SPRINGER BRIEFS IN ENERGY

Tanveer Ahmed

Modeling the Renewable Energy Transition in Canada

Techno-economic Assessments for Energy Management

Springer

SpringerBriefs in Energy

More information about this series at http://www.springer.com/series/8903

Tanveer Ahmed

Modeling the Renewable Energy Transition in Canada

Techno-economic Assessments for Energy Management

Springer

Tanveer Ahmed
Brandenburg University of Technology
Cottbus
Germany

ISSN 2191-5520 ISSN 2191-5539 (electronic)
SpringerBriefs in Energy
ISBN 978-3-319-31503-4 ISBN 978-3-319-31505-8 (eBook)
DOI 10.1007/978-3-319-31505-8

Library of Congress Control Number: 2016934419

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

Preface

The purpose of this work is to demonstrate a techno-economic model (TEM) of power generation for a cost-effective integration of renewable energy sources (RES) in order to reduce greenhouse gas (GHG) emissions in Canada. This will ultimately contribute to reduction of global climate change and will eventually bring a significant benefit for industrial countries.

Canada possesses a variable power generation portfolio in which hydro power has the largest share, followed by fossil fuels, nuclear power, and other renewables. After analysis of the current state of Canadian electricity infrastructure, it can be determined that the National Energy Board of Canada (NEB) is planning for more fossil and nuclear power to overcome its future needs till 2025, in which only 3 % RES capacity will be added. This model has been named as NEBM-2025 in this research.

A techno-economic model (TEM-2025) presented in this work demonstrates that 10 % RES transition is possible, practical, and affordable by using an effective policy till 2025. The methodology used by the author investigates the level of future investment and determines that the country can reduce its heavy reliance on fossil and nuclear fuel and can supply a significant amount of power with RES within a specific timeline. The results of TEM show that 75 % of power can be generated through RES, while reducing 7 % nuclear and 3 % fossil power generation in Canada till 2025. The demand side reliability of wind and PV in the context of intermittency factor has been addressed by utilizing 6823 MW of gas power plants as a standby power. The second and most important goal was to estimate and integrate a significant amount of RES that could potentially be harnessed within the boundaries of available finances without introducing any feed-in tariff or loan-based financial mode. This target has been achieved by periodic simulation of price variations in which all projects could be financed fully, while the total price increase remained less than one CDN $ cent/kWh for only 7 years.

Acknowledgments

The genesis of this book is a renewable energy research work on the Canadian power system, which I have done at Brandenburg University of Technology Cottbus, Germany, and at School of Business Management SCAAT, Toronto, Canada. However, the idea to compile the work in a book form was born in correspondence with Ms. Tiffany Gasbarrini, Senior Editor for Engineering and Energy at Springer New York. My deepest appreciation goes to Tiffany for her excellent cooperation, encouragement, and guidance in a very friendly and efficient manner. My gratitude goes to the whole Springer team, in particular to Brian Halm, Project Coordinator Springer USA, for his comprehensive evaluation and valuable suggestions during the reviewing process.

This book owes its existence to Prof. Dr. Gerhard Lappus, my supervisor at Brandenburg University of Technology, Cottbus, Germany, and my co-supervisor Prof. Dr. A. Naveed Tariq at School of Business Management, SCAAT, Toronto. I am very thankful for their outstanding patience, understanding, and precious time. My thanks are also due to all institutes, utilities, and personalities that helped me to collect the data for this work, particularly to Mr. David Watson at Wind Energy Institute of Canada.

I dedicate this work to my departed mother, Sakina, who made countless sacrifices to ensure that I received a well-rounded education.

I hope that this book will be a vital resource for energy economics, energy policy, and energy planning with the integration of renewable energy sources in Canada and will contribute to maintain an environmental friendly and sustainable planet gifted to all of us by divine providence.

Toronto
February 2016

Tanveer Ahmed

Contents

Acronyms

%	Per Cent or Percent
AB	Alberta
BC	British Columbia
CDN $	Canadian Dollar
CDN $ Cent	Canadian Dollar Cent
CDN $ Cent/kWh	Canadian Dollar Cent per Kilowatt-Hour
CDN $/MW	Canadian Dollar per Megawatt
CDN Cent/kWh	Canadian Cent per Kilowatt Hour
Cent/kWh	Canadian Cent per Kilowatt-Hour
CF	Capacity Factor
CO_2	Carbon dioxide
EC	Environmental Canada
GHG	Greenhouse Gases
GW	Giga-watt
GWh	Giga watt hour
h	Hour
hrs	Hours
HOMER	Hybrid Optimization Model for Electric Renewables
km	Kilometer
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt hour
kWh/kW	Kilowatt Hour per Kilowatt
MB	Manitoba
MW	Megawatt
NB	New Brunswick
NEB	National Energy Board of Canada
NEBM	National Energy Board Model
NEBM-2025	National Energy Board Model for Year 2025
NL	Newfoundland
NS	Nova Scotia

NT	Northwest Territories
NU	Nunavut
ON	Ontario
P_{ac}	AC Power
P_{dc}	DC Power
PE	Prince Edward Island
PP	Power Plant
PV	Photovoltaic
QC	Quebec
RES	Renewable Energy Sources
SK	Saskatchewan
STC	Statistics Canada
STC	Standard Test Conditions
TEM	Techno-economic Model
TEM-2025	Techno-economic Model for Year 2025
TWh	Terawatt Hour
USA	United States of America
YT	Yukon Territory

List of Figures

List of Tables

Chapter 1
Introduction

1.1 Problem Overview

Effective energy management is a major contributor to the long-term competitiveness and the sustainability of every country [1]. Fossil fuels such as oil, coal, and natural gas are not only a major part of global energy mix but these conventional sources together with nuclear power still dominate the global power generation with its 79 % share [2]. Multiple recent studies show that use of conventional power system with fossil and nuclear fuel is associated with environmental, safety, and health issues. The worst environmental changes are primarily due to the excess of greenhouse gases (GHG), especially CO_2 emissions for which the share of electricity and heat is 41 % [3]. Such sort of unsustainable use of energy in global growth scenario is the greatest threat to our collective survival.

Canada generates more than 2 % of global GHG emissions and ranks 7th highest in the world [4]. Per capita electricity consumption of Canada is among the third highest levels in the world after Iceland and Norway, whereas Germany is at 27th place [5]. Moreover, the GHG emissions of Canada are growing faster than those of most other industrialized nations [6]. In spite of this, Canada is planning more fossil and nuclear power plants to overcome its future energy needs. The second problem is that in many parts of Canada, especially in remote areas, diesel generators are still being used to produce power, due to which the power consumers of those areas are forced to buy very expensive power.

On the one hand, power generation is one of the major sources of GHG emissions worldwide but on the other hand, it is also a sector where an alternative solution in the form of renewable energy sources (RES) is available. Power generation technologies with RES such as hydro, wind, and photovoltaic (PV) have low or zero emissions and have no fuel costs. In order to implement such technologies, there are various methodological challenges. The most difficult task is to replace the reliance on fossil fuels for base-load power generation as these fuels provide primarily a cheap and reliable source of electricity around the world

T. Ahmed, *Modeling the Renewable Energy Transition in Canada*,
SpringerBriefs in Energy, DOI 10.1007/978-3-319-31505-8_1

compared to alternative resources. Another key problem with RES like solar and wind power is intermittency, which is a main obstacle to their extensive penetration into the grid. In order to address these issues in Canada, an effective energy management plan within the framework of existing power system in a specific timeline is urgently needed. In this research work, a technically and economically feasible energy model with meaningful integration of RES is presented to overcome all these issues.

1.2 Objective Setup

The power generation system in Canada is already poised to enter into an innovative phase that could lead it to global RES-oriented power production competitiveness. The country has natural untapped potential to produce as much reliable power from RES as it is being produced through both thermal and nuclear sources. There is only a need to develop a vision for a green energy future.

An optimal trade-off economic model between alternative and conventional energy has always been difficult for policy makers, because the uncertainty and variation of power supply with RES is much greater compared to conventional power generation. The large power producers still demonstrate the cost-efficiency of conventional energy. The fact is that conventional energy is only perceived to be cost-effective because the price of this energy is being demonstrated in enigmatic ways, irrelevant to the negative impacts of socio-environmental scenarios. This framework is deeply imbedded into the worldwide energy structure and creates a lot of obstacles to explore every avenue for consumers to change into environmental friendly regenerative technologies. Such behavior can be changed if another activity pattern in the form of an alternative energy model would be introduced, which is technically and economically feasible. The development of such techno-economic model is the whole objective for undertaking this research. After examining a number of technical, economic, and resource implications, an objective has been set to fulfill up to 75 % of power demand with RES within 10 years of time period in Canada.

1.3 Roadmap of the Thesis

The heuristic approach adopted in this thesis can play an important role to make an economical viable transition from conventional power generation toward RES. The techno-economic typology of each RES has been scanned accordingly for simulation purpose in order to draw an adequate model. The selected renewable energy technologies are photovoltaic, wind, and hydropower. These technologies are mature, feasible, and produce none of the pollutants as in the case of fossil fuel and are very safe compared to nuclear generation. To overcome the intermittency issues related to wind and PV power, all planned fossil fueled power plants of 6823 MW are included in form of gas fueled power plants as a standby power.

This work is divided into five chapters. The first chapter summarizes the background of the problem at global level and sets out goals to solve it. The second chapter looks at the main features of the power sector, presents an overview of future power planning by the National Energy Board (NEB) in Canada, and analyzes the issues that need action in the near and long-term future. Third chapter specifically reviews the ascendancy of the existing power generation system as a main source. It also describes the methodology to find the quantity of future power generation with reference to the capacity factors and investigates the capital costs of future power plants according to the current state of market investment in RES. Most of the data related to the capital costs of the power plants presented in this chapter has been gathered from leading firms that are tracking investment in the RES energy sector. These data have been then analyzed in the context of alternative investment. The fourth chapter is the most important part of the thesis, as it investigates the mechanism of finances across all the power generation projects. It encircles the whole economy of additional parameters of suggested RES power generation model, which is called here TEM-2025 and compares it with the power generation model drawn by NEB, which is called here NEBM-2025. After that, an adequate tariff has been simulated with minor price increase to cover the capital costs of RES for the specific time plan. It also examines the capital costs quantitatively by abstracting per kWh price to finance all alternative RES projects. Lastly, the fifth chapter extracts and elaborates on results of the whole research in which a target of 10 % increase in RES power generation till 2025 has been achieved successfully.

1.4 Data Quality and Approach

The data supplied in this research are ensured to be as accurate as possible at the time of compiling and the key values of technical specifications have been drawn from a variety of sources. The primary sources are energy surveys and administrative records received by Statistics Canada (STC) and National Energy Board (NEB) of Canada. To determine the generation investment between 2015 and 2025, a thorough web search was first performed to identify the future planning of NEB and the feasibility of RES investment. The list was then verified using the literature review and key contacts in Canada. At the next step, the retirement and refurbishment dates of existing facilities were identified to determine the substitute RES for future investment paths. The operational fossil and nuclear power plants have been considered to be continued till their life cycle. The capacity of planned fossil power plants has been replaced by RES, but at the same time, this capacity was also shifted to gas fueled power plants to act as standby power to overcome the intermittency of wind and PV power generation. The capacity of planned nuclear power plants was replaced with RES fully. Once the planning timings of the proposed conventional projects were adjusted with RES by determining the future capacity requirements, capital costs were applied to all new generation projects and the total generation investment requirements were calculated by using simulator.

Only power generation prospective has been considered to fix the ideas and to keep this work simple. For such a large country like Canada, the transition of RES can be complex and it would have been difficult to cover all issues related to the power sector, in particular, smart grids, transmission, and distribution system within the framework of this thesis.

The basic idea and methodology to solve the problem in this work are fully owned by author and have not been copied from anywhere. All figures and tables have been designed and drawn by the author. Exception applies only to Figs. 2.1 and 3.1, in which basic partial-idea of image has been taken from external sources. Then, these images were modified by design and by putting the latest data. The data source, where applicable, has been mentioned properly. This research work has been prepared to assist those responsible for developing the medium-term strategies for power generation planning and setting the energy policy in Canada. The basic approach is to reinvigorate the power sector of Canada for global competitiveness. While the best efforts have been used in preparing this work, the author makes no representations or warranties of any kind and assumes no liabilities with respect to the accuracy and completeness of the contents. Subsequently, the author will also not be held liable or responsible to any individual or entity with respect to any incidental or consequential damages cause, or alleged to have been caused, directly or indirectly, due to the contents herein.

References

1. Golusin M, Popov S, Dodic S (2013) Sustainable energy management, 1st edn, 15 Feb 2013. Oxford Elsevier, ISBN 9780124159785
2. IEA (2014) Key world energy statistics, fuel share of electricity generation from 1973 till 2012. International Energy Agency, Paris, p 24
3. OECD/IEA (2012) CO2 emissions from fuel combustion, World CO2 emissions by sector 2010. International Energy Agency, Paris, p 11
4. UNFCCC (2013) United Nations Framework Convention on Climate Change. Key GHG data, Assessed in 2013, Bonn
5. World Fact-book (2013) Data for 2012, Potomac books. Central Intelligent Agency edn, USA, ISBN 1612346219, 9781612346212
6. Marland, Boden, Anders (2008) Global, Regional and National Fossil-Fuel CO2 Emissions, Period of record 1751–2005. Oak Ridge National Laboratory, TN

Chapter 2
Case Study

2.1 System Introduction

Being the second largest country in the world, Canada has a very diverse landscape, economy, and natural resources. This diversification is also reflected in the strategy to deliver power in different regions of the country. These differences in power generation by source are mainly due to the existing energy resource base in each of its 10 provinces and 3 territories with a total population of around 35.2 million [1] Fig. 2.1.

It can be observed from the above given map that the provinces of Quebec, British Columbia, Manitoba, and Newfoundland rely predominantly on hydropower, whereas Alberta, Nova Scotia, and Saskatchewan use mainly coal. Except one reactor in New Brunswick, all of the nuclear power is produced in Ontario. The province of Prince Edward Island fulfills its power demand partially from its diesel fueled power plant, but is mainly dependent to import power from neighboring provinces [3]. Yukon and Northwest Territories use a mixture of stand-alone diesel generators and hydro power, whereas the territory of Nunavut and almost 300 remote areas communities of country are totally dependent upon diesel fueled power generators [4].

The total power generation of Canada in 2013 was 611.31 Terawatt hours (TWh) in which hydroelectricity remained the primary source of generation accounting for 63.4 % [5] Fig. 2.2.

The electricity demand in Canada was 510.99 TWh in 2013, whereas the net export to USA was 51.95 TWh in the same year. The Canadian industry remained the largest consumer of power with its 38.8 % share [7]. The second largest group of consumers was residential customers followed by commercial consumers. Transportation, agricultural and public administration power consumption remained low in 2013. The graph in Fig. 2.3 shows the configuration of power consumption in different sectors of Canada.

Power generated in Canada is transmitted and distributed by means of multiple interconnected transmission and distribution networks between the provinces.

