Understanding the Dynamics of Electricity Supply and Demand in Canada

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Introduction

Currently, the electricity production industry in Canada consists of four major non-renewable sectors, and two major renewable sectors. The majority of nonrenewable electricity comes from crude oil, coal, natural gas, and uranium. On the other hand, the majority of electricity from renewable sources comes from hydroelectric and wind production. The relationship between supply and demand of electricity has changed over the past few economic cycles (Qudrat-Ullah, 2013). It is important to note that conventionally, as the demand for electricity increased, the production of electricity also increased. A notable change came with the 1989–1993 recession, when the demand growth for electricity stalled. With the stall of demand came the stall of supply (IFC Consulting 2006). However, as the economy recovered from the recession, demand growth resumed, however supply did not follow. Instead, the focus on maintaining alignment between supply and demand was on productivity. Demand is driven by increase in electricity using economic activities, and efficiency gains. Productivity may be further divided into mechanical efficiency and conservational efficiency or electricity spent for value addition. The two may be further divided into current machinery efficiency improvements, the invention of more efficient machinery, and the devising of new techniques that improve the value adding capabilities of processes. The driver behind such productivity improvements is research and development, which in turn is driven by investment (Park et al. 2007; Kilanc and Or 2008). For renewable energy sources, technological efficiency does not depend on the demand side dynamics directly. However, the economics and cost competitiveness of the technologies do (IFC Consulting 2006).

Despite considerable improvements in the productivity area, Canada's electricity supply and demand system has experienced significant imbalance in recent history (IFC Consulting 2006; Canada's sector council program powering up the

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future 2008). In fact, complexity of the system makes sustainable policy decision making a difficult task. Complexity of this system primarily comes from the existence and interactions of nonlinear and dynamic variables including various stocks of electricity generation capacity, restricting and regulatory regimes, fuel supply and price dynamics, and advances and challenges in technologies for electricity generation, transmission, and consumption.

Understanding of such complex policy issues and decisions necessitates the use of system simulation (Ford and Bull 1989; Olaya and Dyner 2005; Qudrat-Ullah and BaekSeo 2010). Specifically, researchers from the system dynamics community have found system dynamics simulation models capable of modeling and analyzing complex energy systems. For instance, system dynamics models have successfully been applied to various complex energy issues including (i) national energy policy design and evaluation (Ford 1983; Naill 1992; Qudrat-Ullah and Karakul 2007; Ochoa 2007), (ii) energy conservation analysis (Ford and Bull 1989), (iii) privatization of electricity industry (IFC Consulting 2006; Bun and Larsen 1992; Ford 1997; Dyner and Bunn 1997; Qudrat-Ullah and Davidsen 2001; Assili et al. 2008), (iv) generation expansion planning (Kilanc and Or 2008; Adelino and João 2011), and (v) assessment and mitigation of CO_2 emissions (Qudrat-Ullah and Davidsen 2001; Anand et al. 2005; Ansari and Seifi 2012). Therefore, to better understand the demand and supply dynamics of the electricity industry of Canada, we develop, validate, and utilize a system dynamics based simulation model.

The remainder of this paper is organized as follows: in “Sectorial Overview,” sectorial overview of various electricity consumption sectors in Canada is presented. Key dynamics of the electricity sector are described in “Key Dynamics in the Electricity Sector.” “Development of the Dynamic Model” details the model structure and model validation. Results with status quo scenarios as well as additional investments-based scenarios are discussed in “Results.” “Concluding Remarks” concludes this paper.

Sectorial Overview

Energy Consumption by Sector

Residential Sector

This sector accounts for electricity consumed in Canadian households, and includes energy for space and water heating, air conditioning, appliances and other end use energy devices. In the year 2007, residential energy consumption accounted for 18.4 % of the total electricity end use. The forecasted rate of change for this sector over the next 9 years is + 0.5 %/year. Changes in usage rate are most heavily influenced by government policies and changing consumer preferences (NEB 2011). Government programs aimed at energy use reduction include policies for stricter building codes in Canada’s most populous provinces. New furnace and boiler efficiency standards improve energy intensity of all new homes nationally (NEB 2011; Statistics Canada 2007). Policies for electricity usage in lighting are also becoming strict. Furthermore, much of the common appliances found in households that were formerly unregulated, now have minimum energy performance guidelines (Qudrat-Ullah, 2013).

Natural gas and electricity make up the majority of demand in this sector. Though impressive improvements have been achieved in energy efficiency of space heating and major appliances, aggregate demand still experiences growth as a result of increasing house sizes, preference for air conditioning, and the increase in adoption for electronic goods (NEB 2011; Working document of the NPC global oil & gas supply 2007).

