For a Sustained Canadian Energy Systems Modelling Initiative

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INSTITUT DE L'ÉNERGIE TROTTIER

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About the IET

The mission of the Institut de l'énergie Trottier (IET) is organized around the following three axes: training, research and dissemination. The IET thus seeks to foster a systemic and transdisciplinary understanding of energy issues for the next generation of engineers, to encourage the search for sustainable solutions to ensure the future of energy, and to raise the level of social debate on these issues.

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IQCarbone
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About IQCarbone

The Quebec Carbon Institute (IQCarbone) is a non-profit organization whose objective is to promote and disseminate research on climate change policy in Quebec and beyond.

To this end, the Institute will offer original and innovative research that will be distinguished by its quality and scientific rigor. The Institute also seeks to become one the largest group of specialists, experts and academics working on climate change policy in Quebec and elsewhere.

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The Clean Economy Fund is a funders collaborative designed to maximize and leverage philanthropic giving in support of a clean, low carbon, resilient and prosperous Canadian economy.

Table of contents

Executive Summary

While energy systems[i] are complex by nature, they are increasingly difficult to comprehend when society is being challenged to transform them to reduce the greenhouse gas (GHG) emissions known to be forcing climate change. In addition, disruptive forces such as artificial intelligence, information technologies, rapidly declining costs for distributed energy and storage are challenging industry sectors and business models that have anchored the economy of regions across Canada and around the world.

Indeed, as the emerging energy systems appear to be more centered on information, information technology and energy service markets, and relatively less on natural resources per se, the rationale for national leadership is strengthened. Some of the strongest economies in the OECD have little in the way of energy resources and yet they have significant national energy policies.

Energy systems models are therefore more important than ever to explore and quantify possible future energy pathways[ii], to examine the effectiveness of policy options, and to propose the most effective pathway for regions in their transformation to economic and environmental sustainability.

In this context, energy systems modelling plays a key role, as it is both a mean for understanding changes that are taking place and a prospective tool for decision-makers. It can inform governments and energy sector industries as well as, and perhaps more importantly, many non-energy sectors that are essential to the determination of energy demand and the production of greenhouse gases (GHG).

The validity and relevance of models' output depend intimately on both the quality of the input data (technologies, end-use demands for energy services, price of imported/exported commodities, reserve supply curves, etc.) and that of the models used. This is why it is urgent that Canada put a program in place to ensure sustained development and the application of energy models in support of its energy and climate change objectives.

Energy systems modelling is used in a number of countries to support and inform policy making, especially in the context of GHG reduction efforts. In the four jurisdictions reviewed in this document – the UK, Sweden, the US federal government and California – modelling is conceived as a "knowledge infrastructure" based upon:

- a clear, long-term institutional framework;
- dedicated resources for maintenance and operation; and
- an emphasis on local and national expertise for developing and running models relevant to national needs.

The present review of energy systems modelling best practices in these jurisdictions suggests four key principles to ensure the production of relevant information:

Transparency – Models and data must be **open-source** and **publicly available** to facilitate modelling analysis and ensure public accountability. **Timely access** to accurate and detailed energy data is also crucial for reliable modelling, especially as information requirements emerge with the advent new technologies (such as distributed energy resources and smart grid).

Trust – In order for policy-makers, civil society and the private sector to trust and act upon modelling results, these results need to be presented with a high-level of academic rigour and be **open for discussion, validation and comparison**.

Sustainability – Energy models and their associated data sets need not only to be developed, but also to be continually maintained, improved and updated. A **dedicated knowledge infrastructure** is necessary for this purpose in terms of data access, computational resources, and skilled people who will develop, maintain and run the models.

Clear Policy Linkages – Mandating that energy systems modelling be considered in the policy process is one way of **linking modelling to policy**. Such approaches not only improve accountability by requiring policy-makers to acknowledge the findings of modelling in their decision making, but they also build bridges between modellers and policy-makers, facilitating the understanding of modelling uncertainties and more timely updates on policies, and thus increasing their effectiveness.

[i] Energy systems are the technologies, the infrastructure and the habits associated with the recovery, the conversion, the transportation and the ultimate use of fuels and electricity in the form of services and goods. These systems impact the economy, environment, health and culture of human society.

[ii] Energy pathway is defined as a detailed description of the timing and magnitude of changes in technologies, infrasctructure or behaviour needed to achieve a target for emission reduction

The reality of Canadian federalism makes the actual modelling of energy systems and the design of organizations responsible for this modelling more complex than in unitary systems, increasing the need for modelling insights at both the federal and the provincial level. The political legacy of the 1980 National Energy Program is such that the Canadian federal government continues to be sensitive to anything hinting at a national energy strategy and preferred to let the Council of the Federation (CoF) announce a Canadian Energy Strategy in 2015. This situation, which is far from unique worldwide, does not further the establishment of a solid energy systems modelling capacity in the country.