T. Ahmed, *Modeling the Renewable Energy Transition in Canada*,
SpringerBriefs in Energy, DOI 10.1007/978-3-319-31505-8_2

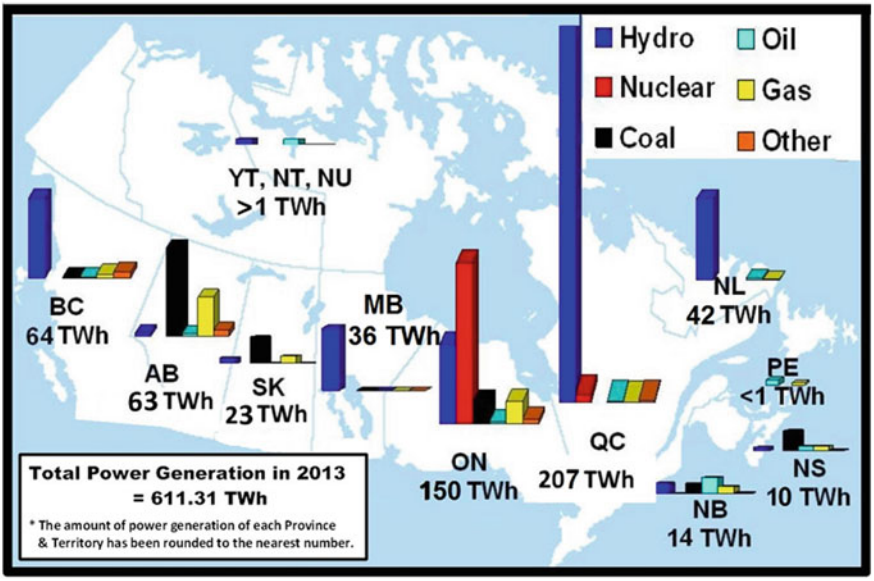


Fig. 2.1 Power generation by source in each province and territory in Canada in 2013 [2]

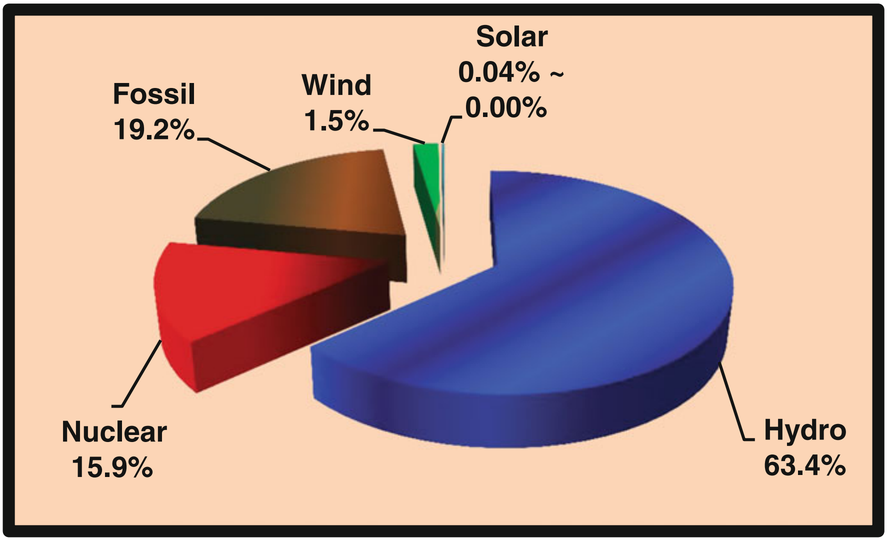


Fig. 2.2 Total power generation by source in Canada in 2013 [6]

In 2013, the transmission system consisted of over 1,00,000 km of transmission lines and the distribution system contained approximately 8,76,509 km of overhead and 1,43,537 km of underground lines [9]. The territories of Yukon, Nunavut, and Northwest as well as small islands and remote areas have no long-distance

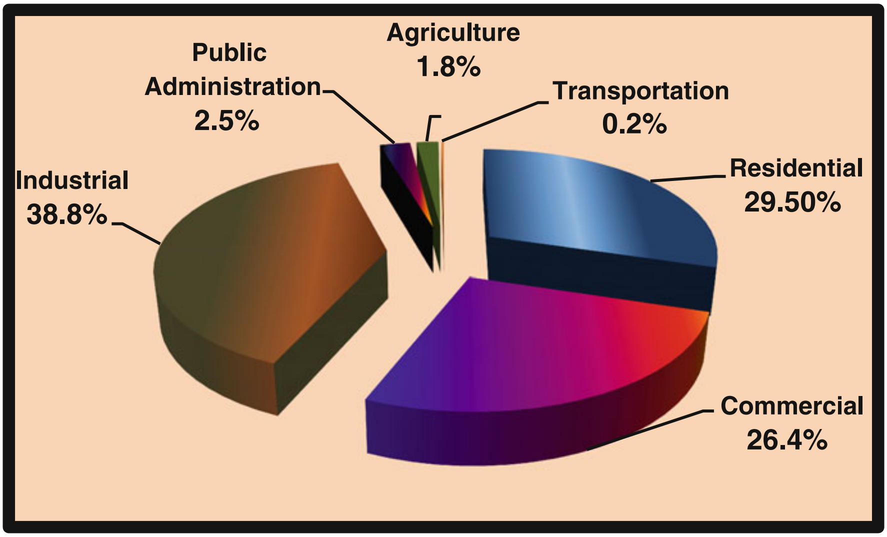


Fig. 2.3 Power distribution in Canada by sector in 2013 [8]

transmission network and interconnection of any kind with other provinces. Many provinces have heavy transmission links in a north–south direction for lucrative power trade between Canada and the United States, instead of having stronger east–west or interprovincial interconnection. For example, the current interconnection between Ontario and Manitoba has only a transmission capacity of 200 MW, whereas the Manitoba-United States interconnection has a transmission capacity of 1850 MW and the Ontario-United States interconnection has a transmission capacity of 3100 MW. As most of the population of Canada is concentrated in a narrow southern belt along the border with the United States, the transmission system of the country is connected with United States via high voltage lines ranging from 69 kV to 765 kV [9] Fig. 2.4.

2.2 Structure of Future Power

The profile history with the combination of increasing population and economic growth indicates that power demand in Canada will continue to grow at an annual rate of 1–2 % [11]. In this regard, various sets of scenarios in different time spans have been described by energy planners in Canada to determine the future electricity landscape in the country. The most recent and authentic scenario was presented by the National Energy Board (NEB) in 2013. According to this scenario, the installed capacity of power generation should be brought from 135 GW in 2013/14 up to 155.5 GW in 2025 [12]. In this scenario, the age of current power

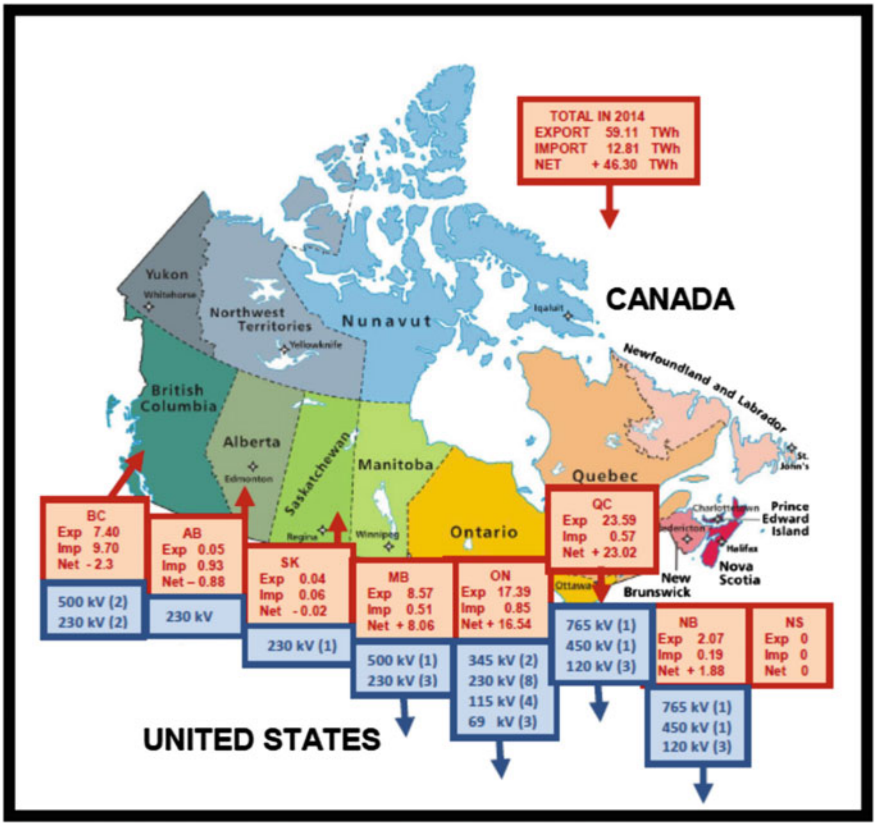


Fig. 2.4 Import/export and transmission capacity between Canada and USA [10]

plants with respect to decommissioning and refurbishment issues, as well as economic factors, have been taken into account by NEB. The quantitative values for future power planning from 2015 to 2025 calculated by policy makers of NEB are shown in Table 2.1 [12].

The data of National Energy Board Model till 2025 (NEBM-2025) given in Table 2.1 will be taken as the prototype in order to draw a techno-economic model for 2025 (TEM-2025) regarding future power generation in Canada. It can be seen from NEBM-2025 that the plan of the National Energy Board is not adequate enough in the framework of global energy competitiveness of the twenty-first century for sustainable power development in Canada. The basic weaknesses can be identified by preliminary investigation of the above-mentioned values. This hypothesis can be demonstrated by making simple comparison between the present installed capacity of power generation and the scenario of power generation capacity to be installed till 2025 as shown in Fig. 2.5.

Table 2.1 National energy board model for 2025 (NEBM-2025) (Planned installed capacity of power generation) [12]

Year	Hydro (MW)	Wind (MW)	Solar (MW)	Nuclear (MW)	Fossil (MW)	Total (MW)
2015	78,955	10,490	3205	13,780	36,778	1,43,208
2016	80,010	11,635	3453	12,415	38,193	1,45,706
2017	80,035	12,332	3573	11,050	38,729	1,45,719
2018	81,314	12,692	3746	10,510	38,899	1,47,161
2019	81,852	12,823	3866	9955	39,678	1,48,174
2020	82,077	13,234	4038	9845	39,219	1,48,413
2021	83,830	13,354	4158	9005	40,089	1,50,436
2022	84,061	13,524	4328	9845	40,629	1,52,387
2023	84,061	13,744	4446	10,145	41,884	1,54,280
2024	84,097	13,914	4613	9305	42,083	1,54,012
2025	84,097	14,134	4728	10,240	42,340	1,55,539

The key drivers of installed capacity in 2013/14 and NEBM-2025 in Table 2.1 show that policy makers of the Canada Energy Board are not adopting the strategies to reduce power generation through fossil fuel. Instead of having a joined-up switching toward strategy-based RES-transition, NEB is endorsing more greenhouse gas (GHG) emitters fossil fueled power plants by increasing its fossil capacity from 37004 MW in 2013/14 to 42340 MW in 2025 by maintaining its share at 27 %. However, the installed capacity of nuclear power will decline simultaneously from 10 to 7 %.

Several key findings of recent research indicate that the world is moving quickly toward energy solutions, predominantly met with RES [18]. In order to address these challenges successfully, it will require a paradigm shift in strategic thinking and public policies. However, such transformation of energy is not foreseeable in NEBM-2025. For instance the hydroelectric power, which is characterized as the most reliable and cost efficient form of RES, is at a declining format from 56 % in 2013/14 to 54 % in 2025 as shown in Fig. 2.5. Besides this, no specific engagement has been launched to raise the perceivable capacity of wind and solar power. There will be only a 3 % growth in wind power till 2025 compared to the level of 2013/14, whereas the increase in solar power will be 2 % during the same period of time. This power configuration of NEBM-2025 will result only in 3 % net growth in RES from 63 % in 2013/14 to 66 % in 2025 as shown in Fig. 2.6.

Figure 2.6 shows that on the one hand, there is a 3 % increase in installed capacity of RES but on the other hand, there will be a 3 % reduction in nuclear power. Moreover, the total share of installed capacity of fossil fueled power plants remained unchanged with some internal fuel shifts, in which 5 % of coal power and 2 % of oil power will be compensated by increasing 7 % share of natural gas power plants. Looking at actual generation data, it can be estimated that the mitigation of GHG emissions with 3 % reduction in nuclear power is by more than 3 % addition

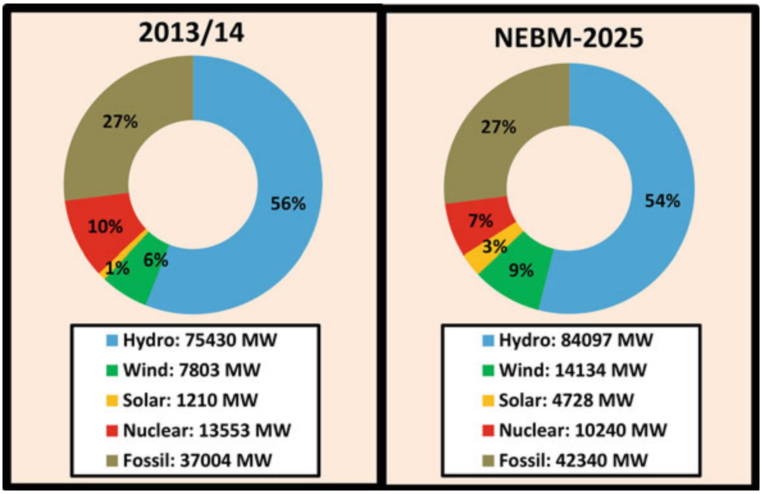


Fig. 2.5 Comparison of installed capacity of future power planning (NEBM-2025) [12, 13–17]

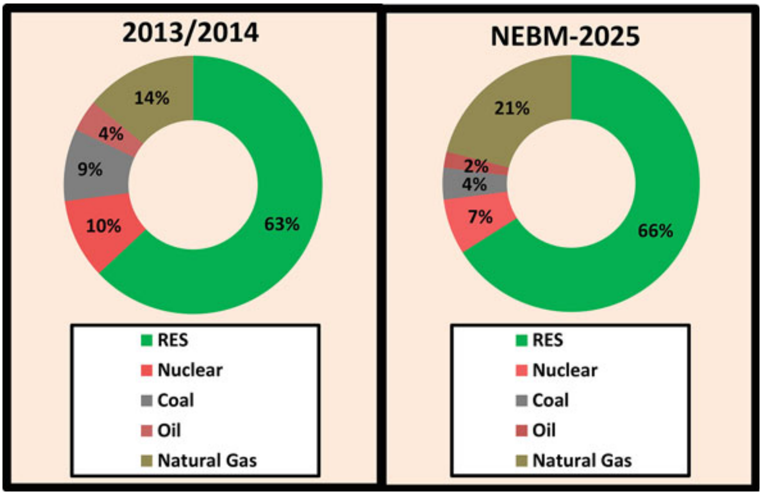


Fig. 2.6 Deployment of fossil and nuclear fuel against RES in NEBM-2025 [12, 13–17]

of wind, PV, and hydro power installed capacity in the future. This is due to the advantage of capacity factor of nuclear power plants compared to capacity factor of wind and PV power. However, there will be some GHG emissions benefits due to 7 % reduction in coal and oil power by compensating it with a 7 % increase in natural gas power generation. In spite of this, the NEBM-2025 can neither contribute to climate change benefits as a whole in the future nor is it compatible with the modern energy solution trends. Hence, the policy makers of Canada should attempt a strategy shift in order to acquire an efficient result that is technically feasible, economically viable, and environmentally acceptable. A key question for designing an alternative model for a transition toward sustainable economy is the availability of technical potential of RES which should be economically achievable. For this purpose, a detailed analysis of RES potential in Canada is a prerequisite.