The methods by which electricity demand for the residential sector has been met depend heavily on the regional availability of fuel, energy prices, and end use demand. In Atlantic Canada for example, hydroelectricity is the dominant source of electricity. In the prairies, natural gas holds the majority of market share (NEB 2011).

Commercial Sector

This sector includes offices, retail, warehousing, government and institutional buildings, utilities, communications and other service industries. It also includes energy consumed by oil and gas pipelines and street lighting (NEB 2011). Electricity demanded by this sector is generally used for similar functions as that of the residential sector, namely, space heating and cooling, water heating, lighting, and electrical plug load. In the year 2007, commercial energy demand, like residential demand, was also 18.4 %. However, growth rate in this sector is much more significant, averaging at 1.4 %/year for the next 9 years (Government of Canada 2011; Electricity generation, by utilities, by source 2005). It is important to note that demand growth rate for both the residential and commercial sectors is at a historical low due to aggressive improvements in energy efficiencies. Energy related policies also severely impact energy consumption in this sector. Building codes, for example require more efficient insulation, heating/ventilation and air conditioning. Such requirements aim at reducing the energy demand by 25 % relative to the Model National Energy Code for Buildings of 1997 (Qudrat-Ullah, 2013). Demand is also being reduced by equipment standards, including minimum boiler efficiency and packaged heating/cooling units as well as improvements in lighting efficiency.

The Industrial Sector

This sector includes manufacturing, forestry, fisheries, agriculture, construction, and mining. Much of the energy demand for this sector comes from a select few energy intensive industries, namely iron and steel, aluminum manufacturing, cement manufacturing, chemicals and fertilizers, pulp and paper, petroleum refining, and oil and gas extraction (NEB 2011). This sector is by far the greatest consumer of electricity in Canada, accounting for 63.2 % of electricity demand in 2007. Market share however is projected to drop to 60.5 % by 2020, reflecting slower economic growth in the Canadian goods producing sector (NEB 2011). This sector is by far the largest contributor to environmental pollutants, and is the target of many regulatory policies, including the cap and trade program.

Key Dynamics in the Electricity Sector

The Shift in Production Mix

Conventionally, much weight has been given to nonrenewable, highly contaminating sources of power (Cappers et al. 2010). As of late however, environmental consciousness, as well as greater acceptance of the finite life of nonrenewable energy, has led to an emergence of new environmentally friendly and high-yield strategies. According to a study by Canada's National Energy Board, hydroelectric, nuclear, natural gas, and wind capacity are projected to increase in the future (NEB 2011; Statistics Canada 2007). Wind power is expected to achieve the greatest relative growth, reaching 10 % of installed capacity by 2020 (NEB 2011). Though some hazardous sources, such as biomass, landfill gas, and waste heat are experiencing growth, technologies such as carbon capture and storage are expected to experience parallel growth, as a method of mitigation of environmental pollution (Qudrat-Ullah, 2013).

Macroeconomic Influences

The stocks and flows of the Canadian energy market are greatly influenced by global trends in energy pricing, technology development, as well as government regulation.

Crude oil supply and pricing for example greatly influence Canada's ability to produce electricity domestically. Over the past decade, many emerging economies including India and China averaged yearly economic growth rates of approximately 7 % each. The sustainability of such growth was largely attributed to the ability of global crude oil supplies to meet growing demand. Such supply did not keep up with demand, leading to an increase in crude oil pricing. In early 2008, oil prices were at a record high US$ 100/barrel. They continued to climb throughout the year to as high as US$ 147/barrel. For most countries, the increase in the commodity's price reduced demand for crude oil. However, demand in some countries including Canada increased as a result of government subsidies to the industry (NEB 2011; NPC 2007). Growth in crude oil prices however stalled and declined throughout the 2008 recession as a result of decreased demand. Crude oil prices and demand, like that of most other energy sources, parallel the health of the economy. The higher the economic growth, the higher the demand is which then leads to higher prices for such resources.

Similar to the demand for crude oil, natural gas demand also fell as a result of the economic slowdown. This slowdown, however, was synchronous with the increased supply of natural gas due to emerging technologies especially with regards to tight gas and shale gas production (NEB 2011). Such an imbalance in the supply and demand for natural gas caused prices to fall by nearly 75 % from peak prices of US$ 13.32/MMBTU in July 2008. Likewise, gas-drilling activity also fell by 50 % in the year 2009. However, such a reduction in prices and supply combined with the slow but sure recovery in the economy drove the demand, prices, and production up once more in a balancing act (Qudrat-Ullah, 2013).