In addition to a number of groups in universities across Canada, three main federal entities have undertaken energy systems modelling activities: the National Energy Board (NEB), Environment and Climate Change Canada (ECCC) and National Resources Canada (NRCan). Although these Canadian government bodies have acquired a certain degree of modelling capacity, it has generally been limited to the production of outlooks based on proprietary codes and data sets developed and run by consulting firms often based outside of Canada. In fact, two of the three main federal entities that have undertaken modelling activities have employed a foreign proprietary model (Energy 2020) in their latest initiatives: Environment and Climate Change Canada (ECCC) for *Canada's GHG Emission Trends*, and the National Energy Board (NEB) for its *Canada's Energy Future 2016*.

Unlike other jurisdictions, Canada does not have a program that supports sustained energy systems modelling. **Lacking long-term institutional support for energy systems modelling infrastructures**, much of the energy systems modelling in the country is performed by private consulting firms using proprietary models and data sets, a situation that raises concerns about a lack of transparency and the validity of the analyses.

Produced by the NEB, *Canada's Energy Future 2016* also highlights the **limited scenarization efforts** invested for producing energy outlooks since it presents only a business-as-usual scenario. For a more comprehensive outlook, we need to go back as far as 2006, the last year National Resources Canada (NRCan) produced one. Such a **limited capacity in the production of Canadian energy information and prospects** greatly limits the impact modelling can have on policy evaluations and design. Timely information on Canada's situation is more likely to be found in the Outlooks produced by the US Energy Information Administration (EIA) and the International Energy Agency (IEA) than in internal sources.

While most Canadian modelling efforts aspire to influence climate and energy policy, they **lack a framework linking them to the policy process**, and, as importantly, **suffer from limited efforts to consider linkages between energy and emission reduction efforts**. Although numerous pan-Canadian studies of the costs of energy and emission reduction are available for Canadian provinces and territories, to the best of our knowledge no study has sought to consider interprovincial cooperation on reducing emissions through pan-Canadian emissions trading or a harmonized carbon tax. ***Integrated energy systems modelling focused on emission trading implications certainly deserves more attention.***

It is clear from our review that Canada possesses world-class modelling expertise. However, two key items are lacking: (i) sustained and predictable long-term funding for the development, maintenance and operation of a variety of energy systems models; and (ii) a national setting that will allow experts to work together in dialogue with policy-makers and the broader public towards energy and climate goals in order to better include a systemic view in the policy process.

We therefore recommend that **the Canadian federal government commit resources to establish a permanent energy systems modelling initiative (ESMI)** that would:

1. Acquire or commission energy systems models that are in the public space, and managed to be open access, open source and transparent to trained users across Canada.
2. Make use of existing institutions to establish and sustain energy systems modelling knowledge infrastructure in a manner that reflects Canada's varied regions.
3. Support coordination of modelling, analysis and communication efforts across the country to ensure openness and independence, as well as collaboration, comparisons, exchanges and innovation.

1/Introduction

Most energy systems[iii] modelling efforts began in the 1970s when the global oil crisis sparked interest in using the then emerging computing power to explain how the economy and energy sector relate (Bahn et al., 2005; Huntington et al., 1982). The climate change challenge has renewed interest in energy systems modelling, which is now part of many climate policy initiatives.

Despite Canada's recent commitments under the 2015 Paris Agreement to reduce emissions by 30% below 2005 levels by 2030, there are serious concerns that the various pathways that could enable the country to reach this objective are not well understood. Canadian policy-makers are therefore left to make decisions largely in the dark, without sufficient knowledge of the technical, economic, social and political consequences – a situation that in part stems from a lack of use of energy systems modelling.

There is of course some energy systems modelling capacity in Canada, but it is spread across a number of only loosely coordinated government bodies, universities and consulting firms. More importantly, this capacity, particularly in the case of techno-economic modelling, tends to be tapped only on a project-by-project basis and mainly relies on closed and private models that are really only understood by their creators. Canada lacks a sustained, open and coordinated modelling program to ensure iterative learning, transparency, training and linkage to the energy and climate policy process.

This lack of capacity and the ensuing poor understanding of the energy sector have undercut Canada's previous climate efforts. Although Canada adopted a 6% reduction below 1990 emission levels target under the 1997 Kyoto Protocol (Bernstein, 2002: 221-223), it lacked the knowledge and planning to reach this ambitious goal. Partly because of the absence of a clear pathway, Canada's emissions have moved in the opposite direction, climbing 16% above 1990 levels by 2014 (Government of Canada, 2016).

Drawing on best practices in other jurisdictions – the United Kingdom, Sweden, the United States federal government, and California – this white paper demonstrates how other advanced economies are using energy systems modelling and energy specialists to devise more effective policies and actions, and makes the case for a sustained long-term energy systems modelling program adapted to Canada's needs and reality.

[iii] Energy systems are the technologies, the infrastructure and the habits associated with the recovery, the conversion, the transportation and the ultimate use of fuels and electricity in the form of services and goods. These systems impact the economy, environment, health and culture of human society.

2/On Energy Systems Modelling

While energy systems are complex by nature, they are increasingly difficult to comprehend when society is being challenged to transform them to reduce the greenhouse gas (GHG) emissions known to be forcing climate change. In addition, disruptive forces such as artificial intelligence, information technologies, rapidly declining costs for distributed energy and storage are challenging industry sectors and business models. Energy systems models are therefore more important than ever to explore and quantify possible future energy pathways[iv], to examine the effectiveness of policy options, and to propose the most effective pathway for regions in their transformation to economic and environmental sustainability.