2.3 RES Analysis

There may be a number of choices to harness RES, but it can be highly constrained due to technical unavailability of production and infrastructure facilities in a particular region [19]. In this work, only that pattern of RES potential will be considered which is decoupled from theoretical potential and is technically and economically feasible.

Canada has a long history of power generation through RES only due to the vital role of hydropower. The first hydroelectric generating station was constructed at Chaudiere Falls in 1891 [20]. The provinces of British Columbia, Manitoba, Quebec, and Newfoundland generate more than 90 % of their electricity from hydropower [21]. The current hydroelectric installed capacity is almost 75,430 MW with more than 500 small and large hydroelectric power plants across the country [13].

As shown in Fig. 2.7, the percentage share of installed capacity of hydropower in Canada is gradually declining. In 1993, the share of hydropower installed capacity was 63 % which declined till 56 % in 2013 and will further fall down to 54 % in 2025 according to the NEBM-2025. At the same time, there is still a 163171 MW of untapped hydropower potential which is technically feasible [23]. Despite all

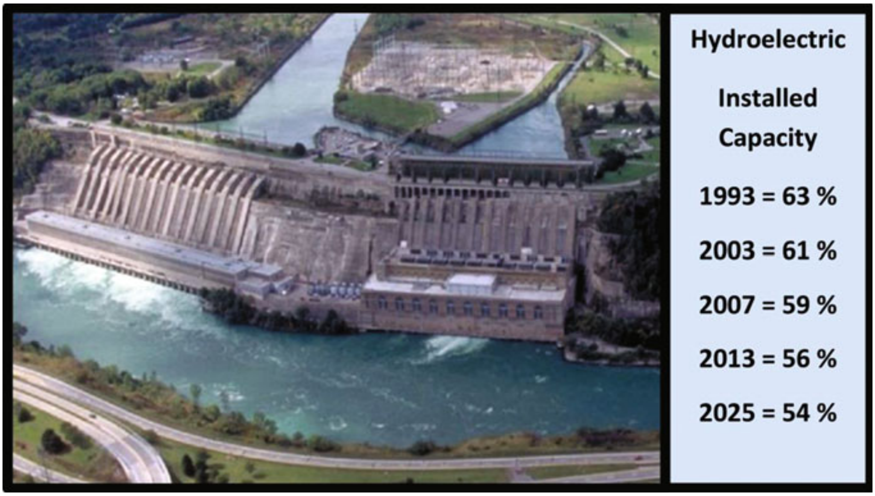


Fig. 2.7 Sir Adam Beck Hydro Power Plant at Niagara Falls [12, 13, 22]

that, hydropower is still a leading technology in Canadian RES installed capacity portfolio with its significant share of 86.9 % [24].

The second largest RES availability after hydropower is wind which is, in contrary to hydropower, in growing phase. The quality of wind resources in Canada is as good or in many cases better than other countries with leading wind capacities like China, United States, and Germany [25]. Alone in the province of Quebec 100,000 MW of wind technical potential exists in the areas that are located within 25 km of existing power transmission lines [25]. At present, 20–30 % of peak demand can be easily fulfilled by wind by creating a technically and economically feasible power planning scenario [25]. About 450 locations having a land area of 5500 km^2 are available across the country to install more than 55,000 MW of wind power [21]. NEBM-2025 shows that government has not taken explicit actions to make wind power installation as a national priority till now. As of December 2014, total installed capacity of wind power in Canada was only 9219 MW with its share of 9.1 % in total energy mix and it will be expanded to 14134 MW in 2025 [12, 17] (Fig. 2.8).

PV systems have been used effectively in Canada to provide power in remote locations for home electricity, transport route signaling, navigational aids, and telecommunication as well as for remote sensing and monitoring. Now the sharp declining cost is the key factor to look for grid connected PV potential in Canada [26]. The installed capacity of PV power in Canada remained relatively small with total of 1210 MW till 2013 [16]. The annual PV potential of south facing tilt PV panel is between 700 and 1400 kWh/kW [27]. In fact, well-populated cities of Canada possess more solar potential as compared to many other cities of the world

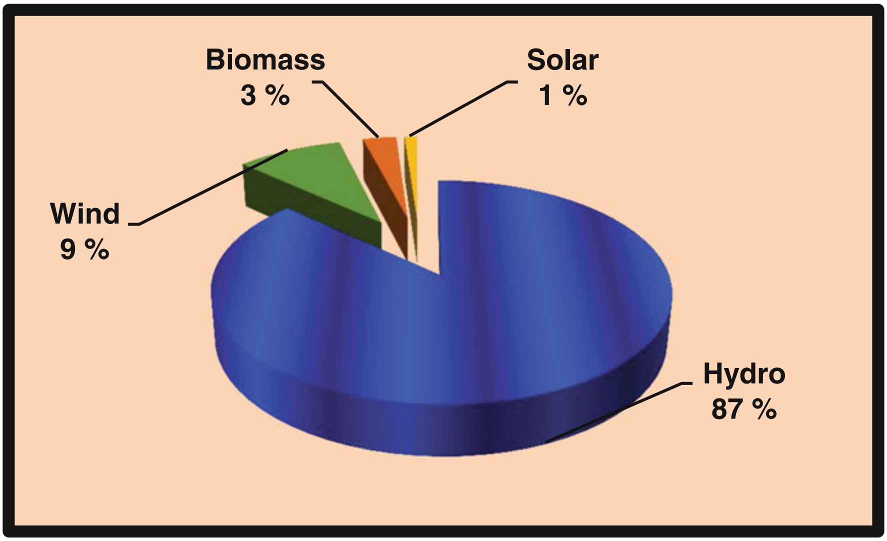


Fig. 2.8 Installed capacity of RES Energy Mix Portfolio—2013/14 [24]

where PV power has been developed with much faster pace than in Canada. For example, Regina (Saskatchewan) has 1361 kWh/kW, Calgary (Alberta) has 1292 kWh/kW, and Toronto (Ontario) has 1161 kWh/kW of solar potential, whereas Beijing (China) has 1148 kWh/kW, Tokyo (Japan) 885 kWh/kW, Berlin (Germany) 868 kWh/kW, and London (England) has 728 kWh/kW of solar potential [28].

It should be noted that Canada has also 2391 MW installed capacity of biomass, 137 MW installed capacity of biogas, and 44 MW installed capacity of municipal solid waste power plants in 2013/14 [24]. This power generation has not been compiled in table and figures of Sects. 1.1 and 1.2 and it will also not be included and analyzed within the context of RES installed capacity and power generation calculations in next chapters. The reason is that biomass, biogas, and municipal waste are only being used by several independent power producers from paper and pulp industry for self-utilization and for district heating. The potential of biomass power generation is tremendously abundant due to the huge magnitude of forests in Canada. Approximately 67 % of landmass in the country consists of forests which include also timber productive forests [29]. Minimum biomass power technical potential has been assessed as 6700 MW [30]. So far, installed capacity of biomass across the country is only 2.9 % within RES [24].

2.4 Findings

In this chapter, the present power system of Canada and the intention of government for future power planning (NEBM-2025) as well as the comprehensive potential of RES have been explained. It is found that the policy makers have not addressed a spectrum of opportunities regarding RES to keep the system up to date according to new challenges in power sector. The information barriers, including lack of awareness about RES among public and power sector stakeholders as well as lack of research about resource locations and potential, seem to be the major reasons.

The authorities in Canada are pursuing a limited approach to address the structural and cost impediments of RES, while the governments of other countries are developing comprehensive strategies to address these barriers. A classic example can be taken from revolutionary steps taken by Germany toward development of RES. German policy makers understood more than a decade ago that an urgent action toward flexible energy transformation only has the potential of economic success. Therefore, an aggressive strategy was developed in the name "Energiewende," translated as "energy transition." Under this program, a substantial deployment of RES has been complied across the residential, commercial, and industrial sectors of country within a decade that boosted more than 68 GW of solar and wind power installed capacity till the end of 2013 [31]. The installed capacity of wind power in Germany was 14.3 GW in 2003 and boosted up to 32.5 GW in 2013 [32]. Overall, there was only 0.4 GW of solar installed capacity in Germany in 2003 which reached 35.7 GW just in 10 years [33]. On the other hand, the installed capacity of wind power in Canada was only 0.3 GW in 2003 which could be increased only up to 7.8 GW till 2013, whereas change in installed capacity of solar power was from 0.01 GW in 2003 to 1.2 GW in 2013 [16, 17]. It means that solar power alone was developed 80 times more in Germany as compared to Canada just in past 10 years. Therefore, the technological ingenuity and initiative of Germans as a response to global climate change, in spite of economic challenges due to RES intermittency, should be fairly recognized. Canadian policy makers should welcome the ideas from Germany and collaborate with the researchers to address the energy-related tough issues to reform their approach.

It must be understood that the landscape of modern energy development and production is changing. There is a need to emphasize that a future without drastic change toward RES can have severe consequences on global climate and environment-related health issues. However, the policy makers in Canada are characterizing this challenge as an existential threat for a conventional power system with an argument that constructions or refurbishments of major hydro facilities are expensive and gas-fired generation can be built more cheaply. The next argument asserts that modern RES like wind and solar power have higher cost than conventional sources of generation, despite having zero fuel costs. Moreover, reliability factor and intermittent nature of RES generation prevent them to undergo most significant changes in power system. Therefore, as seen from NEBM-2025, the power policy makers in Canada will refurbish and rebuild nuclear power plants and will expand the capacity of fossil power plants in future. The reasons for the fossil and nuclear fuel fixation include the usual political gridlock and outsized influence of campaign contribution regarding the highest capital cost of RES. However, only 3 % growth in RES and stagnating share of fossil-fueled power plants for future 10 years can be classified as a futile energy management.

In this context, it is important to overcome the vulnerability of capital cost of RES in order to reengineer the Canadian power generation infrastructure into RES. Moreover, the reliability factor and intermittency of RES should also be addressed. In next chapters, a techno-economic model TEM-2025 regarding power planning till 2025 will be simulated, in which clear, consistent, and stable rules and incentives about RES power generation capital cost and intermittency solutions will be presented. This will allow power sector participants to establish low-price-increase curves with a reasonable degree of certainty. A target will be set to attain the power generation in Canada up to 75 % with RES till 2025 by using abundant indigenous RES potential, especially using hydropower as a base load.

References

1. STC (2013) Demographic growth rate year ending june 30 2013. Government of Canada, Statistics Canada
2. CANSIM (2014) Key Canadian electricity statistics, June 2014, Total electricity generation in Canada (2013), page 1, passage 2; Total electricity generation in Canada by province and type (2013), table page 2 (Background picture source: Environment Canada, Ottawa)
3. Discussion Paper (2012) PEI energy commission, charting our electricity future, February 2012, p 4
4. Ibrahim H, Merabet A, Rajasekaran V (2012) Modeling, simulation and development of supervision control system for hybrid wind diesel system supplying an isolated load. Technical Report, Saint Mary University Halifax, Canada, p 1
5. CEA (2014) Canada's electricity industry, present from Canadian Electricity Association, Ottawa, Canada, p 14
6. Haines A (2015) International electricity summit: Canada Overview, CEA, April 2015, p 3 (Original source: statistics Canada)
7. Statistics (2014) North American industry classification system, Code 91, Statistics Canada CANSIM, Rockaway, USA
8. CANSIM (2014) Key Canadian electricity statistics, June 2014, Total electricity demand in Canada (2013), page 1, passage 1
9. Report (2014) Vision 2050—The future of Canada's electricity system, Canadian Electricity Association, April 2014, Ottawa, Canada
10. CEA (2015) Presentation, Canada's electricity industry, Canada electricity association, Ottawa, p 25, 26 (Original source: National energy board, Canada)
11. STC (2007) Electric power generation, transmission and distribution, Statistics Canada, Catalogue no. 57-202-X
12. NEB (2014) Canada's energy future 2013, Energy supply and demand projection to 2035, An energy market assessment, Nov 2013, National Energy Board. ISSN 2292-1710
13. Statistics (2014) Hydropower installed capacity in Canada. Canadian Hydropower Association, Ottawa, Canada
14. NEB (2014) Canadian energy overview—Energy briefing note, June 2014. ISSN 1917-506X
15. WNA (2014) World Nuclear Association, Nuclear power in Canada, Canada's nuclear operating power reactors, Dec 2014
16. Poissant Y, Luukkonen P (2014) National survey report of PV power application in Canada, Photovoltaic power systems program, Natural Resources Canada, p 8, 9
17. CANWEA (2014) Powering Canada's future, map: Canada's current installed capacity, Dec 2014. Canadian Wind Energy Association, Ottawa, Canada
18. Nelson V (2011) Introduction to renewable energy. CRC Press, Florida, USA. ISBN 978-1-4398-3449-7
19. Lee Willis H, Scott Walter G (2000) Distributed power generation, planning and evaluation. Marcel Dekker Inc., Switzerland. ISBN 0-8247-0336-7
20. Lemieux (2012) Energy Ottawa, Hydro Ottawa completes purchase of chaudiere falls hydroelectric assets, Article of Hydro Ottawa, Nov 22, 2012
21. Conference Report (2013) Canada—A global leader in renewable energy, enhancing collaboration on renewable energy technologies, Energy and mines minister's conference, August 2013, Yellowknife, Northwest Territories, Canada
22. Nyboer (2014) Canadian electricity generation industry 1990 to 2012, CIEEDAC, Canadian Industrial Energy End-use Data and Analysis Centre, March 2014, Simon Fraser University, Burnaby, British Columbia-Canada, (Picture: Ontario Power Generation, Toronto)
23. Report (2008) Hydropower in Canada—Past Present and Future, Library and Archives Canada, p 6. ISBN 978-0-9810346-0-7