Notable in terms of policy and regulation is the increasing trend promoted by the world governing agencies towards environmental protection. The Western Climate Initiative is an example of a policy which aims to make emission production much more costly and difficult. The initiative has developed a carbon market cap-and-trade program (NEB 2011; IEEE Xplore 2011). This program allows participants to emit only as much pollutants as specified in their permits. Should a company wish to produce more, and furthermore emit more, it would have to acquire more permits from other participants—a costly venture. Four Canadian provinces, and seven US states have already been inducted into this program (CIA 2011; NRC 2009; Statistic Canada 2011). Canada also has several provincial level policy directives, including the BC Energy Plan, Alberta's Climate Change and Emissions Management Amendment Act, and Manitoba's Beyond Kyoto (NEB 2011). Such programs, as well as many others, impose emission restrictions and mandate energy efficiency.

Microeconomic Influences

On a micro level, much influence on the price and supply of electricity comes from generation ability, transmission, and distribution costs. Notably, electricity prices are lowest in provinces with a high proportion of supply coming from hydro production (NEB 2011). This suggests high yield and efficiencies in the hydroelectricity industry. Hydroelectric plants have substantial start-up costs, however because of the longevity of such assets, hydro-generating stations that have been installed, and paid off many years ago, are now still in use at low operational costs. At a provincial level, regulators aim at finding a balance between low cost heritage assets, and high start-up cost new assets. Though new assets and technologies have high start-up costs, their long-term profitability is much higher than that of their predecessors. Prices in most jurisdictions are highly dependent on the cost of service provision and the regulated rates of return. Cost of service varies greatly, with large-scale consumers enjoying lower prices due to economies of scale, and small-scale, usually residential, consumers incurring higher costs. It is worth noting that the short-term trend is towards higher electricity prices due in a large part to the development of higher cost generation resources and planned improvements to transmission systems (NEB 2011).

Though the use of coal for power generation is on the decline, it is still Canada's second largest source of electricity (Statistics Canada 2007). The use of coal is more dominant in western provinces where supply is high, and the cost of distribution is relatively low. Coal prices are expected to remain relatively stagnant due to increasing competitive pressures and productivity increases in mining and rail transportation (Qudrat-Ullah, 2013).

Electricity Restructuring

Traditionally, the Canadian industry was composed of integrated companies that performed all electricity logistics, from generation, all the way to customer distribution (Qudrat-Ullah, 2013). Restructuring aims at shifting from monopolistic production to separate generation, transmission, and distribution service companies. The purpose of such restructuring is to promote competition among generators and new entrants to the market, and to provide more open access to the transmission incumbent systems, a system also known as wholesale access (Centre for Energy 2009). Such unbundling also increases competition with regards to marketing of electricity, providing more choices to consumers. In such a system, consumers would have a choice of supplier, expanded metering services, and options with respect to green power. As a result of restructuring, trade is likely to increase. Areas with high electricity prices are likely to begin adopting suppliers they previously did not have access to (Stone 2008).

The Shift to Productivity

A shift from increases in capacity to increases in productivity is made evident by the decrease in energy usage relative to Canada's GDP of 1.3 % per year. Such a decline is heavily attributable to efficiency improvements in electricity and natural gas end use devices, as well as declining heavy industry sectors (NEB 2011).

To exemplify the notion of increased productivity, we will examine the "Smart Grid" initiative being considered by the Ontario Energy Board. Such an initiative is the result of the Green Energy Act that took effect in 2009, requiring an increase in electricity conservation and demand management efficiency. It also requires implementation of a Smart Grid, and promotes the increased use of renewable energy sources (U.S.D. of Energy 2009). Contrary to the conventional response to increased demand, the Green Energy Act facilitates productivity improvements rather than supply increases. The implementation of a Smart Grid does not increase the aggregate supply of electricity, but rather improves flow, turning one-way flow of electricity into a bilateral exchange between households and utility stations. As more and more entities external to the utilities are implementing their own energy producing initiatives, supply no longer comes solely from the government generation stations. Other entities are increasingly producing wind and solar energy, and surplus of such energy may be sold back to the utilities (U.S.D. of Energy 2009). Such efficiencies remove redundant provisions of power and reduce the costs associated with such inefficient electricity transportation. A Smart Grid also greatly improves informational flows through networks, greatly improving demand management potential, and reducing costs associated with information aggregation. Further benefits of implementing a Smart Grid include (Qudrat-Ullah, 2013):

