues [Report]. - Moscow-Washington : World Bank, 2005.

World Bank Energy Security Issues [Report]. - Moscow-Washington : World Bank, 2005.

Xiaoyu Yan and Roy Crookesa Reduction potentials of energy demand and GHG emissions in China's road transport sector [Article]. - [s.l.] : ELSEVIER, Nov 2008. - 2 : Vol. 37.

Appendix A: Simulation Results for 2011

The input data required for the visualization tool for simulating monthly and weekly data are for 2011 shown here. The input data shows the amount of energy generated by the two wind-farms for each time step. Table 5 shows the 15% weekly input data for 2011. PS1 represents the input data from the Summerside wind farm; PS2 represents the input data from the West Cape wind farm. The 15% load for each time step is also shown in the Table 5.

The weekly and monthly input and output data for 2011 are as follows

Table 5: 15% weekly simulation input data for 2011

Time Period	**PS1** (MWh)	**PS2** (MWh)	**DEMAND$_{IN}$** (MWh)
1	478	545.6	379.8
2	835	960.5	383.5
3	572	521.8	400.2
4	676	880.4	419.9
5	503	557.3	410.3
6	608	667.7	397.7
7	846	878.1	399.6
8	760	933.7	388.4
9	964	939.6	401.9
10	687	853.3	375.6
11	842	1097.3	370.2
12	355	493.9	366.1
13	827	835.1	364.3
14	698	690.3	357.3
15	575	787.3	340.8
16	563	601.6	343.2
17	658	826.8	329.7
18	641	962.5	333.9
19	758	1276.4	342.8
20	218	240.2	338.8
21	599	716.2	325.7
22	531	668.2	325.5
23	236	374.4	326.2
24	242	430.4	322.3
25	344	392.7	324
26	225	208.9	331.8
27	397	502.5	345.4
28	424	758.5	336.3

29	323	442.5	348.2
30	166	330.5	345.5
31	298	412.9	344.2
32	287	292.2	345.8
33	160	366.2	347.5
34	585	743.5	353.2
35	256	308.3	344.8
36	326	594.2	334.4
37	628	717.2	330.1
38	256	280.6	329.2
39	441	502.3	333.7
40	704	802.5	339.8
41	603	593.4	329.9
42	769	726.7	332.1
43	539	305.3	341.9
44	656	594.7	353.5
45	619	654.9	346.2
46	829	934.1	350.0
47	684	568.6	379.7
48	716	676.0	367.3
49	531	640.5	379.2
50	674	695.3	401.4
51	627	682.2	414.8
52	895	1126.6	457.1

Table 6: 15% weekly simulation output data for 2011

Time Period	**PC E_{OUT}** (MWh)	**DIST E_{OUT}** (MWh)	**SC E_{OUT}** (MWh)	**TOT E_{OUT}** (MWh)	**TOT $DEMAND_{IN}$** (MWh)	**NB Emm** (kgCO2e)	**Wind Cost** ($)	**Wind Charge** ($)	**NB Cost** ($)	**NB Charge** ($)
1	1023.6	972.4	972.4	972.4	379.8	0	72932.9	77795.1	0	0
2	1795.5	1705.7	1705.7	1705.7	383.5	0	127929.3	136458	0	0
3	1093.8	1039.1	1039.1	1039.1	400.2	0	77935.3	83131.0	0	0
4	1556.4	1478.6	1478.6	1478.6	419.9	0	110897.7	118290.9	0	0
5	1060.3	1007.3	1007.3	1007.3	410.3	0	75552.0	80588.8	0	0
6	1275.7	1211.9	1211.9	1211.9	397.7	0	90897.1	96957	0	0
7	1724.1	1637.9	1637.9	1637.9	399.6	0	122844.9	131034.6	0	0
8	1693.7	1609.0	1609.0	1609.0	388.4	0	120680.4	128725.7	0	0
9	1903.6	1808.4	1808.4	1808.4	401.9	0	135632.9	144675.1	0	0
10	1540.3	1463.3	1463.3	1463.3	375.6	0	109747.8	117064.3	0	0
11	1939.3	1842.4	1842.4	1842.4	370.2	0	138180.1	147392.1	0	0