24. Nyboer J, Melton N, Goldberg S (2014) Renewable energy in Canada 2013, CIEEDAC, March 2014, p 11 (Original source: CIEEDAC renewable energy database)
25. Report (2013) Wind Vision 2025, Powering Canada's Future, Canada Wind Association, p 10, 11
26. Soteris A. Kalogirou (2009) Solar energy engineering processes and systems, Elsevier London, UK, pp 665–696. ISBN 978-0-12-374501-9
27. PV Map (2013) PV Potential and Insolation, issued on 13.12.2013, Natural Resources of Canada
28. Data (2014) Photovoltaic potential and solar resource maps of Canada, Photovoltaic municipal rankings in terms of yearly PV potential (for South-Facing PV Panels with Latitude tilt), 27 Nov 2014, Natural Resources Canada
29. Wood L (2003) A Canadian biomass inventory: feed-stocks for a bio-based economy, 27 June 2003, BIOCAP canada foundation. Queen's University, Kingston-Canada, p 2
30. Tampier M (2004) Building the Renewable Energy Market in North America, Renewable Energy Potential in Canada, October 28–29, 2004, Presentation from Environmental Intelligence, Montreal-Canada, p 10
31. Burger B (2013) Electricity production from solar and wind in Germany in 2013, Fraunhofer Institute fpr Solar Energy Systems ISE, Freiburg Germany, Presentation on 09 Jan 2014, p 4
32. Report (2004) Wind Report 2004, Wind Year 2003—an overview, E.ON Netz GmbH, Bayreuth-Germany, p 2
33. Mayer J (2013) Results of the PV Grid Research in Germany. The Dutch 20 GW Challenge Amsterdam 17th of May 2013, BSW Solar, German Solar Industry Association, p 5

Chapter 3
Methodological Approach

3.1 Overview

This chapter reviews the addition and subtraction of the installed capacity of power in MW between 2015 and 2025 which is summarized in the National Energy Board Model (NEBM-2025) in Table 2.1. The information in Table 2.1 gives a starting point to determine the quantity of power generation till 2025 and the investment shift from conventional power toward the RES-oriented techno-economic model (TEM-2025). After calculating the capacity factors of all the present power generation sources in the recent years, the quantity of power generation in TWh can be determined in order to calculate the capital investment required for the power shift from fossil and nuclear toward RES. In TEM-2025, the level of required additional power will be maintained for all the years, while accommodating the power growth forecast of the Canadian decision makers as described in NEBM-2025 in the previous chapter. Only the investment in generation side will be taken into account because the generation costs are among the biggest factors affecting the electricity prices although transmission and distribution costs also play an important role. However, a backup power in terms of extra gas power plants will be established due to the intermittent nature of wind and PV power.

3.2 Recalculation of Future Power Planning

As the first step, investigation must be made to establish a base case by considering the future power demand of the entire system and benchmarking it as a key driver for system conditions. From Table 2.1 (Chap. 2), a contingency-installed capacity development forecast of policy makers can be sorted out for nuclear and fossil powers separately. The values of commissioning or refurbishment as well as the

T. Ahmed, *Modeling the Renewable Energy Transition in Canada*,
SpringerBriefs in Energy, DOI 10.1007/978-3-319-31505-8_3

Table 3.1 Calculation of commissioning/refurbishment and decommissioning of nuclear power plants installed capacity till 2025 (Ref. Table 2.1)

Year	Nuclear MW	Power to be retired MW	Power to be added MW	Remaining power MW	Annual power increase MW
2015	13,780	0	0	13,780	0
2016	12,415	−1365	0	12,415	0
2017	11,050	−1365	0	11,050	0
2018	10,510	−540	0	10,510	0
2019	9955	−555	0	9955	0
2020	9845	−110	0	9845	0
2021	9005	−840	0	9005	0
2022	9845	0	+840	9005	840
2023	10,145	0	+300	9005	1140
2024	9305	−840	0	8165	1140
2025	10,240	0	+935	8165	2075
Total	10,240	−5615	+2075	8165	2075

values of decommissioning of nuclear power plants are being estimated from Table 2.1 (Chap. 2) and are summarized in Table 3.1 for 10 years.

Table 3.2 reflects that 5615 MW of nuclear power will be taken out from the system till the year 2025 and 2075 MW of nuclear power is supposed to be added in the system within the same period of time.

In the same way, the calculation of commissioning or refurbishment and decommissioning for fossil-fueled power plants till 2025 can be abstracted from

Table 3.2 Calculation of commissioning/refurbishment and decommissioning of fossil power plants installed capacity till 2025 (Ref. Table 2.1)

Year	Fossil MW	Power to be retired MW	Power to be added MW	Remaining power MW	Power required MW
2015	36,778	0	0	36,778	0
2016	38,193	0	+1415	36,778	1415
2017	38,729	0	+536	36,778	1951
2018	38,899	0	+170	36,778	2121
2019	39,678	0	+779	36,778	2900
2020	39,219	−459	0	36,319	2900
2021	40,089	0	+870	36,319	3770
2022	40,629	0	+540	36,319	4310
2023	41,884	0	+1255	36,319	5565
2024	42,083	0	+199	36,319	5764
2025	42,340	0	+257	36,319	6021
Total	42,340	−459	+6021	36,319	6021

Table 2.1. The result, which is elaborated in Table 3.2, reflects that 459 MW of fossil-fueled power will be taken out of the system till the year 2025 and 6021 MW of fossil-fueled power is supposed to be added within the same period of time. It can be observed that in case of nuclear power, more power is subtracted as compared to power addition, whereas in case of fossil-fueled power plants, more power will be added as compared to the subtraction of power as shown in Table 3.2.

In order to simulate the RES performance-based model (TEM-2025) for the future 10-years power generation plan in Canada, a strategy of fossil and nuclear power reduction and a shift toward RES will be adopted in this research. Under this strategy, a target of 10 % penetration of RES by replacing nuclear and fossil generation will be focused. Based on the installed capacity demonstration in Tables 3.1 and 3.2, the additional nuclear power of 2075 MW will be removed from the system and the additional fossil power of 6021 MW will be considered as standby power by shifting it toward gas power generation technology. It means that 8165 MW of nuclear power and 36319 MW of fossil power will remain in the system till 2025. However, it is important to compensate the quantity of power that should have to be generated from 2075 MW nuclear power plants and 6021 MW fossil power plants in order to meet the demand side forecast till 2025. This compensation of power will be demonstrated by adding RES in the system.

3.3 Data Simulation

The data of power from all the generating sources for year 2013 has been taken as a key driver to calculate the existing capacity factor of hydro, fossil, nuclear, wind, and solar power generation in Canada. The value of present capacity factor plays an important role to determine the quantity of future power generation, future installed capacity, and relevant capital cost of new power plants till 2025. Table 3.3 shows a detail of power generation and the installed capacity for the years 2013–2014.

Table 3.3 Detail of power generation in 2013 (Ref. Figs. 2.2 and 2.5 Chap. 2)

Power Source	Installed capacity in 2013/14 135 GW		Power generation in 2013/14 611.31 TWh	
	Capacity in MW	Capacity in %	Generation in TWh	Generation in %
Hydro	75,430	56	387.64	63
Fossil	37,004	27	121.03	19
Nuclear	13,553	10	88.55	14
Wind	7803	6	12.7	2.1
Solar	1210	1	1.39	0.2

3.3.1 Capacity Factor Calculation

Net Capacity Factor of Hydroelectric Power Plants in Canada in 2013

$$= \frac{387.64\,\text{TWh}}{75430\,\text{MW} \times 760\,\text{h}} = 58\,\% \tag{3.1}$$

Net Capacity Factor of Fossil Power Plants in Canada in 2013

$$= \frac{121.03\,\text{TWh}}{37004\,\text{MW} \times 8760\,\text{h}} = 37\,\% \tag{3.2}$$

Net Capacity Factor of Nuclear Power Plant in Canada in 2013

$$= \frac{88.55\,\text{TWh}}{13553\,\text{MW} \times 8760\,\text{h}} = 75\,\% \tag{3.3}$$

Net Capacity Factor of Wind Power Plant in Canada in 2013

$$= \frac{12.7\,\text{TWh}}{7803\,\text{MW} \times 8760\,\text{h}} = 19\,\% \tag{3.4}$$

Net Capacity Factor of PV Power Plant in Canada in 2013

$$= \frac{1.39\,\text{TWh}}{1210\,\text{MW} \times 8760\,\text{h}} = 13\,\% \tag{3.5}$$

3.3.2 Power Generation Calculation for 2025

From Table 3.1, it can be seen that after the decommissioning of some nuclear power plants, the nuclear power will remain 8165 MW till 2025. On the other hand, some nuclear power plants will be refurbished or newly constructed which will add 2075 MW of nuclear power to the system till 2025. As the techno-economic model (TEM-2025) presented in this thesis will consist of more RES and possibly less nuclear and fossil power, 2075 MW of nuclear power will not be added in this model. However, this power should be compensated through RES. For this purpose, the quantity of power, that would have to be generated from additional nuclear power according to policy makers of Canada, must be calculated with respect to the capacity factor of the nuclear power plants. The quantity of this nuclear power generation is shown in Eq. 3.6:

$$75\,\% \times 2075\,\text{MW} \times 8760\,\text{h} = 13.63\,\text{TWh} \tag{3.6}$$

In the same way, Table 3.2 shows that the retirement of some fossil power plants will reduce the fossil power down to 36,319 MW till 2025. At the same time, 6021 MW of fossil power has to be added in the system to keep the system running. This additional power will also be compensated with RES in TEM-2025. Hence, the quantity of fossil fuel will be calculated according to the capacity factor of fossil fuel in Canada as following:

$$37\,\% \times 6021\,\mathrm{MW} \times 8760\,\mathrm{h} = 19.52\,\mathrm{TWh} \tag{3.7}$$

By adding Eqs. 3.6 and 3.7, total addition of power generation till 2025 will be as following:

$$13.63\,\mathrm{TWh} + 19.52\,\mathrm{TWh} = 33.15\,\mathrm{TWh} \tag{3.8}$$

Equation 3.8 shows that 33.15 TWh power must be generated through RES from 2015 to 2025 in order to compensate the additional nuclear and fossil power that otherwise would have to be added in Canadian power system.

3.4 Cost Profile and Power Adjustment

The current and future projected cost and performance characteristics of new power capacity are critical input into the development of RES projections and analysis. Several steps are necessary to estimate the level of investment that is likely to be required over the coming 10 years. Generation of power through RES is a capital-intensive business and it is extremely difficult to finance a RES project. The financial barrier remains the most significant obstacle toward RES shift in Canada today. But at the same time, the main cost of producing power from RES is the capital cost rather than the operating cost. That means that the cost of power from RES is more predictable than the cost of the power from fossil fuels. This is an important factor for mitigation of electricity price shifts. Within RES, the cost of power varies by its type, power availability, and technical maturity. In TEM-2025, only the mature RES like hydropower, wind, and PV will be considered because these technologies are accounted for proven market investment.

A detailed research has been performed in this study for economically feasible projects throughout Canada in order to determine the investment for power generation from RES between 2015 and 2025. Equations 3.6 and 3.7 from Sect. 3.3 have specified the level of power generation that should have been produced in case of addition of fossil and nuclear power plants till 2025 (Table 3.4).

Table 3.4 Additional power planned by NEB till 2025 (Ref. Tables 3.1 and 3.2)

Power to be added (2015–2025)	Installed capacity (MW)	Level of power generation (TWh)
Fossil	6021	19.52 (from Eq. 3.7)
Nuclear	2075	13.63 (from Eq. 3.6)
Total	8096	33.15 (from Eq. 3.8)

3.4.1 RES Intermittency Control Costs

The most important and disturbing factor of power generation with RES like wind and PV is that these RES have extreme intermittent nature and the world is accustomed to reliable on-demand electricity. The only way to turn naturally fluctuating wind and PV power into a dispatched power is to have some storage capacity or standby power to take up the slack. Natural gas power plants are fine solution to overcome this intermittency by ramping up and down to accommodate wind and PV fluctuation. Therefore, the fossil-installed capacity of 6021 MW will not be removed in TEM-2025. This capacity will be constructed as a standby power in the form of natural gas power plants. The funds to construct these power plants are already allocated in the power planning of policy makers in Canada. It yields that a level of 19.52 TWh (Eq. 3.7) of power generation will be available as a standby power in order to overcome the intermittency of wind and PV between 2015 and 2025.

3.4.2 Capital Costs Shift from Nuclear Power into Hydropower

Costs of nuclear and hydropower plants have been estimated using a consistent methodology that includes a broad project scope with direct and indirect costs. The cost figures of different studies in this region were not matching with one another due to the implementation of different approaches used for cost estimation. Therefore, only site-specific capital costs or overnight costs of the planned 2075 MW of nuclear power projects were evaluated with different parameters which gives an average value of 6.1 million CDN $/MW till 2025 [1].

Capital cost needed to construct 2075MW nuclear power till 2025:

$$2075\,\text{MW} \times 6.1\,\text{million CDN \$/MW} = 12657.5\,\text{million CDN \$} \tag{3.9}$$

Large- and small-scale hydropower plants with storage capabilities are perfect matches for quick response power management and are the main focus of TEM-2025. As the model of this thesis excludes new nuclear power addition between 2015 and 2025, the cost calculated in Eq. 3.9 should be diverted toward the construction of new hydropower plants. The capital cost or overnight cost of new hydropower is 3.469 million CDN $/MW and funds available for new hydropower construction are 12657.5 million CDN $ (Eq. 3.9). With this amount, the following quantity of hydropower can be brought to Canadian gird till 2025 [1].