- Self-healing from power disturbance events
- Enabling active participation by consumers in demand response
- Operating resiliently against physical and cyber attack
- Providing power quality for twenty-first-century needs
- Accommodating all generation and storage options
- Enabling new products, services, and markets
- Optimizing assets and operating efficiently

Another macro level initiative that aims to improve productivity within the power generation and distribution system is the increase in interoperability standards. Collaboration among all entities within the network ensures alignment between operating standards, and compatibility among operating and delivery systems. The unification of the power system leads to a flexible, uniform, and technology neutral environment that improves customer choice, and yields economies of scale (U.S.D. of Energy 2009). Closely related to the alignment of standards is interconnection planning and analysis. Collaboration in industry analysis and forecasting reduces volatility with respect to future generation. Such collaboration also encourages the development of uniform industry-wide strategies for dealing with the supply and demand of power in Canada. It is important to note however, that such initiatives as indicated above are impeded by a shortage of workers knowledgeable in emerging technologies such as Smart Grids. For this reason, many workforce development programs are under development in attempts to update the practical knowledge of industry employees. The Consortium for Electric Reliability Technology Solutions for example is a consortium of national laboratories, universities, and industries that performs research and develops and disseminates new methods, tools, and techniques to protect and enhance the reliability of the electric power system (U.S.D. of Energy 2009). The consortium works with energy boards in developing employee development programs. A final notable industry-wide initiative aimed at productivity enhancement is the increasing use of stakeholder engagement and outreach activities. Such activities disseminate information regarding changes in industry practices, cost performance data, environmental considerations, etc., in attempts to encourage investment primarily for research and development purposes.

Grid Energy Storage

Another benefit of a Smart Grid is its ability to store electricity produced in excess of demand. Conversely, when electricity demand exceeds supply, the electricity stored within the grid is released to various destinations with an electricity deficit. This system of electricity storage allows generation plants to run more efficiently, as production shifts both up and down need not be extreme, as electricity stored within the grid will aid in balancing supply and demand, even if the amount being produced differs from the amount demanded (Centre for Energy 2009). Below we will present a circumstance, which greatly benefits from the storage capacities of the grid.

Peak Demand

Currently, peak demand in Canada is growing much faster than average demand. Peak demand in the country occurs in the summertime, and results from the high-usage rate and high-adoption rate of air conditioning systems. Much of this increase comes from the adoption of large-scale industrial air conditioners. However, it is important to note that this growth in peak usage, which contributes to an increasing gap between supply and demand, will not continue on the same trend for much longer. This is because the air conditioning market will become saturated, preventing adoption from continuing indefinitely.

Traditionally, such a deviation from regular production as described above would require large swings in electricity production. However as grid storage prevalence increases, such swings in production need be less and less severe, as electricity stored in times of electricity surpluses will be used to balance the supply and demand gap.

Demand Side Factors

In this section, we will discuss demand side changes, which hold stake in the discourse regarding the gap. According to forecasts, there are sufficient "demand side" resources available to close the gap or at least to delay its appearance beyond 2020 (IFC Consulting 2006). In fact, research shows that even if the increasing productivity trends within the last 15 years were to slow down or reverse, a gap would still not materialize if about 50 % of potential for fuel substitution, demand management, and energy efficiency were realized, along with a modest growth in cogeneration (IFC Consulting 2006). Subsequently, we will explore the dynamics of such demand side developments:

Fuel Substitution

Currently, electric space and water heating account for 37 % of total residential electricity usage (IFC Consulting 2006). However, alternative methods of electric space and water heating are becoming cheaper and more attractive. High efficiency gas heating for example, is now 40 % cheaper than electric heating (IFC Consulting 2006). Such a wide variance in cost is projected to lead to significant electricity savings, through substitution.

Presently, baseboard heaters provide over half of electric space heating. Traditionally switching to more energy efficient alternatives has been made difficult by the costs of retrofitting the infrastructure of the dwelling. Recent advances however, in small diameter, flexible piping, hydronic heat distribution systems that allow conversions from electric baseboard heating with relatively little disruption to the household and at a much lower capital cost than regularly, have made such substitutions much more attractive. Fuel substitution for the above uses of electricity is projected to reduce the potential gap in 2020 by 400 MW.

Demand Side Management Potential

This notion involves changing the level or pattern of demand for energy. Examples of tactics in demand side management include improving efficiency with which a service is provided, decreasing the underlying demand for the service, and influencing or controlling the timing of the service demanded (IFC Consulting 2006). The Smart Grid discussed above is a key factor in managing demand through efficient informational flow. Studies show that the gap may be reduced by 1,500 MW by 2020 through demand management efficiencies (IFC Consulting 2006).