2.1/What Is System Modelling?

In system modelling and simulation, mathematical equations are used to describe the interaction between the system's components, with the aim of reproducing the behaviour of specific characteristics of the system. By solving this set of equations or iterating its evolution under the influence of different constraints, information can be obtained for example about possible pathways to decarbonization, interactions across and between energy systems, impacts of various policies and technical measures, and costs associated with certain energy scenarios (Hall and Buckley, 2016: 612).

Energy systems modelling and simulation must be seen as a means for understanding changes taking place, as well as a prospective tool for decision-makers. It can inform policy and investment decisions not only by governments and energy sector industries, but also, and perhaps more importantly, by many non-energy sector industries that are central in determining energy demand and GHG emissions (e.g. building design, food system, personal mobility, urban design, etc.).

2.2/Data Requirements

All energy models require data as input, providing information about various technologies, end-use demands for energy services, the price of imported/exported commodities, reserve supply curves, etc. (Vaillancourt, 2010). The validity of the model output will depend intimately on the relevance of the model and the quality of the input data. It is therefore of crucial importance that up-to-date, reliable and pertinent energy data, including time series, be available as input to models.

2.3/Main Types of Models

Energy system models are typically classified[v] as either bottom-up or top-down (Bahn et al., 2005; Rivers and Jaccard, 2005; Vaillancourt, 2010). As summarized in Bahn et al. (2005):

> The bottom-up approach follows a technico-economic philosophy that leads to disaggregated models representing the energy sector with great details. By contrast, the top-down approach follows a macro-economic philosophy that leads to aggregate models in the sense that they use aggregate economic variables [...] These two categories of models are complementary [...] Bottom-up models are appropriate for assessment of new technologies and marginal cost analysis. Top-down models are more adapted to the analysis of the macro-economic impacts of energy policies.

Top-Down

Top-down models adhere to a macro-economic philosophy in order to simulate an energy system using aggregate economic relationships derived empirically from historical data. They capture relationships between the economic sector and other sectors of the economy, but they are not technologically explicit. This allows policy-makers to study the impacts of policies on the global economy and macro-economic variables such as employment and

[iv] Energy pathway is defined as a detailed description of the timing and magnitude of changes in technologies, infrasctructure or behaviour needed to achieve a target for emission reduction

[v] Another possible classification is between simulation and optimization, the latter corresponding to models computing optimal energy transition pathways (Bahn et al., 2005).

gross domestic product. Examples of such top-down models include computational equilibrium models like the R-GEEM (Regional General Equilibrium Energy Model) developed for Canada or the E-DRAM in California.

Bottom-up

Bottom-up models adhere to a techno-economic engineering philosophy in order to either explore a wide range of energy futures driven by technology, infrastructure or behaviour changes (exploratory models), or identify the lowest cost pathway to meeting energy service demands (while achieving emission reduction targets) based on best available technologies (optimization models).

Exploratory models allow researchers to assess the implications of changes (including disruptive changes) impacting our energy systems that are driven by a wide range of forces, including, but not limited to, GHG emissions or climate change policies. The concept behind exploratory models is to first identify a credible, compelling and desirable future that will meet societal objectives, and then explore the policy instruments that are best able to achieve that future. The Canadian energy system simulator (CanESS) model developed by WhatIf? Technologies Inc. is an example of an exploratory model.

Optimization models focus on specific criteria for energy systems change (e.g. lowering GHG emissions). Technology and various energy sources are considered in detail and are characterized explicitly according to their technical and economic attributes, while (useful) energy demand is expressed exogenously (Söderholm, 2012; Vaillancourt, 2010). By doing so, optimization models are able to predict how technology-oriented policies or carbon pricing schemes, are likely to shape energy systems change. Such studies are often of considerable interest to policy-makers. Examples of bottom-up optimization models include the IEA's MARKAL and TIMES.

Hybrid

Given the advantages and disadvantages of bottom-up and top-down models, hybrid models have been developed. One example is the CIMS model, developed at Simon-Fraser University for the modelling of Canadian climate policy (Rivers and Jaccard, 2005). Other examples include TIMES-MACRO models and the MERGE model (Manne and Richels, 2005; Kypreos and Bahn, 2003). Hybrid models are in particular expected to produce better costs estimates since bottom-up models alone usually tend to predict relatively low costs estimates for reducing emissions compared to top-down models.

Sectoral Models

In addition to these models representing typically whole energy sectors, a number of energy models focus on sectoral aspects crucial to the production, transport and use of energy. They include extraction and mining models, network and grid models, and building, energy efficiency and transportation models (see for instance Weijermars et al. [2012]). While these models have primarily been used in silos, energy transition requires a more integrated approach with increasing exchanges and communications between the various energy systems modelling communities.

Emerging Behaviour Modelling

The availability of large data sets and computational power has opened the door to new energy system modelling approaches based on detailed information about linked consumption patterns.