Hydroelectric power plants (2015–2025)

$$= \frac{12657.5\,\text{million CDN \$}}{3.469\,\text{million CDN \$/MW}} = 3649\,\text{MW} \tag{3.10}$$

Estimated annual power production from additional hydroelectric power plants between 2015 and 2025:

$$58\,\% \times 3649\,\text{MW} \times 8760\,\text{h} = 18.54\,\text{TWh} \tag{3.11}$$

Equation 3.9 shows that the policy makers in Canada have planned to invest 12657.5 million CDN $ to establish 2075 MW of new nuclear power stations between 2015 and 2025. This amount has now been replaced to build 3649 MW (Eq. 3.10) of extra hydropower plants that will produce annually 18.54 TWh (Eq. 3.11) of hydropower in this model. The value of the remaining power which is required to replace future nuclear- and fossil-generated power into RES power can be calculated as following:

$$33.15\,\text{TWh}\ (\text{Eq. 3.3}) - 18.54\,\text{TWh}\ (\text{Eq. 3.6}) = 14.61\,\text{TWh} \tag{3.12}$$

It means that 14.61 TWh of power is needed to be produced from RES to compensate the power gap till 2025. It is being suggested in the next sections of this chapter to adjust this power by means of clusters of wind and PV power generation as following:

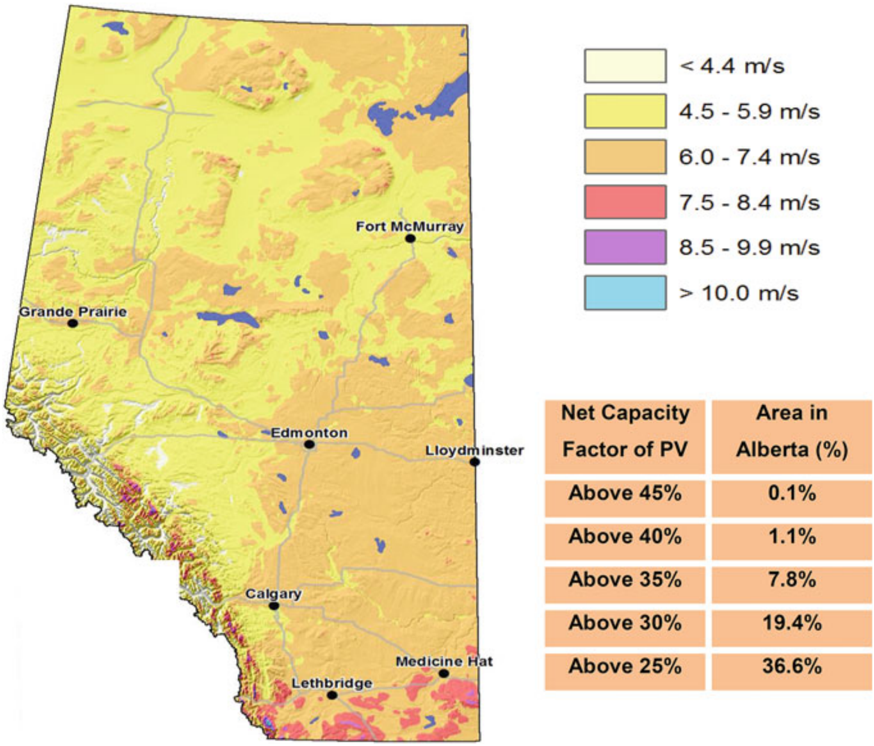
$$\text{Wind power} = 10\,\text{TWh} \tag{3.13}$$

$$\text{PV Power} = 4.61\,\text{TWh} \tag{3.14}$$

3.5 Wind Power Integration

Wind energy has now established itself as a mainstream technology and it can play a key role to present the future vision of power production with RES in Canada [2]. There are several provinces in Canada which have not taken serious steps to reduce using fossil fuel and to install a significant quantity of green power. The province of Alberta is generating 85 % of its electricity from fossil fuels and intends to keep on burning it for decades [3]. Therefore, it is compulsive for this province to act more quickly to replace at least a part of its power production with wind.

Figure 3.1 shows the wind speed and capacity factor data that has been recorded by the Environmental Department of Canada at different recording stations in Alberta. This data is available for approximately 160 sites across the province [4]. After quantifying this data with all its physical constraints, different factors of wind resource map can be demonstrated by using a representative wind turbine with an



Net Capacity Factor of PV	Area in Alberta (%)
Above 45%	0.1%
Above 40%	1.1%
Above 35%	7.8%
Above 30%	19.4%
Above 25%	36.6%

Fig. 3.1 Wind speed and net capacity factor in Alberta at 80 m [4]

80-meter hub height and a 113-meter rotor [4]. It can be observed from Fig. 3.1 that Alberta has a massive potential of wind power generation. It is estimated that over 35 % of land area in the province has a potential of almost 150 GW of wind power capacity [4].

As of December 2014, the wind-installed capacity of Alberta was only 1471.1 MW [5]. Germany with a land mass half the size of the province of Alberta had 35678 MW of installed wind power capacity in November 2014 which is 24 times more as that of the present wind power capacity in Alberta [6]. Hence, the high-quality wind potential of Alberta regarding net capacity factor can be harnessed to replace the older fossil fuel units that are close to their retirement age. For this purpose, the above-mentioned net capacity factor and speed values are used to set up a scenario. Net capacity factor of 35 % is taken from wind potential guidelines to landmark the technically feasible sites to construct multiple wind farms [4]. The available wind speed data has been then combined with the selected net capacity factors to compile the best result [7]. After spatial analysis, a target of 10 TWh (Eq. 3.8) power is easily achievable through wind sources within a period of 10 years.

Required installed capacity to produce 10 TWh of electricity with a capacity factor of 35 % will be:

$$= \frac{10\,\text{TWh}}{35\,\% \times 8760} = 3262\,\text{W} \tag{3.15}$$

The current cost estimate of onshore wind turbine installation is 1.98 million CDN $/MW [1]. Therefore, an incremental capital investment for wind integration scenario between 2015 and 2025 will be:

$$\begin{aligned} &= 1.98\,\text{Million CDN}\ \$/\text{MW} \times 3262\,\text{MW} \\ &= 6459\,\text{Million CDN}\ \$ \end{aligned} \tag{3.16}$$

Equation 3.16 shows that an investment of 6459 million CDN $ is required to establish 3262 MW of installed capacity of wind power throughout Canada. This cluster of wind farms will generate a total of 10 TWh of electric power annually.

3.6 PV Power Integration

The final step to integrate the RES in Canadian system is the integration of PV by setting the appropriate data. The PV deployment system model can be developed by simulating the potential adoption of photovoltaic in different geospatially rich regions of Canada. The second and most important factor to be considered is the combination of the solar resource regions with the regions of high electricity price, especially those areas where diesel generators are being used to generate the power. The solar resources have been estimated by using mesoscale resources nearby more than 175 communities in Alberta, Ontario, Saskatchewan, Manitoba, Prince Edward Island, Nova Scotia, Yukon, and Northwest Territories [8]. After the examination of market competitiveness of regional solar resources, capital costs, electricity prices, utility rate structures, the following 12 regions were selected as a muster for grid-connected PV farms.

From all these PV-rich regions that are identified in Table 3.5, almost 175 solar parks can be assumed to be utilized. To make this study simple, an average annual potential of all these numerous projects in 12 regions can be taken as a reference potential. It means that the solar potential of each solar park will be the average potential of all the selected regions and it will be considered as a reference potential to be replicated for all these 175 solar parks.

Average annual PV potential of identified 12 regions in Canada will be:

$$= \frac{15201\,\text{Wh/kW}}{12} = 1267\,\text{kWh/kW} \tag{3.17}$$

Table 3.5 PV hotspots in terms of annual PV potential for south-facing panels [9]

Region	Annual PV potential kWh/kW	Region	Annual PV potential kWh/kW
Regway SK	1384	Lethbridge AB	1331
Wild Horse AB	1373	Thunder Bay ON	1226
Waskada MB	1370	Miminegash PE	1136
Medicine Hat AB	1367	Fort Smith NT	1126
Regina SK	1361	Amherst NS	1125
Saskatoon SK	1346	Burwash YT	1056

Even under standard irradiance and temperature conditions or under standard test conditions (STC), the impact of losses like inverter efficiency, dirt and dust on PV collectors, mismatched modules, and differences in ambient conditions can derate the power output by 20–30 % and reduce the conversion efficiency of PV system [10]. After the loss calculations of PV module for these specific regions, the conversion efficiency in this case will be considered as 74.7 %.

$$\begin{aligned} P_{ac} &= P_{dc(STC)} \times 74.7\,\%\, P_{ac} \\ &= 1267\,\mathrm{kWh/kW} \times 74.7\,\%\, P_{ac} \\ &= 946\,\mathrm{kWh/kW} \end{aligned} \tag{3.18}$$

This predicted power output will be used to calculate the PV-installed capacity for targeted power output which is 4.61 TWh (Eq. 3.14). This value is the remaining part for the integration of RES in Canadian power system.

Required PV Capacity to be installed

$$= \frac{4.61\mathrm{TWh}}{946\,\mathrm{kWh/kW}} = 4873\ \mathrm{MW} \tag{3.19}$$

Obtained Net PV Capacity Factor of Solar PV Park

$$= \frac{4.61\,\mathrm{TWh}}{4873\,\mathrm{MW} \times 8760\,\mathrm{h}} = 10.8\,\% \tag{3.20}$$

It means that 4873 MW of PV power capacity has to be installed throughout Canada within the period of 10 years in order to produce 4.61 TWh of sustainable power per annum with a net capacity factor of 10.8 %.

The general downward trend in PV system pricing has continued in the recent years and will continue in the near future [11]. After comparative analysis of the capital cost of PV for solar park, the cost of ground-mounted PV power in 2014 was

1.55/W and it will reduce to 1.16/W till 2020 [12]. The upper-level price factor has been considered as reference price to mitigate the cost–uncertainty risk. Therefore, the capital cost to establish solar PV parks in solar-rich regions throughout Canada will be as follows:

Capital Cost of PV Power between 2015 and 2025

$$\begin{aligned} &= 4873\,\text{MW}\ (\text{Eq. } 3.19)\ \times\ 1.55\ \text{CDN\$}\,/\text{W}\ [6\text{a}] \\ &= 7553\,\text{Million CDN}\,\$(3.21) \end{aligned} \tag{3.21}$$

Equation 3.21 shows that an investment of 7553 million CDN $ is required to establish the 4873 MW installed capacity of PV power throughout Canada. This will generate 4.61 TWh of electric power annually with the capacity factor of 10.8 %.

3.7 Synopsis

In this chapter, it has been found that NEB is planning to add 2075 MW (Table 3.1) of nuclear power and 6021 MW (Table 3.2) of fossil power in the system. This combined capacity should produce 33.15 TWh (Eq. 3.8) of electricity in order to fulfill the demand side management till 2025.

According to techno-economic model (TEM-2025) presented in this research, the investment of fossil-fueled power plants has been used to build 6021 MW (Table 3.2) of gas power plants which will produce 19.52 TWh (Eq. 3.7) standby power to mitigate the risk of intermittency for additional RES at this stage. The investment of 12657.5 million CDN $ (Eq. 3.9) which was needed for nuclear power addition has been shifted to build 3649 MW (Eq. 3.10) of hydropower which will produce 18.54 TWh (Eq. 3.11) of electricity. To fulfill the gap of the remaining 14.61 TWh (Eq. 3.12) of power production, 3262 MW (Eq. 3.15) of wind power will be installed to produce 10 TWh (Eq. 3.13) and 4873 MW (Eq. 3.19) of PV will be installed to produce 4.61 TWh (Eq. 3.14).

In order to build 3262 MW wind power, a long-term, low-cost investment of 6459 million CDN $ (Eq. 3.16) is needed. In the same manner, an investment of 7553 million CDN $ (Eq. 3.21) is required for the installation of PV power. The policy makers in Canada cannot provide these investments because they are already facing fiscal constraints and still-recovering financial system. To meet this challenge, a techno-economic financial model (TEM-2025) will be simulated in the next chapter.

References

1. Cost Report (2012) Cost and performance data for power generation technologies, national renewable energy laboratory, Feb 2012, Black and Veatch, Overland Park, USA, pp 10 (Nuclear), 34 (Hydro), 46 (Wind)
2. Ackermann T (2005) Wind power in power systems. West Sussex, England. ISBN 13:978-0-470-85508-9 (H/B)
3. Report (2014) Alberta's future energy mix: exploring the potential for renewables, Feb 2014, Issue 3, KPMG, Calgary, Alberta-Canada
4. Project Report (2013) Alberta wind vision technical overview report, the canadian wind energy association, Version 2.0, May 2013, Ottawa-Canada, pp 10–11
5. CANWEA (2015) Canada's current installed capacity wind map as of Dec 2014, Canada wind energy association, Info map issued in January 2015, Ottawa-Canada
6. Presentation (2014), Electricity production from solar and wind in Germany in 2014, Presentation from Prof. Dr. Bruno Burger, 29 Dec 2014, Frauenhofer Institute for Solar Energy Systems ISE, Freiburg-Germany
7. Ali MH (2012) Wind energy systems, solutions for power quality and stabilization. CRC Press, Florida, USA. ISBN 978-1-4398-5614-7
8. Report (2012)Sector profile for solar photovoltaics in Canada, Navigant Consulting, Inc., 29 March 2012, Toronto, Ontario, 2012-063 (RP-TEC), pp 18–27
9. NRC (2014), Photovoltaic Potential and solar resource maps of Canada, Photovoltaic Municipal ranking in terms of Yearly PV potential (for South-Facing PV Panels with Latitude tilt), Natural Resources Canada, 27 Nov 2014, Ottawa-Canada
10. Markvart T, Castaner L (2005) Practical handbook of photovoltaics, fundamentals and applications. Elsevier, Oxford, UK, pp 565–584. ISBN 1 85617 390 9 (British Library)
11. Markvart T, Castaner L (2005) Solar cells materials, manufacture and operation. Elsevier, Netherlands. ISBN 13:978-1-85617-457-1
12. Chase J (2014) Levelised cost of electricity—PV, H1-2014. Presentation for Bloomberg, Feb 2014, New York, USA, p 4

Chapter 4
Energy Management with RES

4.1 Summary

This chapter presents a techno-economic model (TEM-2025) to achieve a target of 10 % increase in RES share within the period of 10 years without involving any state investment in Canada. It will give the detail of power planning for each year between 2015 and 2025 and the respective investment plans for RES power generation in Canada according to the future energy demand. At the same time, the power generation and installed capacity planning with respective power addition from the prospective of policy makers in Canada have also been shown for each year between 2015 and 2025. This is the power planning from the side of National Energy Board of Canada called here as NEBM-2025, in which the existing power generation infrastructure has been sustained and renewed. As shown in the tables of Sect. 4.2, the cutting down of fossil and nuclear additional power will take place from NEBM-2025 and the same magnitude of power will be compensated in TEM-2025 by accommodating the anticipated power growth in the form of RES. Under this plan, a sufficient amount of gas power plants will be kept as a source of extra or standby power to meet the challenges of behavioral shifts in future energy management such as to overcome the intermittency of wind and solar power. The capital costs of RES have been managed by imposing a slight increase of electricity price for a few years. After that, the price increase will fall down to its original level.

The online software HOMER was used for optimal result in order to develop a mathematical model of power generation, in which only a simple power balance equation was assumed without any representation of grid connection [1]. With sufficient data collection, a power generation profile will be mapped within the framework of time function which is 10 years in this case. The values of power generation installed capacity mix from policy makers can be analyzed statistically

T. Ahmed, *Modeling the Renewable Energy Transition in Canada*,
SpringerBriefs in Energy, DOI 10.1007/978-3-319-31505-8_4

with reference to addition of RES and subtraction of fossil and nuclear power till 2025. After exposure of all features, an RES energy management decision-making scenario can be developed. In this regard, effective generation capacity and price modeling can be simulated on the software HOMER. With the help of HOMER, all possible configurations of installed capacity and generation mode with feasible investment and kWh price can be calculated in different time frames. The strategies to create an optimal design with least cost will be illustrated in this model.

4.2 Planning Computation Methodology

This section presents the results of different power production levels for which data is collected for 10 years and compiled in the form of detailed tables which are shown in the next pages of this chapter.