Cogeneration

Cogeneration or “combined heat and power” is a method of simultaneously producing both electricity as well as heat. Traditionally, heat is produced as a byproduct of electricity production, and such heat is released into the environment. Through cogeneration however, such heat can be captured in steam or water, and reused to produce more electricity. A study conducted by the Ministry of Energy suggested that cogeneration could reduce the supply and demand gap by as much as 8,250 MW (IFC Consulting 2006). Cogeneration was also found to be much more cost competitive than regular generation, having prices for electricity delivered at about 40 % below the average market price.

Energy Efficiency

According to an ICF Consulting study, technical potential for energy efficiency improvements could reduce electricity use by 36.6 TWh, and cut peak demand by 8.2 GW. This is equivalent to 26 % of Ontario’s current electricity use and 33 % of system peak. However, improvements only as far as economically feasible yielded lower savings, at 29.6 TWh and 5.2 GWh for peak times (NPC 2007). Though significantly lower than total potential, such improvements still represent 21 % of total energy sales. According to the same study, such improvements may help reduce the gap between supply and demand by 2,150 MW by 2020 (Qudrat-Ullah, 2013).

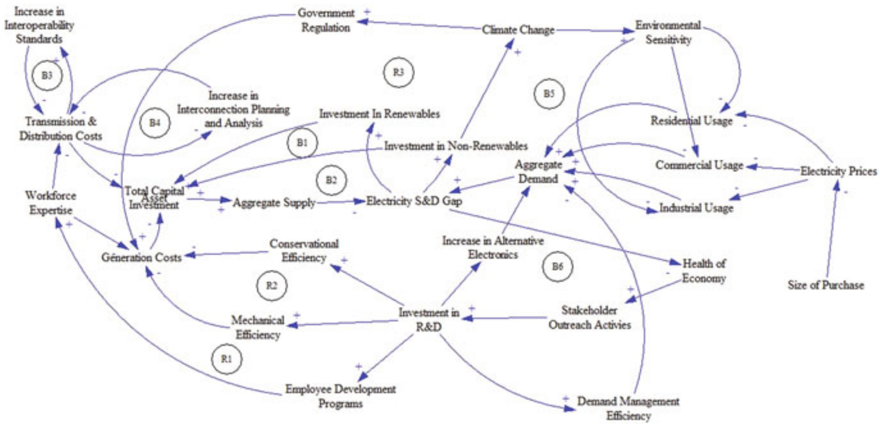

Fig. 1 Dynamic hypothesis. *Ri* represents reenforcing or positive feedback loops and *Bi* represents balancing or negative feedback loops (for details, please see in Sterman (2000))

Dynamic Hypothesis

Based on the comprehensive review of factors and policies on both the demand side and the supply side of electricity generation sector of Canada, we postulate a dynamic hypothesis, given in Fig. 1.

Figure 1 aims to describe the cause and effect relationships within our system. Below, we will identify and describe each loop in our diagram.

Investment in Renewables Loop Beginning with a large supply and demand gap (S&D gap), we notice that a large investment in renewable energy takes place. Furthermore, the higher the investment in renewable energy is, the higher the total investment in energy capital assets. The higher the investment in capital assets, the higher our aggregate supply will be, and the smaller our gap between supply and demand will be.

Investment in Nonrenewables Loop Beginning with a large S&D gap, we notice that a large investment in nonrenewable energy takes place. Furthermore, the higher the investment in nonrenewable energy is, the higher the total investment in energy capital assets. The higher the investment in capital assets, the higher our supply will be, and the smaller our gap between supply and demand will be.

Interoperability Standards Loop The higher our costs, the higher our increase in interoperability standards will be. This will result in cost reductions. As our costs decrease, the marginal benefit of increasing interoperability standards will decrease, and the rate of increase in interoperability standards will decrease as well, as its opportunity cost increases.