Commonly referred to as "Big Data" (Manyika et al., 2011), those new large data pools suggest fresh opportunities for energy systems modelling. Manyika et al. propose that Big Data will generate benefits not only by enabling experimentation to discover preferences, expose variability and improve performance, but also by replacing/supporting human decision making with automated algorithms, opening the way for innovative new business models, products and services. For those new system behaviours to be included in prospective modelling, a different family of models is required.

One such family is Agent-Based Modelling (ABM), where basic elements – or agents – are used to model system actors' heterogeneity, their social interactions and decision-making processes, including some complex emerging phenomena that cannot be easily captured by more traditional approaches, such as the diffusion of an innovation in a socio-economic system (Kiesling et al., 2012). One recent example is the arrival of distributed generation technologies like solar PV, which implies a "major technological and business model shift" that was not captured in traditional modelling forecasts (Rai and Henry, 2016).

2.4/Beyond Models

Improved modelling requires not only improved analytical techniques and computing power, but also understanding of the role of modelling in the policy process (Geels, 2016, No. 4036). The development of modelling capacity must therefore include support for an expert "outside" view than can provide a critical analysis of modelling results, recognizing the uncertainties, biases and limitations of each model, as well as of the approach as a whole (Flyvbjerg, 2013; Lovallo and Kahneman, 2003).

This topic is only beginning to attract the attention it deserves, given that the highly technical nature of modelling tends to inhibit interdisciplinary and transdisciplinary research. In the absence of a concerted energy systems modelling community, this aspect is under-developed and crucially lacking in Canada.

3/Best Practices for Integrating Energy and Climate Modelling into Policy Making

Energy systems modelling is used in a number of countries to support and inform policy making, especially in the context of GHG reduction efforts. Below we present four cases that are especially relevant to Canada.

3.1/United Kingdom

Institutional Framework

Climate Change Committee: The main organization responsible for coordinating the maintenance, use and development of different energy system models in the UK is the Committee on Climate Change (CCC). The CCC was officially formed in December 2008 under the Climate Change Act (CCC, 2008). An independent body, the CCC was established with the following mandate:

> Advising on the appropriate level of the UK's carbon budgets and steps required to meet them, monitoring progress towards meeting carbon budgets and recommending actions to keep budgets on track, conducting independent analysis into climate change science, economics and policy, and engaging with a wide range of organisations and individuals to promote understanding, and inform evidence-based debate on climate change and its impacts, in order to support robust decision-making (CCC, 2014).

Most of the members of the CCC are university professors, ensuring a link between this committee and the academic community, where most energy systems modelling activities are taking place in the UK. This includes the Grantham Research Institute on Climate Change and the Environment, which has offices at Imperial College, the LSE and the University of Cambridge. It is important to emphasize, however, that the CCC plays an advisory role only, with final decisions retained by Parliament. The CCC has been funded by the Department of Energy and Climate Change (DECC) and the Devolved Administrations (CCC, 2010b).

To perform these tasks, the CCC is also running energy models it has itself developed, although it can also use models developed and maintained by other organizations or mandate organizations to perform modelling work

Department for Business, Energy and Industrial Strategy (DBEIS), formerly DECC: The CCC was created under the DECC, which became the Department for Business, Energy and Industrial Strategy (DBEIS) in July 2016. The UK was one of the first countries to integrate climate change and energy issues in one department. The DBEIS publishes energy use and GHG emission projections every year for the UK, based on assumptions of future economic growth, UK population, electricity generation costs, fossil fuel prices, and other regularly updated key variables (DBEIS, 2017). The DBEIS has also developed the so-called Low Carbon Transition Plan to deliver government mandated Carbon Budgets (Lockwood, 2013), which are discussed in more detail below. While it undertakes its own modelling for this plan, it also takes the CCC's work into consideration.

Data Collection and Management

The main source of energy data in the UK is the Digest of UK Energy Statistics, also known as DUKES (Department for Business Energy and Industrial Strategy, 2017). It is managed by the Department for Business, Energy and Industrial Strategy and is updated and published every year with an extensive and detailed sector-by-sector picture of energy production and use over the past five years. Data sets, which date back to 1970, are freely accessible on the UK government website.

Existing Energy and Climate Models

Hall and Buckley performed a thorough review of the energy systems models used in the UK (Hall and Buckley, 2016). The DECC Energy Model, the primary forecast model applied by the UK government (AEA, 2011), is a top-down model intended to support diverse policy initiatives, which include deciding on the legislated Carbon Budget target levels (DECC, 2015). Other modelling approaches have been considered by the CCC to perform high-level analysis of pathways for reaching domestic reductions of CO2 to levels consistent with targets. Top-down approaches include HMRC's general equilibrium model and the Cambridge Econometrics macroeconomic model (CCC, 2010a). Bottom-up approaches include MARKAL-UK, as well as bottom-up scenarios developed by the CCC (CCC, 2010a).