In the table of year 2015, no change has been shown between the proposed TEM and the existing National Energy Board Model (NEBM). The power plants from point 1 (hydro) to point 5 (solar) will be brought online according to the planning. There will be no extra power or power addition from point 6 (fossil Addition) to point 11 (extra RES). The capacity factors (CF) of the power plants from point 1 to point 8 and point 13 will be extracted from the capacity factors calculated from power generation in the year 2013. Total installed capacity (143208 MW) and total power production (632 TWh) for NEBM are same as that of TEM for 2015 as shown in point 12. The power consumption (point 15) forecast has been taken from the assessment hierarchy of policy makers and it will be the 83.59 % of total power production which is calculated with reference to the ratio of power production and consumption in 2013 [2]. A part of remaining 16.41 % of produced power will be exported to USA and another part of this power will be exhausted in the form of transmission and distribution losses [3]. The power consumption values will coincide with one another in both the TEM and NEBM cases throughout the 10-year power planning scenarios (Table 4.1).

The capacity factor (CF) of the existing wind power is 19 % (point 4) and it will be kept same for 10 years in case of NEBM; however, the capacity factor of the new wind addition in case of TEM has been taken as 35 %. This value has been considered after proving it viable in wind-rich areas by simulating these values in HOMER. The CF of solar in NEBM will remain 13 % but the CF of PV in TEM has been reduced down to 10.8 %. The reason is that all PV parks in TEM have not been planned in solar peak areas but the other factors like the areas producing power with diesel generators have also been taken into account.

According to NEBM in Table 4.2, 1415 MW of fossil power should be added into system in 2016 (point 6). In the proposed techno-economic (TEM) model, this power will be added in the form of gas-fueled power plants and will act as a standby power (point 13). The power generation from 1415 MW in NEBM should be

Table 4.1 Power planning scenario for year 2015

Power source	Power 2015 (NEBM) (policy-makers model)		Power 2015 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	78,955	401.2	78,955	401.2
2. Fossil (existing CF: 37 %)	36,778	119.2	36,778	119.2
3. Nuclear (existing CF: 75 %)	13,780	90.5	13,780	90.5
4. Wind (existing CF: 19 %)	10,490	17.5	10,490	17.5
5. Solar (existing CF: 13 %)	3205	3.6	3205	3.6
6. Fossil addition (CF: 37 %)	0	0	0	0
7. Nuclear addition (CF: 75 %)	0	0	0	0
8. Hydro addition (CF: 58 %)	0	0	0	0
9. Wind addition (CF: 35 %)	0	0	0	0
10. Solar addition (CF: 10.8 %)	0	0	0	0
11. Extra RES: (for existing gas PP)	0	0	0	0
12. Total installed capacity: total power production:	1,43,208	632	1,43,208	632
13. Standby power: gas (CF: 37 %)	0	0	0	0
14. Total power achieved	1,43,208	632	1,43,208	632
15. Total power consumption: (632 × 83.59 %)	528.29 TWh		528.29 TWh	

4.6 TWh. The same amount of power generation will be compensated in the form of 1305 MW of wind power and 634 MW of solar power in the proposed TEM as shown in points 9 and 10 of Table 4.2. The simulation has been programmed in a way that end-power-production in both models (NEBM and TEM) remains the same (point 12) which is 635.20 TWh in 2016. In case of any deviation of power in TEM due to the intermittency of RES, an equal amount of power will be available immediately from the gas-fueled power plants which, otherwise, play the role of standby power (point 13). It means that the total achievable power in TEM will be more than the achievable power of NEBM (point 14). In the same way, in years 2017, 2018, 2019, and in 2021, further fossil power will be added in NEBM which will be compensated with RES in TEM and the added power will be shifted to gas-fueled standby power. In years 2022, 2023, and 2025, a total amount of 2075 MW of nuclear power will be added in NEBM. This nuclear power will not be added in TEM but instead of this, RES will be added in the system in a way that equal amount of power from RES could be achieved as it would have been achieved through nuclear power in NEBM (Tables 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, and 4.10).

Table 4.2 Power planning scenario for year 2016

Power source	Power 2016 (NEBM) (policy-makers model)		Power 2016 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	80,010	406.5	80,010	406.5
2. Fossil (existing CF: 37 %)	36,778	119.2	36,778	119.2
3. Nuclear (existing CF: 75 %)	12,415	81.6	12,415	81.6
4. Wind (existing CF: 19 %)	11,635	19.4	11,635	19.4
5. Solar (existing CF: 13 %)	3453	3.9	3453	3.9
6. Fossil addition (CF: 37 %)	1415	4.6	0	0
7. Nuclear addition (CF: 75 %)	0	0	0	0
8. Hydro addition (CF: 58 %)	0	0	0	0
9. Wind addition (35 %)	0	0	1305	4
10. Solar addition (10.8 %)	0	0	634	0.6
11. Extra RES: (for existing gas PP)	0	0	0	0
12. Total installed capacity: total power production	1,45,706	635.2	1,46,230	635.2
13. Standby: gas (CF: 37 %)	0	0	1415	4.6
14. Total achievable power	1,45,706	635.2	1,47,645	639.8
15. Total power consumption: (635.2 × 83.59 %)	530.9 TWh		530.9 TWh	

It can be seen from Table 4.11 that the policy makers of Canada want to plan a model (NEBM-2025), in which 6021 MW (point 6) of fossil fuel and 2075 MW (point 7) of additional nuclear power will be added into the system. A techno-economic model (TEM-2025) proposed in this work shows that the 6021 MW of fossil power will only be constructed in the form of gas-fueled power plants and will be used as a standby power. Moreover, 802 MW of existing gas power plants will also act as standby power. The total of 6823 MW (point 13) of standby gas-fueled power plants have the ability to produce 22.10 TWh, which is sufficient to mitigate the intermittency of wind and PV power. The nuclear power addition of NEBM has not been included in TEM. The target of 3649 MW of hydroelectric power (Eq. 3.10, Chap. 3), 3262 MW of wind power (Eq. 3.15, Chap. 3), and 4873 MW of PV power (Eq. 3.19, Chap. 3) has been achieved in TEM-2025 which is shown in Table 4.11, points 8, 9, and 10. In order to achieve the objective of 10 % increase in RES, an additional power of 4.1 TWh was needed to include in TEM-2025. This power has been added in the form of 483 MW of wind power and 503 MW of hydroelectric power as mentioned in points 11a and 11b of Table 4.11.

Table 4.3 Power planning scenario for year 2017

Power source	Power 2017 (NEBM) (policy-makers model)		Power 2017 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	80,035	406.6	80,035	406.6
2. Fossil (existing CF: 37 %)	36,778	119.2	36,778	119.2
3. Nuclear (existing CF: 75 %)	11,050	75.6	11,050	75.6
4. Wind (existing CF: 19 %)	12,332	20.5	12,332	20.5
5. Solar (existing CF: 13 %)	3573	4.1	3573	4.1
6. Fossil addition (CF: 37 %)	1415 + 536 = 1951	4.6 + 1.7 = 6.3	0	0
7. Nuclear addition (CF: 75 %)	0	0	0	0
8. Hydro addition (CF: 58 %)	0	0	0	0
9. Wind addition (35 %)	0	0	1305 + 326 = 1631	4 + 1 = 5
10. Solar addition (10.8 %)	0	0	634 + 740 = 1374	0.6 + 0.7 = 1.3
11. Extra RES: (for existing gas PP)	0	0	0	0
12. Total installed capacity: total power production	1,45,719	632.3	1,47,504	632.3
13. Standby: gas (CF: 37 %)	0	0	1951	6.3
14. Total achievable power	1,45,719	632.3	1,49,455	638.6
15. Total power consumption: (632.3 × 83.59 %)	528.54 TWh		528.54 TWh	

Table 4.4 Power planning scenario for year 2018

Power source	Power 2018 (NEBM) (policy-makers model)		Power 2018 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	81,314	413.1	81,314	413.1
2. Fossil (existing CF: 37 %)	36,778	119.2	36,778	119.2
3. Nuclear (existing CF: 75 %)	10,510	69.1	10,510	69.1
4. Wind (existing CF: 19 %)	12,692	21.1	12,692	21.1
5. Solar (existing CF: 13 %)	3746	4.3	3746	4.3
6. Fossil addition (CF: 37 %)	1951 + 170 = 2121	6.3 + 0.6 = 6.9	0	0
7. Nuclear addition (CF: 75 %)	0	0	0	0
8. Hydro addition (CF: 58 %)	0	0	118	0.6
9. Wind addition (CF: 35 %)	0	0	1631	5
10. Solar addition (CF: 10.8 %)	0	0	1374	1.3
11. Extra RES: (for existing gas PP)	0	0	0	0
12. Total installed capacity: total power production	1,47,161	633.7	1,48,550	633.7
13. Standby: gas (CF: 37 %)	0	0	2121	6.9
14. Total achievable Power:	1,47,161	633.7	1,50,671	640.6
15. Total power consumption: (633.7 × 83.59 %)	529.62 TWh		529.62 TWh	

Table 4.5 Power planning scenario for year 2019

Power source	Power 2019 (NEBM) (policy-makers model)		Power 2019 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	81,852	415.9	81,852	415.9
2. Fossil (existing CF: 37 %)	36,778	119.2	36778 − 247 = 36531	119.2 − 0.8 = 118.4
3. Nuclear (existing CF: 75 %)	9955	65.4	9955	65.4
4. Wind (existing CF: 19 %)	12,823	21.3	12,823	21.3
5. Solar (existing CF: 13 %)	3866	4.4	3866	4.4
6. Fossil addition (CF: 37 %)	2121 + 779 = 2900	6.9 + 2.5 = 9.4	0	0
7. Nuclear addition (CF: 75 %)	0	0	0	0
8. Hydro addition (CF: 58 %)	0	0	118 + 394 = 512	0.6 + 2 = 2.6
9. Wind addition (CF: 35 %)	0	0	1631	5
10. Solar addition (CF: 10.8 %)	0	0	1374 + 529 = 1903	1.3 + 0.5 = 1.8
11. Extra RES (Wind CF: 35 %) (for existing gas PP)	0	0	256	0.8
12. Total installed capacity: total power production	1,48,174	635.6	1,49,705	635.6
13. Standby power (CF: 37 %) (new gas PP—old gas PP)	0	0	2900 + 247 = 3147	9.4 + 0.8 = 10.2
14. Total power achieved	1,48,174	635.6	1,52,852	645.8
15. Total power consumption: (635.6 × 83.59 %)	531.30 TWh		531.30 TWh	

Table 4.6 Power planning scenario for year 2020

Power source	Power 2020 (NEBM) (policy-makers model)		Power 2020 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	82,077	417	82,077	417
2. Fossil (existing CF: 37 %)	36,319	117.7	36,319 − 247 = 36,072	116.9
3. Nuclear (existing CF: 75 %)	9845	64.7	9845	64.7
4. Wind (existing CF: 19 %)	13,234	22	13,234	22
5. Solar (existing CF: 13 %)	4038	4.6	4038	4.6
6. Fossil addition (CF: 37 %)	2900	9.4	0	
7. Nuclear addition (CF: 75 %)	0	0	0	
8. Hydro addition (CF: 58 %)	0	0	512	2.6
9. Wind addition (CF: 35 %)	0	0	1631	5
10. Solar addition (CF: 10.8 %)	0	0	1903	1.8
11. Extra RES (Wind CF: 35 %) (for existing gas PP)	0	0	256 + 0 = 256	0.8 + 0 = 0.8
12. Total installed capacity: total power production	1,48,413	635.4	1,50,117	635.4
13. Standby: gas (CF: 37 %)	0	0	2900	9.4
14. Total power achieved	1,48,413	635.4	1,53,017	644.8
15. Total power consumption: (635.4 × 83.59 %)	531.13 TWh		531.13 TWh	

Table 4.7 Power planning scenario for year 2021

Power source	Power 2021 (NEBM) (policy-makers model)		Power 2021 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	83,830	425.9	83,830	425.9
2. Fossil (existing CF: 37 %)	36,319	117.7	36072 − 216 = 35856	116.9 − 0.7 = 116.2
3. Nuclear (existing CF: 75 %)	9005	59.2	9005	59.2
4. Wind (existing CF: 19 %)	13,354	22.2	13,354	22.2
5. Solar (existing CF: 13 %)	4158	4.7	4158	4.7
6. Fossil addition (CF: 37 %)	2900 + 870 = 3770	9.4 + 2.8 = 12.2	0	0
7. Nuclear addition (CF: 75 %)	0	0	0	0
8. Hydro addition (CF: 58 %)	0	0	512 + 433 = 945	2.6 + 2.2 = 4.8
9. Wind addition (CF: 35 %)	0	0	1631	5
10. Solar addition (CF: 10.8 %)	0	0	1903 + 634 = 2537	1.8 + 0.6 = 2.4
11. Extra RES (Wind CF: 35 %) (for existing gas PP)	0	0	256 + 227 = 483	0.8 + 0.7 = 1.5
12. Total installed capacity: total power production	1,50,436	641.9	1,52,165	641.9
13. Standby: gas (CF: 37 %)	0	0	3770	12.2
14. Total power achieved	1,50,436	641.9	1,55,935	654.1
15. Total power consumption: (641.9 × 83.59 %)	536.56 TWh		536.56 TWh	

Table 4.8 Power planning scenario for year 2022

Power source	Power 2022 (NEBM) (policy-makers model)		Power 2022 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	84,061	427.1	84,061	427.1
2. Fossil (existing CF: 37 %)	36,319	117.7	35,856	116.2
3. Nuclear (existing CF: 75 %)	9005	59.2	9005	59.2
4. Wind (existing CF: 19 %)	13,524	22.5	13,524	22.5
5. Solar (existing CF: 13 %)	4328	4.9	4328	4.9
6. Fossil addition (CF: 37 %)	3770 + 540 = 4310	12.2 + 1.8 = 14	0	0
7. Nuclear addition (CF: 75 %)	840	5.5	0	0
8. Hydro addition (CF: 58 %)	0	0	945 + 1023 = 1968	4.8 + 5.2 = 10
9. Wind addition (CF: 35 %)	0	0	1631 + 489 = 2120	5 + 1.5 = 6.5
10. Solar addition (CF: 10.8 %)	0	0	2537 + 634 = 3171	2.4 + 0.6 = 3
11. Extra RES (Wind CF: 35 %) (for existing gas PP)	0	0	483	1.5
12. Total installed capacity: total power production	1,52,387	650.9	1,55,356	650.9
13. Standby: gas (CF: 37 %)	0	0	4310	14
14. Total power achieved	1,52,387	650.9	1,59,654	664.9
15. Total power consumption: (650.9 × 83.59 %)	544.09 TWh		544.09 TWh	