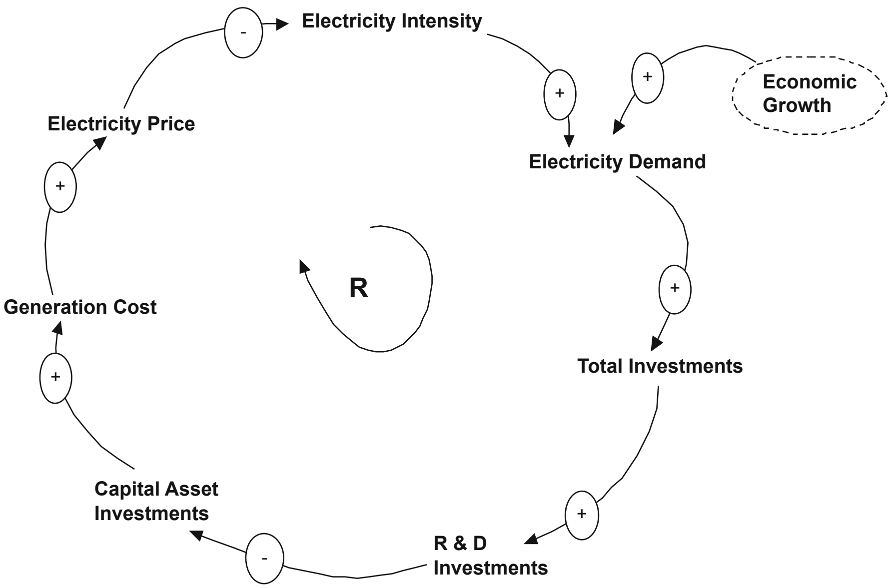

Fig. 2 Causal loop diagram of electricity pricing feedback loop

Interconnection Planning and Analysis (IP&A) Loop The higher our costs, the higher an increase in IP&A will be. This will result in cost reductions. As our costs decrease, the marginal benefit of increasing IP&A will decrease, and the rate of increase in interoperability standards will decrease as well as its opportunity cost increases.

Environmental Sensitivity Loop The higher our S&D gap, the higher our investment in nonrenewables will be. This will result in an increase in climate change, and as climate change becomes more noticeable, environmental sensitivity will increase. Environmental sensitivity will decrease our propensity to use electricity throughout the industry as a whole. Aggregate demand will decrease as a result, and our gap will narrow down.

Alternative Electronics Loop The smaller our S&D gap, the higher the health of our economy will be. Economic prosperity will foster an environment for stakeholder outreach activities, which in turn will increase investment in research and development. As a result of the increased research and development, our rate of increase in alternative electronics and equipment will increase, effectively reducing our aggregate demand through efficiency improvement. This in turn will narrow the S&D gap.

Employee Development Loop The higher our investment in R&D, the more employee development programs we will have. As a result, workforce expertise will increase, decreasing our generation costs, and increasing our capital asset investment. As a result, aggregate supply will increase, decreasing our gap, eventually leading to further increases in R&D, and more employee development programs. Figure 2 presents the electricity pricing loop explicitly.

Efficiency Loop The higher our investment in R&D, the higher both our conservational and mechanical efficiencies will be, decreasing our generation costs and increasing our total capital asset investment as a result. Aggregate supply will increase, decreasing our S&D gap, eventually leading to further investments in R&D, perpetuating an increasing cycle.

Government Regulation Loop The higher the climate change, the more government regulation we will have. This will increase our generation costs and decrease our capital asset investments, and furthermore our supply, increasing our gap. An increase in our gap results in further investment in substitute nonrenewables, which will continue climate change, increasing government regulation further later on.

Development of the Dynamic Model

Model Assumptions

In Ontario alone, the gap between supply and demand for electricity is expected to reach 15,000 MW by 2020. In order to get the total gap between supply and demand in Canada as a whole, we will use a relative value calculation. Ontario generates 26 % of total capacity in Canada. Assuming the gap in capacity will be a constant percentage throughout the country, we face a total gap of approximately 57,700 MW. This represents a 46 % requirement for capacity increase. We will also make the assumption that the % deficit in total capacity may be applied to each source of generation in the same manner. Therefore, the gap in hydro production will be 33,780 MW. The gap attributed to nuclear capacity will be 8,915 MW. The gap attributed to coal will be 10,401 MW. The gap attributed to natural gas will be 2,800 MW. Finally, the gap attributed to crude oil will be 1,314 MW (percent of total capacity by individual source provided by Statistics Canada).

In 2000, Canada had a total installed capacity of 111,000 MW. Today, capacity is 12 % higher, at 124,240 MW (Statistic Canada 2011). Because throughout the first decade of the new millennium capacity has grown in similar proportions, we will attribute this 12 % gain to each source in the same manner, to isolate for individual capacity growth. Between 2000 and now, hydroelectricity has therefore experienced an increase in capacity of 12,216 MW. Nuclear capacity experienced an increase of 2,077 MW (WNA 1996). Coal capacity experienced a growth of 2,422 MW. Natural gas experienced a growth of 652 MW. Finally, crude oil capacity experienced a growth of 306 MW. Accordingly, the growth rates per year are 2,036 MW/year for hydroelectricity, 346 MW/year for nuclear energy, 404 MW/year for coal energy, 109 MW/year for natural gas energy, and 51 MW/year for crude oil energy (WNA 2011).