Use of Energy and Climate Models in Decision Making

One of the clearest and most important uses of modelling in UK energy and climate policy has been its use in setting Carbon Budgets. In its first report from 2008, the CCC recommended the first three carbon budgets covering the period 2008-2022. Its propositions were easily adopted by the UK government in 2009. Although agreement over the CCC's proposal for a fourth Carbon Budget (covering the period 2023-2027) was not as straightforward (Lockwood, 2013), it was nonetheless finally adopted in 2011.

According to Lockwood, the fierce political debate over the fourth Carbon Budget demonstrates the value of the Climate Change Act: "[...] it is quite likely that without a law with long-term targets and an institution like the Committee on Climate Change standing behind it, a carbon budget for the 2020s would never have been agreed to by the Government." (p. 1346).

The fourth Carbon Budget emissions level and the identification of pathways to reach them were determined using the DECC Energy Model and MARKAL-UK (CCC, 2010a), demonstrating how central modelling is to decision making. The CCC's recommendation in the fourth Carbon Budget for electricity market reform, also based on modelling, included decarbonizing the electricity supply, ensuring security of supply and minimizing the cost of energy to consumers. The UK Government implemented this electricity market reform in 2013 (UK Government, 2013).

Beyond the use of energy systems modelling in the decision-making process, the UK has developed an innovative approach to use it as an education tool for the broader public. The 2050 Energy Calculator allows anyone to create their own energy pathway for the country and consider the choices and trade-offs involved (UK-DECC, 2013a). It enables the public to explore the fundamental question of how the UK can best meet energy needs while reducing emissions through (i) a Webtool, (ii) a simplified My2050 simulation game and (iii) the full Excel version for experts who want to look at the underpinning model (UK-DECC, 2013b).[vi]

3.2/Sweden

Institutional Framework

The Swedish Energy Agency (SEA) and the Swedish Environmental Protection Agency (SEPA) are together responsible for Swedish energy policy and modelling of the Swedish energy system. Both agencies report to the Ministry of Environment and Energy.

The SEPA has the primary responsibility for developing environmental policy and its implementation (SEPA, 2017) through drafting environmental scenario forecasts with the help of its sister agency, the SEA (IEA, 2013). It is also responsible for the biannual *Report for Sweden on Assessment of Projected Progress* that is submitted every two years to the European Parliament (SEPA, 2015a). For its part, the SEA is responsible for implementing the energy policy and performs, among other things, energy and environment computer modelling projections and forecasts, as well as related policy analysis. Every two years it produces a long-term scenario analysis that is the basis for climate reporting to the EU (Swedish Energy Agency, 2014b). Additionally, the SEA manages the Swedish arm of the EU Emission Trading System.

The SEA has been supporting research in the field of energy systems since the 1970s, with two main objectives: "to secure competence for future needs as well as to create direct benefits to decision-makers" (Swedish Energy Agency, 2014a), supporting more than 70 PhD theses through a dedicated energy research program. There is a clear effort to retain this knowledge and expertise in Sweden: more than half of these researchers have continued to work in Swedish universities and colleges, while the rest have been employed in other sectors of the "Swedish energy system" (e.g. SEA, Swedish Research Council, energy consulting firms, etc.).

In 2014, the Ministry of the Environment and Energy (Ministry of the Environment and Energy, 2014) tasked the SEA and SEPA to compare the Swedish experience with efforts employed elsewhere to undertake climate-economy modelling, including other Nordic countries, as well as Germany and the UK. This exercise led to the following recommendations: improved cooperation between the relevant agencies regarding long-term model development, better transparency, and a general leadership for the evaluation of the political instruments used in the climate policy.

In 2010, a special Parliamentary committee (Miljömålsberedningen, 2016a) was formed to examine what Sweden might learn specifically from UK energy and climate policy efforts (Miljömålsberedningen, 2016b). It concluded

[vi] The 2050 Energy Calculator is available on the internet at http://2050-calculator-tool.decc.gov.uk/#/home. The simulation game can be found at http://my2050.decc.gov.uk and the Excel spreadsheet at https://www.gov.uk/government/publications/2050-pathways-calculator-with-costs.

that the UK's ambitious modelling efforts, which involve detailed analysis of individual economic sectors to assess opportunities for emission reductions, was exemplary. The importance of the coordinating role of the UK's CCC was particularly highlighted: "A variety of different analyses also requires a coordinating role that translates and synthesizes them into an overall basis for decisions" (Miljömålsberedningen, 2016c: 402).

Data Collection and Management

The Swedish Energy Agency is responsible for official statistics concerning energy supply and use, energy balances and evolution of energy prices (Swedish Energy Agency, 2017). It has compiled all available energy statistics in a publicly available report entitled *Energiläget* (Energy Situation) every year since 1970.

Existing Energy and Climate Models

The Swedish government uses two main climate/energy/economic models to analyze energy and climate policies (2015b). The first is the Environmental Medium Term Economic Model (EMEC), developed and maintained by the National Institute of Economic Research (2017), which is a general equilibrium top-down model, and is used mainly for policy analysis (Östblom, 1999). The second model, MARKAL-Nordic, is a bottom-up energy-system model that is used to develop scenarios for energy use. The EMEC focuses on the interaction between the economy and environment, while MARKAL-Nordic targets the interaction between the energy and the environment (Riekkola, 2015). Along with others, these models were used to produce the *Report for Sweden on Assessment of Projected Progress* submitted to the European Parliament in March 2015 (SEPA, 2015a).