Table 4.9 Power planning scenario for year 2023

Power source	Power 2023 (NEBM) (policy-makers model)		Power 2023 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	84,061	427.1	84,061	427.1
2. Fossil (existing CF: 37 %)	36,319	117.7	35,856	116.2
3. Nuclear (existing CF: 75 %)	9005	59.2	9005	59.2
4. Wind (existing CF: 19 %)	13,744	22.9	13,744	22.9
5. Solar (existing CF: 13 %)	4446	5.1	4446	5.1
6. Fossil addition (CF: 37 %)	4310 + 1255 = 5565	14 + 4 = 18	0	0
7. Nuclear addition (CF: 75 %)	840 + 300 = 1140	5.5 + 2 = 7.5	0	0
8. Hydro addition (CF: 58 %)	0	0	1968 + 689 = 2657	10 + 3.5 = 13.5
9. Wind addition (CF: 35 %)	0	0	2120 + 489 = 2609	6.5 + 1.5 = 8
10. Solar addition (CF: 10.8 %)	0	0	3171 + 1057 = 4228	3 + 1 = 4
11. Extra RES (Wind CF: 35 %) (for existing gas PP)	0	0	483	1.5
12. Total installed capacity: total power production	1,54,280	657.50	1,57,517	657.50
13. Standby: gas (CF: 37 %)	0	0	5565	17.5
14. Total achievable power	1,54,280	657.50	1,63,082	675
15. Total power consumption: (657.5 × 83.59 %)	549.60 TWh		549.60 TWh	

Table 4.10 Power planning scenario for year 2024

Power source	Power 2024 (NEBM) (policy-makers model)		Power 2024 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	84,097	427.3	84,097	427.3
2. Fossil (existing CF: 37 %)	36,319	117.7	35,856	116.2
3. Nuclear (existing CF: 75 %)	8165	53.6	8165	53.6
4. Wind (existing CF: 19 %)	13,914	23.2	13,914	23.2
5. Solar (existing CF: 13 %)	4613	5.3	4613	5.3
6. Fossil addition (CF: 37 %)	5565 + 199 = 5764	18 + 0.7 = 18.7	0	0
7. Nuclear addition (CF: 75 %)	1140	7.5	0	0
8. Hydro addition (CF: 58 %)	0	0	2657 + 98 = 2755	13.5 + 0.5 = 14
9. Wind addition (CF: 35 %)	0	0	2609 + 66 = 2675	8 + 0.2 = 8.2
10. Solar addition (CF: 10.8 %)	0	0	4228	4
11. Extra RES (Wind CF: 35 %) (for existing gas PP)	0	0	483	1.5
12. Total installed capacity: total power production	1,54,012	653.3	1,57,611	653.3
13. Standby: gas (CF: 37 %)	0	0	5764	18.1
14. Total power achieved:	1,54,012	632.7	1,63,375	650.8
15. Total power consumption: (653.3 × 83.59 %)	546.09 TWh		546.09 TWh	

Table 4.11 Power planning scenario for year 2025

Power source	Power 2025 (NEBM) (policy-makers model)		Power 2025 (TEM) (proposed TE model)	
	Capacity (MW)	Generation (TWh)	Capacity (MW)	Generation (TWh)
1. Hydro (existing CF: 58 %)	84,097	427.3	84,097	427.3
2. Fossil (existing CF: 37 %)	36,319	117.7	35,856 − 802 = 35,054	116.2 − 2.6 = 113.60
3. Nuclear (existing CF: 75 %)	8165	53.6	8165	53.6
4. Wind (existing CF: 19 %)	14,134	23.5	14,134	23.5
5. Solar (existing CF: 13 %)	4728	5.4	4728	5.4
6. Fossil addition (CF: 37 %)	5764 + 257 = 6021	18.7 + 0.8 = 19.5	0	0
7. Nuclear addition (CF: 75 %)	1140 + 935 = 2075	7.5 + 6.1 = 13.6	0	0
8. Hydro addition (CF: 58 %)	0	0	2755 + 894 = 3649	14 + 4.54 = 18.54
9. Wind addition (CF: 35 %)	0	0	2675 + 587 = 3262	8.2 + 1.8 = 10
10. Solar addition (CF: 10.8 %)	0	0	4228 + 645 = 4873	4 + 0.61 = 4.61
11a. Extra RES (Wind CF: 35 %) (for existing gas PP)	0	0	483	1.5
11b. Extra RES (Hydro CF: 58 %)	0	0	503	2.6
12. Total installed capacity: total power production:	1,55,539	660.6	1,58,948	660.65
13. Standby: gas (CF: 37 %)	0	0	6021 + 802 = 6823	19.5 + 2.6 = 22.10
14. Total achievable power	1,55,539 MW	640.2 TWh	1,65,771 MW	682.7 TWh
15. Total power consumption: (660.6 × 83.59 %)	552.20 TWh		552.20 TWh	

4.3 Project Planning

In order to plan the electricity infrastructure for the next 10 years in Canada, this thesis looks only one main component of the sector which is power generation through RES. As the fossil-fueled power plants are already in pipeline according to NEBM-2025, it is assumed that these power plants will be constructed in the form of natural gas-fueled power plants in TEM-2025 and will act as standby power. The RES project planning was done by compiling the feasibility database of the future projects in each province and territory. In this scenario, the area selection of small hydroelectric power plants, wind farms, and PV parks has been investigated in those regions where diesel fuel is being used as the sole energy source to produce electricity. From this gathered information, the selected RES projects include the total facility name plate capacity (MW) with primary energy source, project starting year, and the initial year of operation. After collection of this data, a list of all projects can be determined as shown in Table 4.12 [4–6].

4.4 Investment Planning

An effective investment planning mechanism has been developed in this section in order to ensure the availability of funds before the starting date of RES projects. The final detail of RES-installed capacity, power output, and required capital cost has been shown in Table 4.13.

According to this scenario, a new investment of around 29.37 billion CDN$ is required in RES by 2025, of which 12.65 billion CDN$ (hydro-I) has already been provided in terms of investment for reciprocal of nuclear power which has been calculated in Eq. 3.9 in Chap. 3. Hence, the residual investment will be as following:

$$\begin{aligned}\text{Required Residual Investment} &= 29371 - 12658(\text{Hydro-I}) \\ &= 16713 \text{ Million CDN \$}\end{aligned} \tag{4.1}$$

Tables 4.14 and 4.15 cover the investment simulation for 7 years (2015–2021), in which “Hydro-1” projects have been adjusted through the investment for nuclear planning by NEBM-2025 and the investment of 16,713 million Canadian dollars for other RES projects have been adjusted through the simulation of electricity price increase for 7 years.

Table 4.12 Projects-planning scenario for future 10 years

RES Capacity MW	Year										
	15	16	17	18	19	20	21	22	23	24	25
Hydro (118)	■	■	■	■							
Wind (1305)	■	■									
PV (634)	■	■									
Hydro (394)		■	■	■	■						
Wind (326)		■	■								
PV (740)		■	■								
PV (529)		■	■	■	■						
Hydro (433)			■	■	■	■	■				
Wind (489)			■	■	■	■	■	■			
PV (634)			■	■	■	■	■				
Wind (256)			■	■	■						
Hydro (1023)				■	■	■	■	■			
Wind (227)				■	■	■	■				
PV (634)				■	■	■	■	■			
Wind (489)				■	■	■	■	■	■		
Hydro (689)					■	■	■	■	■		
Wind (587)					■	■	■	■	■	■	■
PV (645)					■	■	■	■	■	■	■
Hydro (98)						■	■	■	■	■	
Wind (66)						■	■	■	■	■	
Hydro (503)						■	■	■	■	■	■
Hydro (894)							■	■	■	■	■
PV (1057)							■	■	■		
Total Power:	**12770 MW**										

Table 4.13 Total RES-installed capacity, power output and costs till 2025

RES type	Installed capacity (MW)	Power output (TWh)	Capital cost Million CDN $
Hydro-I	3649	18.54	12,658
Hydro-II	503	2.6	1745
Wind-I	3262	10	6459
Wind-II	483	1.5	956
PV parks	4873	4.61	7553
Total:	12,770	37.25	29,371

Table 4.14 describes the steps followed in applying the simulation methodology in TEM to solve the problem of capital investment in the area of RES from 2015–2018. In this table, four electricity prices are identified after the proper application of the simulation. The price obtained at the end of one-year calculation should suffice to fulfil the total cost of all RES for the projects starting in that year.

In Table 4.15, some further steps of the previous phase described in Table 4.14 are investigated. Here, the electricity price increase has been determined for the years 2019–2021. The price has been calculated after obtaining the value of investment for projects starting in each year as well as the value of power consumption for that year. For example, the investment required to start the projects of 587 MW wind power and 645 MW PV power is 2162.01 Million CDN$ in year 2019. The electricity price increase for that year will be 0.4069 CDN Cent/kWh. For the same year, 689 MW hydro project will also be started and will be supported through the investment which otherwise would have been spent on nuclear power.

The fundamental weakness of the power structure in Canada is that it has high electricity price variation from one region to other due to the diversified landscape of the country. The policies of price variation are effective at supporting the utility cost adoption but can threaten the financial stability of the electricity distribution companies and result in cross-subsidies between the electricity users of different regions. There are many factors contributing to this phenomenon, in which the most important are the fuel costs associated with geographical costs. For example, the price of electricity for residential consumers in certain communities in the territory of Nunavut is up till 114 cent/kWh, whereas the price in other communities in Quebec is 5.57 cent/kWh [7, 8]. According to Canadian key electricity statistics released in June 2014, the average residential electricity price in 2013 was 12.07 cent/kWh, whereas the average industrial electricity price in 2013 was 7.96 cent/kWh [9]. These rates vary strongly from one province to another province or territory. In order to calculate the increase in total price due to deployment of new RES in system, an average amount of residential and commercial prices has been assumed as a reference fix price of electricity during the investigation period, which is 10.06 cent/kWh. The following graph shows the increase in price due to new RES from 2015 to 2021.

Table 4.14 Investment adjustment with reference to price increase (2015–2018)

RES type	Completion period	Investment calculation	Total investment	Power consumed
Hydro (118 MW)	2015–2018	118 × 3.469 = 409.34 (adjusted with nuclear costs)		
Wind (1305 MW)	2015–2016	1305 × 1.98 = 2583.9	3566.60 Million CDN $ (2015)	528.29 TWh (2015)
PV (634 MW)	2015–2016	634 × 1.55 = 982.7		
Electricity price increase to compensate the investment in 2015: $= \frac{3566600000 \text{ CDN \$}}{528290000000 \text{ kWh}} = 0.6751$ CDN cent/kWh				
Hydro (394 MW)	2016–2019	394 × 3.469 = 1366.79 (adjusted with nuclear costs)		
Wind (326 MW)	2016–2017	326 × 1.98 = 645.48	2612.43 Million CDN $ (2016)	530.9 TWh (2016)
PV (740 MW)	2016–2017	740 × 1.55 = 1147		
PV (529 MW)	2016–2019	529 × 1.55 = 819.95		
Electricity price increase to compensate the investment in 2016: $= \frac{2612430000 \text{ CDN \$}}{530900000000 \text{ kWh}} = 0.4921$ CDN cent/kWh				
Hydro (433 MW)	2017–2021	433 × 3.469 = 1502.08 (adjusted with nuclear costs)		
Wind (489 MW)	2017–2022	489 × 1.98 = 968.22	2457.80 Million CDN $ (2017)	528.54 TWh (2017)
PV (634 MW)	2017–2021	634 × 1.55 = 982.70		
Wind (256 MW)	2017–2019	256 × 1.98 = 506.88		
Electricity price increase to compensate the investment in 2017: $= \frac{2457800000 \text{ CDN \$}}{528540000000 \text{ kWh}} = 0.4650 \text{ CDN cent/kWh}$				
Hydro (1023 MW)	2018–2022	1023 × 3.469 = 3548.79 (adjusted with nuclear costs)		
Wind (227 MW)	2018–2021	227 × 1.98 = 449.46	2400.38 Million CDN $ (2018)	529.62 TWh (2018)
PV (634 MW)	2018–2022	634 × 1.55 = 982.7		
Wind (489 MW)	2018–2023	489 × 1.98 = 968.22		
Electricity price increase to compensate the investment in 2018: $= \frac{2400380000 \text{ CDN \$}}{529620000000 \text{ kWh}} = 0.4532 \text{ CDN cent/kWh}$				

Table 4.15 Investment adjustment with reference to price increase (2019–2021)

RES type	Completion period	Investment calculation	Total investment	Power consumed
Hydro (689 MW)	2019–2023	689 × 3.469 = 2390.14 (adjusted with nuclear costs)		
Wind (587 MW)	2019–2025	587 × 1.98 = 1162.26	2162.01 Million CDN $ (2019)	531.30 TWh (2019)
PV (645 MW)	2019–2025	645 × 1.55 = 999.75		
Electricity price increase to compensate the investment in 2019: $= \frac{2162010000 \text{ CDN } \$}{531300000000 \text{ kWh}} = 0.4069$ CDN cent/kWh				
Hydro (98)	2020–2024	98 × 3.469 = 339.96 (adjusted with nuclear costs)		
Wind (66 MW)	2020–2024	66 × 1.98 = 130.68	1875.59 Million CDN $ (2020)	531.13 TWh (2020)
Hydro (503 MW)	2020–2025	503 × 3.469 = 1744.91		
Electricity price increase to compensate the investment in 2020: $= \frac{1875590000 \text{ CDN } \$}{531130000000 \text{ kWh}} = 0.3531$ CDN cent/kWh				
Hydro (894 MW)	2021–2025	894 × 3.469 = 3101.29 (adjusted with nuclear costs)		
PV (1057 MW)	2021–2023	1057 × 1.55 = 1638.35	1638.35 Million CDN $ (2021)	536.56 TWh (2021)
Electricity price increase to compensate the investment in 2021: $= \frac{1638350000 \text{ CDN } \$}{536560000000 \text{ kWh}} = 0.3053$ CDN cent/kWh				

Figure 4.1 shows that the electricity price will increase from 10.06 cent/kWh in 2014 to 10.74 cent/kWh in 2015, as three main projects of wind, hydro, and PV power will start in this year (Table 2.14). From 2016 to 2021, the price will decline gradually as the financial solution of all of the projects will be attained till 2021. In year 2022, the price will come down to its original level as it was in year 2014.

The simulation of this chapter has established that a slight increase in electricity rate can produce huge funds to plan and construct a lot of new RES projects. As a whole, the emergent behavior of such funding system together with the shift of planned nuclear and thermal investment can solely finance all RES projects in TEM-2025. This methodology provides information to underpin the policy and strategy for sustainable energy development which is being concluded in the next chapter.