As noted above, our forecasted deficit in electricity capacity will be 57,700 MW by 2025. For the purpose of this paper, we used Canada's 2006 capacity of 124,240 MW. Accordingly, in order to avoid a deficit in the year 2025, Canada's aggregate capacity needs to be 181,940 MW.

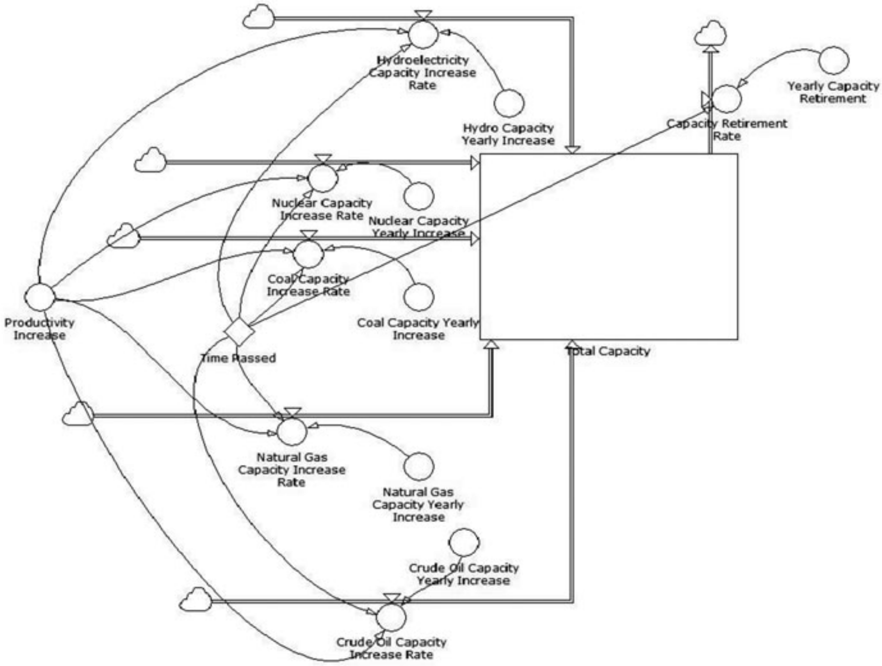

Fig. 3 The stock and flow structure of the dynamic model

Stock and Flow Structure of the Dynamic Model

The stock and flow structure of our dynamic model is presented in Fig. 3.[1] This model aims to assess various outcomes according to changes in rates of change in capital assets within the system.

Total capacity is a stock that has an initial value of 124,240 MW, Canada's total capacity to produce electricity in 2000. It is the aggregate capacity of the above 5 major sources for electricity production. This stock is increased by the flows representing rates of change of capacity by each individual source. Hydroelectricity capacity increase for example, is a function of the historical yearly change in capacity, productivity increases, and the time elapsed, which is set to one year, as all rates of change are assessed on a yearly basis. The same formula is applied to each of the five sources of energy. The auxiliary "productivity increase" represents a 0.3 % increase in usage efficiency, decreasing the amount that is required to be supplied (Canada's sector council program powering up the future 2008). Thus, all rates are multiplied by 99.7 %. Draining the stock is the decrease in capacity caused by asset retirement rate. This rate was attained by multiplying the retirement rate of 5,750

[1] Interested reader can contact the author for mathematical equations of this dynamic model.

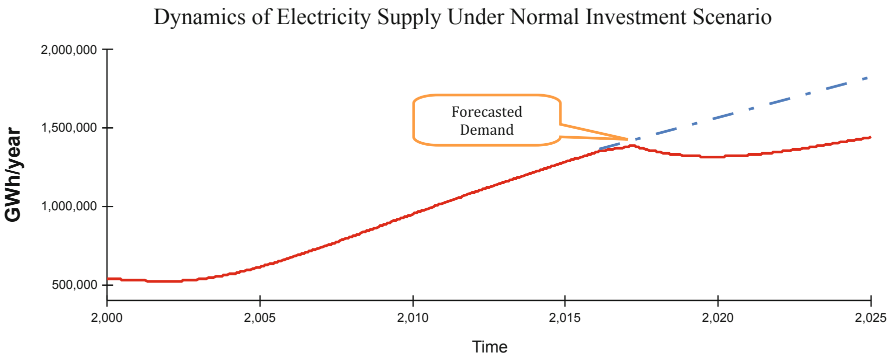

Fig. 4 Dynamics of electricity supply under status quo scenario

GWh worth of production per year by the average utility efficiency rate of 35.6 (NPC 2007; WNA 1996).