12	848.9	806.5	806.5	806.5	366.1	0	60490.5	64523.2	0	0
13	1662.1	1579.0	1579	1579.0	364.3	0	118427.4	126322.6	0	0
14	1388.3	1318.9	1318.9	1318.9	357.3	0	98922.7	105517.6	0	0
15	1362.3	1294.2	1294.2	1294.2	340.8	0	97067.4	103538.6	0	0
16	1164.6	1106.3	1106.3	1106.3	343.2	0	82979.8	88511.8	0	0
17	1484.8	1410.6	1410.6	1410.6	329.7	0	105798.4	112851.6	0	0
18	1603.5	1523.3	1523.3	1523.3	333.9	0	114254.3	121871.3	0	0
19	2034.4	1932.7	1932.7	1932.7	342.8	0	144954.5	154618.2	0	0
20	458.2	435.3	435.3	435.3	338.8	0	32650.3	34827	0	0
21	1315.2	1249.4	1249.4	1249.4	325.7	0	93711.5	99959	0	0
22	1199.2	1139.2	1139.2	1139.2	325.5	0	85443	91139.2	0	0
23	610.4	579.8	579.8	579.8	326.2	0	43491.7	46391.1	0	0
24	672.4	638.8	638.8	638.8	322.3	0	47911.3	51105.4	0	0
25	736.7	699.9	699.9	699.9	324	0	52493.4	55993	0	0
26	433.9	412.2	412.2	412.2	331.8	0	30916.8	32977.9	0	0
27	899.5	854.5	854.5	854.5	345.4	0	64089.3	68362	0	0
28	1182.5	1123.4	1123.4	1123.4	336.3	0	84257.4	89874.5	0	0
29	765.5	727.2	727.2	727.2	348.2	0	54544.7	58181.0	0	0
30	496.5	471.7	471.7	471.7	345.5	0	35380.6	37739.3	0	0
31	710.9	675.4	675.4	675.4	344.2	0	50658.0	54035.2	0	0
32	579.2	550.3	550.3	550.3	345.8	0	41272.9	44024.5	0	0
33	526.2	499.9	499.9	499.9	347.5	0	37496.7	39996.5	0	0
34	1328.5	1262.1	1262.1	1262.1	353.2	0	94659.1	100969.8	0	0
35	564.3	536.1	536.1	536.1	344.8	0	40209.9	42890.6	0	0
36	920.2	874.2	874.2	874.2	334.4	0	65570.6	69942.0	0	0
37	1345.2	1277.9	1277.9	1277.9	330.1	0	95847.6	102237.4	0	0
38	536.6	509.79	509.7	509.7	329.2	0	38234.8	40783.8	0	0
39	943.3	896.1	896.1	896.1	333.7	0	67210.8	71691.5	0	0
40	1506.5	1431.2	1431.2	1431.2	339.8	0	107341.6	114497.8	0	0
41	1196.4	1136.5	1136.5	1136.5	329.9	0	85244.9	90927.9	0	0
42	1495.7	1420.9	1420.9	1420.9	332.1	0	106572.1	113677	0	0
43	844.3	802.1	802.1	802.1	341.9	0	60160.6	64171.3	0	0
44	1250.7	1188.2	1188.2	1188.2	353.5	0	89117.3	95058.5	0	0
45	1273.9	1210.2	1210.2	1210.2	346.2	0	90768.9	96820.2	0	0
46	1763.1	1675.0	1675.0	1675	350.0	0	125626.5	134001.6	0	0
47	1252.5	1190.0	1190.0	1190	379.7	0	89251.312	95201.4	0	0
48	1392.0	1322.4	1322.4	1322.4	367.3	0	99182.8	105795	0	0
49	1171.5	1112.9	1112.9	1112.9	379.2	0	83473.6	89038.5	0	0
50	1369.3	1300.8	1300.8	1300.8	401.4	0	97564.762	104069	0	0
51	1309.2	1243.8	1243.8	1243.8	414.8	0	93286.912	99506	0	0
52	2021.6	1920.5	1920.5	1920.5	457.1	0	144044.7	153647.6	0	0

This section also shows the output data produced by each process for each time step. PCE_{OUT} is the output from primary conversion process, $DISTE_{OUT}$ is the output from distribution process, SCE_{OUT} is the output from secondary conversion process, $TOTE_{OUT}$ is the total energy output generated by the energy chain to satisfy the end demand, TOT $DEMAND_{IN}$ is the total energy demand from the energy service, NB Emm is the emissions made from the NB Power, and the rest will be the output cost and charge from the wind farms and NB Power. Table 6 shows the 15% weekly output data generated by Summerside energy system.

Table 7: 15% monthly simulation input data for 2011

Time Period	**PS1** (MWh)	**PS2** (MWh)	**$DEMAND_{IN}$** (MWh)
1	2733	3040.3	1751.6
2	2918	3244.0	1596.4
3	3224	3791.3	1657.3
4	2667	3168.6	1469.9
5	2370	3327.6	1477.7
6	1322	1756.1	1403.2
7	1392	2130.9	1510.1
8	1486	2024.7	1545.3
9	1676	2109.5	1427.8
10	2992	2688.5	1493.6
11	2992	3085.8	1539
12	2862	3227.0	1761

Table 7 shows the 15% monthly input data for the year 2011. PS1 represents the input data from the Summerside wind farm; PS2 represents the input data from the West Cape wind farm. The 15% load for each time step is also shown in the Table 7.

Table 8: 15% monthly simulation output data for 2011

Time Period	PC E_{OUT} (MWh)	DIST E_{OUT} (MWh)	SC E_{OUT} (MWh)	TOT E_{OUT} (MWh)	TOT $DEMAND_{IN}$ (MWh)	NB EMM (kgCO2e)	Wind Cost ($)	Wind Charge ($)	NB Cost ($)	NB Charge ($)
1	5773.3	5484.6	5484.6	5484.6	1751.6	0	411351.9	438775.3	0	0
2	6162.0	5853.9	5853.9	5853.9	1596.3	0	439044.6	468314.2	0	0
3	7015.3	6664.5	6664.5	6664.5	1657.3	0	499842.2	533165	0	0
4	5835.6	5543.8	5543.8	5543.8	1469.9	0	415788.6	443507.8	0	0
5	5697.6	5412.7	5412.7	5412.7	1477.7	0	405956.8	433020.6	0	0
6	3078.1	2924.2	2924.2	2924.2	1403.2	0	219321	233942.4	0	0
7	3522.9	3346.7	3346.7	3346.7	1510.1	0	251006.6	267740.4	0	0
8	3510.7	3335.2	3335.2	3335.2	1545.3	0	250143.0	266819.2	0	0
9	3785.5	3596.2	3596.2	3596.2	1427.8	0	269720.4	287701.8	0	0
10	5680.5	5396.5	5396.5	5396.5	1493.6	0	404738.4	431721.0	0	0
11	6077.8	5773.9	5773.9	5773.9	1539	0	433049.6	461919.6	0	0
12	6089.0	5784.6	5784.6	5784.6	1761	0	433847.6	462770.8	0	0

The energy output data for each month is shown in Table 8. The energy generated from each process and total 15% load for each month is shown. The level of emissions for each month and the wind production cost and charge for each month is also shown.