Use of Energy and Climate Models in Decision Making

Energy system modelling results produced by the SEA and SEPA inform government decisions to reach Sweden's emission reduction targets and other climate-related policy objectives.

In 2011, the Swedish Government tasked the SEPA to produce a roadmap for reaching a target of "zero net emissions" by 2050, considering various emission trajectories in different economic sectors (SEPA, 2012). This was to be done in collaboration with the SEA and other national authorities, including the National Institute of Economic Research; the National Board of Housing, Building and Planning; and the Swedish Transport Agency. Various modelling approaches were employed in the different sectors considered. For example, MARKAL-Nordic was used to identify the most cost-effective strategy to develop Sweden's 2050 energy system for the electricity and district heating sectors (IEA, 2013; Profu, 2012). Later in 2014, a Cross-Party Committee on Environmental Objectives was appointed to engage in a "broad political dialogue" about how to design a climate policy framework, taking into consideration results from the above 2050 roadmap work, and also to perform its own modelling work (Swedish Government, 2016b). The use of modelling was crucial in building a large consensus in the Swedish Parliament (Swedish Government, 2016a). While it is too early to say how these recommendations will be used in the decision-making process, there appears to be considerable political will in government to continue using modelling to determine how to most efficiently meet Sweden's emission reduction targets.

The SEPA and SEA also prepare the biannual *Report for Sweden on Assessment of Projected Progress* to the European Parliament The latest report, published in 2015, presents five-year emission projections between 2015 and 2035, based on analysis of policies and measures approved by the Swedish Parliament up to 2014 (SEPA, 2015a). In making these projections, different models are used for each sub-sector of the energy system in order to estimate energy use and corresponding emission trends.

3.3/US Federal Government

The United States, which, like Canada, has a federalist system of government, offers a number of important insights on how to involve energy systems modelling in decision making. Institutions that have been established in the US to advance energy systems modelling are reviewed below, followed by a discussion of the Energy Modelling Forum (EMF), an innovative partnership between government, academia and the private sector.

Institutional Framework

Department of Energy: The DOE has a broad role in developing energy policy and implementing the US federal government's energy research and development portfolio. Its mission is to ensure the country's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions. The DOE was established only in 1977, consolidating, among others, the Federal Energy Administration, the Energy Research and Development Administration, and the Federal Power Commission. It is ultimately responsible for the Energy Information Administration and the National Laboratories system.

Energy Information Administration (EIA): The EIA was established in 1977 as a department of the DOE in order to understand the implications of the global oil embargo. Now an agency within the DOE, the EIA collects, analyzes and disseminates high-quality independent and impartial energy information, owning and developing a number of modelling tools. Located in Washington, DC, the EIA counts about 370 federal employees and had an annual budget in fiscal year 2016 of $122 million. The EIA retains comprehensive state energy statistics in its State Energy Data System (SEDS), which allows for comparative inquiry into energy production, consumption, prices and expenditures across individual states. All data and analysis are available in a timely fashion for free on its website. The EIA's approach to data collection/management and its existing portfolio of energy and climate models are discussed in more detail below.

DOE National Laboratories: A key element towards realizing the DOE's mission is the system of 17 National Laboratories and Technology Centers that the department oversees. With capabilities that cut across the needs of the DOE's mission areas — such as high performance computing and accelerators — the national laboratories are key to mission success across the broad spectrum of the DOE's responsibilities and beyond. They are federally funded research and development centres that are designed to address special, long-term needs that cannot be met as effectively by government or private sector entities alone (DOE, 2017: 9-10). The National Laboratories are required to maintain expertise in areas critical to the national interest, operate with objectivity and a high degree of autonomy, and provide agile and rapid response capabilities.

Energy Modelling Forum (EMF): The EMF was established at Stanford in 1976 to bring together leading experts and decision-makers from government, industry, universities, and other research organizations to study important energy and environmental issues (Huntington et al., 1982). Its mission is to improve the use of energy and environmental policy models for making important corporate and government decisions by (i) harnessing the collective capabilities of multiple models, (ii) explaining the strengths and limitations of competing approaches to a given problem, and (iii) providing guidance for future research efforts (EMF, 2017). The EMF operates on the basis of the following four guiding principles:

(i) Impartiality – one technology, policy or energy perspective is not favoured over another;

(ii) User Orientation – models cannot improve decisions unless they are answering the right question;

(iii) Disclosure – "truth-in-modelling" flows from disclosing rather than hiding important assumptions, parameters, judgments and sensitivities; and

(iv) Understanding – insights about how markets work are much more valuable than precise numerical results (EMF, 2017).

At the heart of the EMF are ad-hoc working groups organized around a specific energy-related project. Each working group develops a study design in order to analyze and compare various models. These working groups do not try to forge a consensus but instead highlight why experts may disagree, with each group publishing a summary report and companion technical volume. The EMF inserts findings into policy debates through the participation of government staff in EMF activities and EMF staff provision of Congressional testimony. Corporate participants help to frame research questions and also learn about new technical issues. Finally, the EMF supports graduate students to pursue energy and environmental topics throughout the university, although it offers no formal degrees (Fawcett et al., 2015).