Validation of the Dynamic Model

System dynamics models are causal models (Barlas 1989). The essence of system dynamics modeling lies in identifying how the structure and decision policies help generate the observable patterns of behaviors of a system. Therefore, both the structural and behavioral validity procedures constitute the core of validation process for any system dynamics model. Our developed model was successfully exposed to both the structural and behavior validity procedures (for details on these tests, please see (Qudrat-Ullah 2012)).

Results

Capacity Under Status Quo Scenario

Our first simulation attempts to model Canada's electricity generation capacity if it continues to change at the current rate, as shown in Fig. 4. Involved in this simulation are the growth rates of capacity by each industry according to historical trends. We have only included major sources of electricity in this model, accounting for over 97 % of total capacity. The omitted sources are negligible at this time. According to this initial simulation, capacity will reach a total of 149,396 MW by 2025. This is 32,544 MW short of covering the forecasted gap. Therefore, maintaining current policy will not help in achieving the goal of having a balanced and sustainable supply and demand system of electricity in Canada.

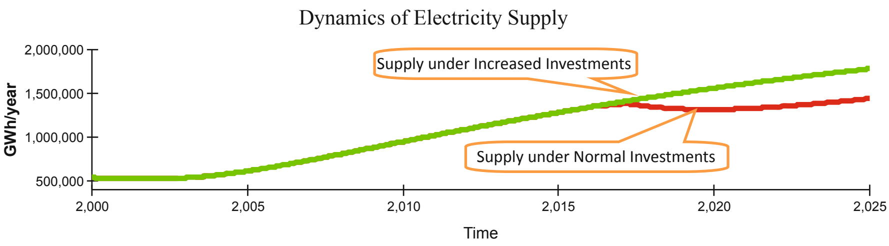

Fig. 5 Electricity Supply Dynamics

New Investments-Based Scenario

Our second simulation, however, involves the recommended US$ 95 billion investment in generation, US$ 27 billion investment in transmission, and US$ 63 billion investment in distribution (Canada's sector council program powering up the future 2008), as shown in Fig. 5. With this investment, capacity growth rate is expected to rise further by 58 % per year (IFC Consulting 2006). The adjusted rates of growth would therefore be 3,217 MW/year for hydro, 547 MW/year for nuclear, 638 MW/year for coal, 172 MW/year for natural gas, and 81 MW/year for crude oil. This policy is forecasted to close the projected gap between supply and demand for electricity. Accordingly, our model displays that according to this growth rate, capacity by 2025 will be 181,867 MW. Therefore, under this scenario, we can see the possibility of achieving the goal of having a balanced and sustainable electricity supply and demand system in Canada.

Concluding Remarks

With our theoretical review, dynamic hypothesis, and simulation model-based scenarios, we have attempted to explain the dynamics of variables acting within the electricity supply and demand system of Canada. Specifically, we have looked at variables within our generation capacity system. The key to the avoidance of a gap between electricity supply and demand, as well as sustainable, safe, and cost-competitive production, is to take advantage of the identified factors and potential policy decisions. In addressing our current supply and demand gap issue, we must not only continue to invest in capital assets for electricity production, but also continue our increased investments in R&D and productivity initiatives. Demand management and reduction, as well as production and end use machinery efficiency, play prominent roles in maintaining stability throughout the system. Canada must be prepared to diverge from traditional adjustment methods and adopt new strategies focused on *capital assets, productivity, and efficiency* in order to avoid a downward spiral of electricity industry deficiency.

As per our model-based analysis, an additional investment of about US$ 10 billion over a decade (2015–2025) will not only allow Canada to effectively close the supply and demand gap but also in a relatively greener way. With these additional investments, Canadian economy can also expect better energy intensity (0.21 versus 0.25 toe/million US$). This will result in wider recognition of Canada as a green economy (Conference Board of Canada 2010; Qudrat-Ullah, 2013).

By utilizing our developed simulation model, future research can investigate other related issues in the context of alternative policy design for Canadian electricity sector. For instance, in the identified capacity-mix, which capital asset should be preferred the most to support low-carbon economic regime. Our developed model is flexible enough to be adapted to model and analyze such issues. Therefore, besides providing useful policy insights on electricity generation capacity dynamics in Canada, this research contributes with an effective policy analysis and design tool in the form of a unique system dynamics-based simulation model. Researchers can calibrate the developed model to their case-specific data and can perform desired scenario-based analysis.

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