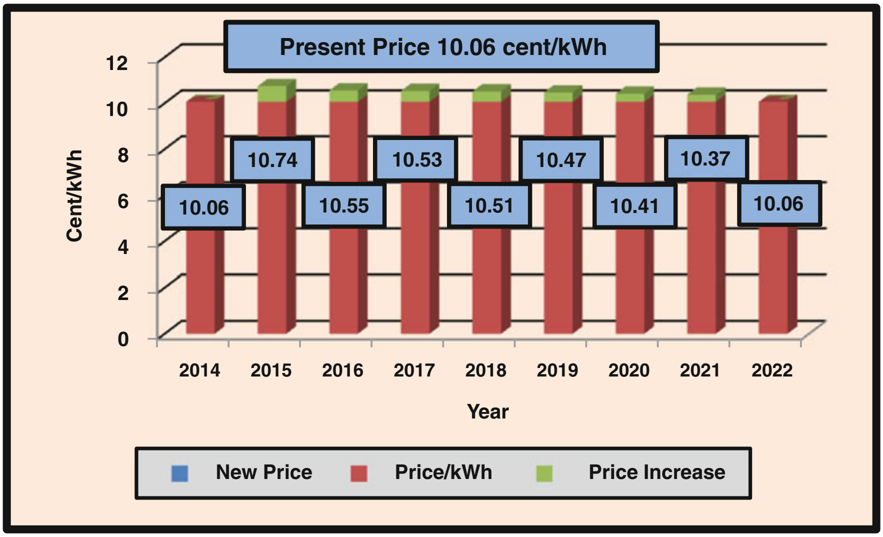


Fig. 4.1 New electricity price after integration of RES 2015–2021

References

1. HOMER Energy LLC (2013) Homer software for simulation, optimization and sensitivity analysis. Boulder, USA
2. CEA (2014) Canada electricity industry, power demand in Canada, presentation, Canada electricity association, Ottawa-Canada, p 12
3. World Bank (2014) Electric power transmission and distribution losses (% of output), World Bank Data 2014. The World Bank Group, Washington-USA
4. NEB (2011) Energy use in Canada's North: an overview of Yukon, Northwest Territories and Nunavut. National Energy Board, Calgary, Alberta-Canada
5. Glave J, Thibault B (2014) Power to change: how Alberta can green its grid and embrace clean energy. Pembina Institute, Calgary-Canada
6. CBC (2011) Canada's electricity infrastructure, building a case for investment. In: The conference board of Canada, Ottawa, Canada, Publication No. 11-257
7. QEC (2014) Electricity rate of Kugaaruk community, rate schedule effective. Qulliq Energy Corporation 1 May 2014
8. Hydro Quebec (2014) Understanding your bills, residential rates, rate D for residential or agricultural use. Hydro Quebec-Canada
9. Hydro Quebec (2013), Comparison of electricity prices in major north American cities. National Library of Canada. ISBN 978-2-550-67971-4, p 20, 1 Apr 2013

Chapter 5
Conclusion

The methodology used in this work demonstrates that RES transition and transformation is possible, practical, and affordable. With an effective policy, any country can reduce its heavy reliance on fossil and nuclear fuel and can supply a significant amount of power with RES within a specific time frame. In this research, the result of techno-economic model (TEM-2025) shows that 75 % of power can be generated through RES in Canada till 2025. The growth of 10 % integration of RES within the time span of 10 years has been achieved successfully. Extra gas power plants of 6823 MW have also been planned to utilize as a standby power to overcome the intermittency factor of wind and PV power generation to an optimum level in order to meet the demand side reliability factor. The second and most important goal was to estimate and integrate a significant amount of RES that could potentially be harnessed within the boundaries of available finances without introducing any feed-in tariff or loan-based financial mode. This target has been achieved by periodic simulation of price variations in which all projects could be financed fully while the total price increase remained less than one cent/kWh for 7 years.

In Table 5.1, the power configuration of three different models has been reflected for comparative analysis. In the first part, the present power configuration in Canada has been replicated as a reference point. In the second part, the scenario of policy makers in the form of National Energy Board Model till 2025 (NEBM-2025) has been illustrated, whereas in the third scenario, a vision of techno-economic model till 2025 (TEM-2025), which is simulated in the previous chapter, has been shown. This two-track approach in comparison with the existing power configuration shows very clearly that the roadmap of NEBM-2025 is leveraging to explore more conventional power till 2025; however, the scenario proposed in TEM-2025 is in particular upscaled in RES power generation for the benefit of the whole region.

Table 5.1 shows that NEBM-2025 has planned to increase only 3 % share of RES installed capacity till 2025, which will produce 4 % more power through RES from the level of power generation in 2013/14. The installed capacity of fossil fueled power plants in NEBM-2025 will remain constant at the level of 27 %, but

T. Ahmed, *Modeling the Renewable Energy Transition in Canada*,
SpringerBriefs in Energy, DOI 10.1007/978-3-319-31505-8_5

Table 5.1 Quantification of installed capacity and power generation under present, NEBM-2025 and TEM-2025 scenarios (Ref. Figs. 2.2, 2.5, 3.3 and 4.11)

	Power type	Hydro	Wind	Solar	Nuclear	Fossil	Total
Power in 2013/2014	Installed capacity (MW)	75430	7803	1210	13553	37004	135000
	Installed capacity (%)	56	6	1	10	27	100
	Generation (TWh)	387.64	12.7	1.39	88.55	121.03	611.31
	Generation (%)	63	2	0	15	20	100
NEBM 2025	Installed capacity (MW)	84097	14134	4728	10240	42340	155539
	Installed capacity (%)	54	9	3	7	27	100
	Generation (TWh)	427.3	23.5	5.4	67.2	137.2	660.6
	Generation (%)	65	3	1	10	21	100
TEM 2025	Installed capacity (MW)	88249	17879	9601	8165	35054	158948
	Installed capacity (%)	56	11	6	5	22	100
	Generation (TWh)	448.44	35	10.01	53.6	113.6	660.6
	Generation (%)	68	5	2	8	17	100
	Standby power (MW)	X	X	X	X	6823	6823
	Standby (TWh) generation	X	X	X	X	22.10	22.10

the share of power generation from fossil fueled power plants will be increased from 20 to 21 %. In 2025 the installed capacity of nuclear power will fall by 3 % compared to 2013/14, which will bring the reduction in nuclear power generation from 15 to 10 %. This means that 5 % less nuclear power generation will be compensated with 4 % RES and 1 % fossil power generation. As both nuclear and RES power generation do not contribute to GHG emissions primarily and fossil fueled power generation is mainly responsible for GHG emission, therefore by reducing 5 % nuclear power generation and expanding 4 % RES with the combination of 1 % fossil fueled power generation will give a net increase of 1 % in GHG emission by 2025. Considering these facts, the energy management of NEBM-2025 is contradictory in view of enforcing environmental protection in Canada.

Contrary to the above given model, TEM-2025 shows remarkable progress of 10 % increase in RES installed capacity that will also generate 10 % more RES power in 2025. Here, the values of hydro, wind, and PV power installed capacity will rise from 63 to 73 % between 2013/14 and 2025 and the rate of power generation will expand substantially from 65 % in 2013/14 to 75 % in 2025. The fossil fueled power installed capacity will reduce from 27 to 22 %, which will deliver power from 20 % in 2013/14 to 17 % in 2025. The nuclear power generation will be reduced from 15 to 8 % between 2013/14 and 2025. This means that 3 % reduction in fossil fueled power generation and 7 % reduction in nuclear power generation will be compensated by 10 % expansion in RES over the whole period. On average, in the period 2013–2025, annual GHG emissions will remain 3 % below the base year levels. This is significantly 4 % less than the 1 % expansion level achieved by NEBM-2025. Therefore, the structural shifts implemented in TEM-2025 are on track to deliver timely-mannered reliable power with less emissions and more RES power generation (Figs. 5.1 and 5.2).

The central attribute of the framework in TEM-2025 was the binding target to ensure the generation of 10 % more RES power with a methodology that involves no external finances. The simulation of such financial methodology with techno-economic objectives has been explained in Chap. 4 of this work. It shows that price shift of nuclear projects and an average of 0.45 cent/kWh or 4.5 % price increase for 7 years can financially support all RES projects to expand the share of RES by 10 % till 2025.

Figure 5.3 of this plausible financial scenario shows that the price of electricity will increase by 0.68 CDN Cent/kWh in 2015 in order to collect 3566 million CDN$ to finance two projects of wind and PV to be completed in 2016 (Chap. 4, Table 4.14). After that the price will gradually start to decrease from 0.49 CDN Cent/kWh in 2016 till 0.31 CDN Cent/kWh in 2021 to support the rest of the projects that should be completed till 2025. In 2022 the electricity price will come back to its original level as it was in 2014.

This work has proposed a techno-economic modeling (TEM-2025) of energy management for the transition of RES in Canada. It proves that the objective of increasing the share of RES to at least 75 % by the year 2025, as shown in Fig. 5.4, can be achieved by means of a quantitative heuristic approach. By continuing the same roadmap, it can even be raised up to 85 % in further 10 years. The need for

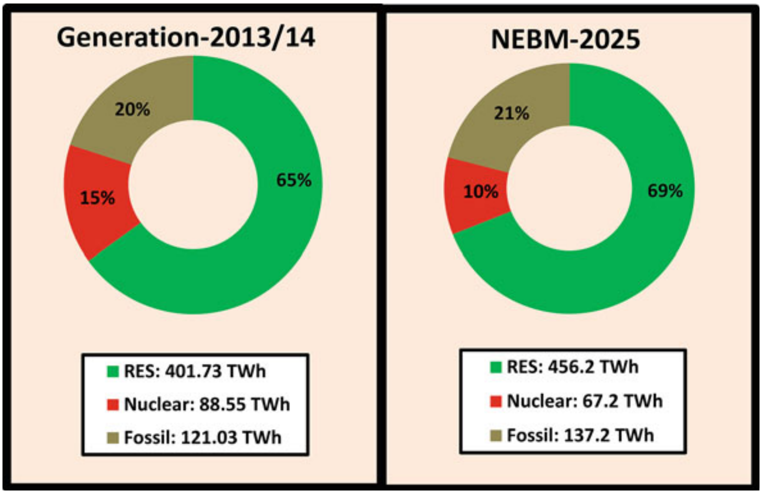


Fig. 5.1 RES, Nuclear and fossil power generation till 2025 by NEBM-2025 (Ref. Table 5.1)

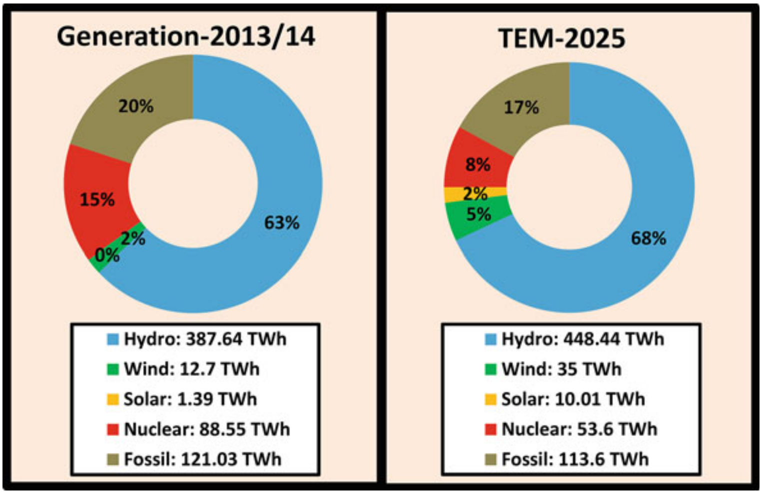


Fig. 5.2 Comparison of TEM-2025 power generation configuration with present power generation (Ref. Table 5.1)

action by Canadian power planners is urgent to stay competitive among global power economies. This competitiveness requires ambitious, aggressive, and innovative power sector planning. History shows that natural gas and oil prices are notoriously volatile. It is very plausible that its price will rise and fall unpredictably. Renewable energy sources present an opportunity to mitigate these price risks by diversifying supply and addressing the supply–demand gap with secure fixed-cost

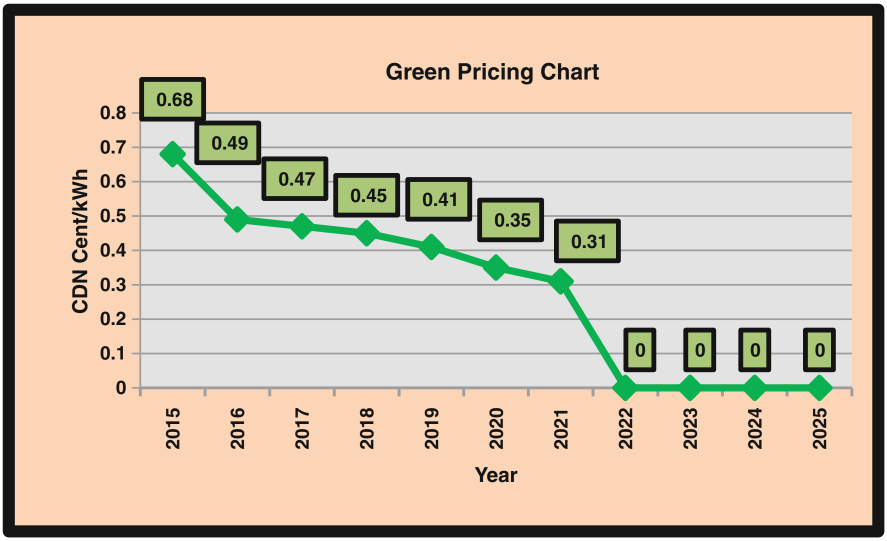


Fig. 5.3 Projection of price increase under TEM-2025 scenario (Ref. Fig. 4.2)

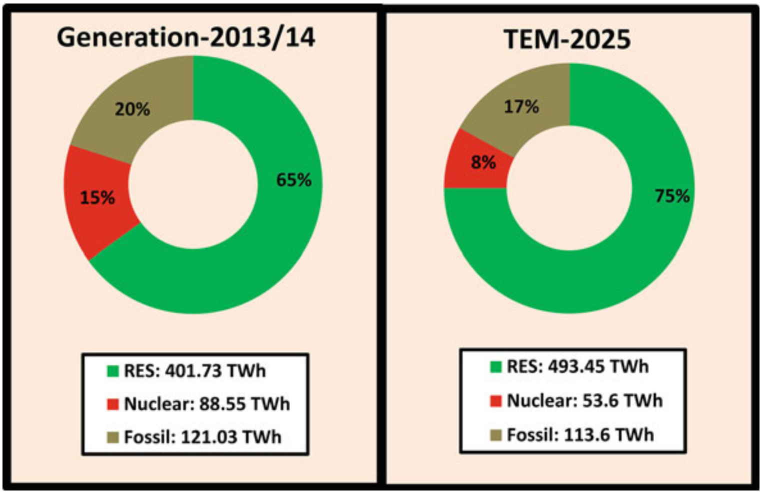


Fig. 5.4 Projection of RES power generation in TEM-2025 scenario (Ref. Table 5.1)

power generation. The National Energy Board of Canada should re-evaluate its planning NEBM-2025 using the variables of this research for optimization of its power system.

The ideas presented in this work provide some avenues for future research and can be verified by reverse simulation techniques. There is clearly significant work ahead for researchers to create an RES-oriented power network of the future in Canada. While the emerging RES technologies may represent significant opportunities for many firms or industries, it may just as well represent a significant threat to some conventional power businesses. However, the intent of this research work is to help in bringing some clarity to a possible high-tech energy future for the economy of Canada. This will allow better informed decision-making and smarter RES-oriented forecasting. It is expected that additional research and discussions among business, government, and academia may help to determine the policies and actions that can enable the transition of RES in Canada.

Index

T. Ahmed, *Modeling the Renewable Energy Transition in Canada*,
SpringerBriefs in Energy, DOI 10.1007/978-3-319-31505-8