Data Collection and Management

Energy Information Administration (EIA): The EIA has two unique characteristics that facilitate data collection and management. First, its data, analyses and forecasts are, by law, independent of approval by any other officer of the government. Such independence has arguably allowed the EIA to establish the trust of data providers. Specifically, the EIA has the legal right to collect energy data as well as the legal obligation to protect it. Second, it is the only arm of the federal agency that actually does analysis, producing well-known projections including Short-Term, Annual and International Energy Outlooks, which are published on a regular basis and widely recognized as timely, authoritative outlooks on energy. This virtuous circle between energy data collection and analysis allows for results in mutual improvements in both data collection and analysis. The EIA's data collection program covers the full spectrum of energy sources, end-uses and energy flows, including coal, petroleum, natural gas, electricity, and renewable and nuclear energy.

Existing Energy and Climate Models

Energy Information Administration (EIA): The EIA uses different models for its various Energy Outlooks; the Short-term Energy Outlook uses the Regional Short-Term Energy Model, or RSTEM (EIA, No Date). This model relies on estimated econometric relationships between supply, inventories, prices and demand to forecast energy market outcomes one-to-two years ahead across key sectors and throughout nine regions of the US. The Annual Energy Outlook is developed using the National Energy Modelling System (NEMS), which is an energy-economic equilibrium model that aims to capture various interactions of economic changes and energy supply, demand and prices, with a projection horizon of approximately 25 years into the future (EIA, 2009; Gabriel et al., 2001). The NEMS can also be used to examine the impact of new energy programs and policies. Importantly, it is a regional model, though the regional disaggregation for each module reflects the availability of data as well as the regions determined to be the most useful for policy analysis. Finally, the EIA's International Energy Outlook uses the EIA's World Energy Projection System Plus (WEPS+) model (EIA, 2016: 273-274), which consists of a system of individual sectoral energy models using an integrated iterative solution process that allows for convergence of consumption and prices to an equilibrium solution. It is used to build Reference case energy projections, as well as Alternative energy projections based on different assumptions about GDP growth and fossil fuel prices. WEPS+ produces projections for 16 regions and/or countries worldwide.

National Laboratories and the EMF: In addition, a large number of technical and techno-economic energy and climate models are developed, maintained and used at National Labs (e.g. NREL and NASA) and universities across the USA for research and policy support. A recent study by the Energy Systems Modelling Forum (EMF 24) compared nine models in their capacity to model different technology strategies for achieving climate policy objectives (Fawcett et al., 2015). See Table A1 in the Appendix. In general, models differed in the breadth of their coverage, geographic resolution, technological choice and foresight projections, as well as in assumptions about the availability of negative emissions technology such as CCS with bioenergy.

Use of Energy and Climate Models in Decision Making

In the US, models are used at various levels for decision making. For example, the NEMS is regularly used for special analyses at the request of government officials and agencies, typically with specific scenarios and assumptions provided for the analysis (EIA, 2009:2-3). They have included the energy market and the related economic impacts of the American Clean Energy and Security Act of 2009 and the Lieberman-Warner Climate Security Act of 2007.

To ensure more informed decision making, the Quadrennial Energy Review (QER) was established under the Obama administration to enable the federal government to translate policy goals into a set of analytically based, integrated actions — executive actions, legislative proposals and budget and resource requirements for proposed investments — over a four-year planning horizon. Enabled by the science, technology and analytical expertise within the National Laboratory System, the first instalment of the QER, focusing on national infrastructure for energy transmission, storage and distribution, was published in 2015 (QER, 2015), while a second instalment, reviewing the nation's electricity system from generation to end-use, was published in 2017 (QER, 2017).

3.4/California

Institutional Framework

California offers an opportunity to look at how energy and climate modelling is undertaken within a subfederal jurisdiction. Because of California's early efforts to tackle air pollution, the state obtained privileged status under the 1970 Clean Air Act to implement stricter vehicle air pollution regulations than the federal government (Berck et al., 2010; Corman, 2004; Hanemann, 2007). California's air pollution standards are at the heart of its overall climate strategy (Mendelson, 2008). While efforts to reduce California's emissions to 1990 levels by 2020 are well known (Mazmanian et al., 2008; Mazmanian et al., 2013), including a cap-and-trade system and regulations such as vehicle emissions standards, the California state legislature has recently committed to reducing emissions 40% below 1990 levels by 2030 (Siders, 2016).

The relative autonomy of California in the US federal system helps explain the robustness and capacity of its organizations for energy and climate policy in the state: that is, the California Energy Commission (CEC) and the California Air Resources Board (CARB). The CEC is responsible for the biannual *Integrated Energy Policy Report* (IEPR), while the CARB updates a climate change Scoping Plan every five years. The mandates of the two organizations have become increasingly intertwined with the most recent IEPR stating that "Addressing Climate Change Is the Foundation of California's Energy Policy" (CEC, 2015: 8).

Data Collection and Management

Through its Energy Assessments Division, the CEC collects energy-related data and conducts surveys and assessments of California's energy systems and trends, while also building in-house modelling and analytical capacity (CEC, 2017). The Supply Analysis Office collects data, produces analyses and provides policy expertise on a wide range of energy supply issues, including the markets and infrastructure that provide energy to California. The office is comprised of engineers, economists and other scientists who offer a multi-disciplinary view of California's energy sector. The Demand Analysis Office provides energy demand forecasts to policy-makers by collecting and analyzing data on electricity peak demand and consumption, natural gas consumption and transportation fuel use. The staff of engineers, economists and statisticians also relies on information collected, using surveys to better understand Californians' energy-related behaviour and end-use.

The CARB is the principal steward of California's GHG emission inventory (CARB, 2017). Its primary data is sourced from reports submitted to the Board through the Regulation for the Mandatory Reporting (MRR) of GHG emissions. The MRR requires facilities and entities with more than 10,000 tCO2e of combustion and process emissions, all facilities belonging to certain industries, and all electric power entities to submit an annual GHG emissions data report directly to the CARB. Reports from facilities and entities that emit more than 25,000 MTCO2e are verified by a CARB-accredited third-party verification body.

Existing Energy and Climate Models

The CARB uses bottom-up and top-down models to evaluate policy options for reducing emissions across all sectors of California's economy: Energy 2020 (bottom-up) and E-DRAM (top-down) (CARB, 2010; E3, 2017). In addition, the CEC and CPUC have used the PATHWAYS model to develop several scenarios that varied the mix of low-carbon technologies and the timing of deployment (E3, 2017). Significantly, the CARB has also undertaken modelling exercises of its carbon market linkage with Quebec (CARB, 2012), which has also been studied by the Western Climate Initiative (WCI Economic Modeling Team, 2012).

Use of Energy and Climate Models in Decision Making

In the biannual IEPR, the CEC reports on trends and issues concerning electricity and natural gas, transportation, energy efficiency, renewables, and public interest energy research. One of the most important applications of energy systems modelling policy is the production of a single forecast set in the context of the CEC's biannual IEPR (CEC, 2015: 138-145). It is composed of a baseline forecast and projections for additional achievable energy efficiency savings (AAEE). An AAEE is a forecast scenario depicting energy efficiency savings deemed likely to occur in the foreseeable future, including impacts from future policies. The forecast set forms the basis for a managed forecast to be used for planning purposes in the subsequent year by the CEC, the California Public Utilities Commission (CPUC), and the California Independent System Operator (CAISO). The electricity and natural gas forecasts are used in various planning processes that are meant to ensure that California customers can rely on an adequate energy supply at reasonable prices. The CEC has joined forces with the CPUC and CAISO to form an interagency process alignment technical team to discuss technical issues and improve infrastructure planning coordination (CEC, 2015: 130).

Under the Global Warming Solutions Act of 2006, known as Assembly Bill 32 (AB-32), California is required to develop a comprehensive Scoping Plan to "identify and make recommendations on direct emission reduction measures, alternative compliance mechanisms, market-based compliance mechanisms, and potential monetary and nonmonetary incentives" in order to attain California's 2020 emission reduction goal, as well as to achieve "the maximum technologically feasible and cost effective GHG emission reductions" (Núñez, Chapter 488, Statutes of 2006: §38560, 38561(b)). A first Scoping Plan was adopted in 2008 (CARB, 2008), which, under AB-32, must be updated at least every five years. The most recent update, presented in early 2017, maps a strategy to meet California's 2030 emission reduction target (CARB, 2017). The 2008 Scoping Plan relied on economic models (CARB, 2008: 73-80). Most importantly, to evaluate the economic impacts of the Scoping Plan, the CARB compared estimated economic activity under a business-as-usual (BAU) case to the results obtained when actions recommended in the Plan are implemented. The BAU case represents the forecasted statewide emissions with existing policies and programs, but without any further action to reduce emissions. Significantly, the BAU case was constructed using forecasts from the California Department of Finance, the California Energy Commission and the E-DRAM model. In order to examine the economic impacts of cap-and-trade, California and other WCI partner jurisdictions contracted with ICF International and Systematic Solutions, Inc. (SSI) to perform economic analyses using ENERGY 2020, a multiregion, multi-sector energy model.

4/Energy Systems Modelling Key Principles

Our review of energy systems modelling best practices in the UK, Sweden, the US federal government and California points to a number of best practice principles for energy systems modelling.

4.1/Transparency: Open Data and Modelling

The case-study countries investigated suggest continued movement towards open data and modelling. First, access to high-quality, detailed and timely energy data is crucial for reliable modelling, especially as information requirements for energy systems modelling and smart grid management increase. Any modelling outputs will only be as good as their underlying data: "garbage in, garbage out." Efforts to improve data acquisition at appropriate institutional levels should be emphasized. We also noted that a single agency is responsible for gathering and providing such data in the UK, Sweden and the US. Complementarity between federal and sub-federal institutions is also not to be shunned, as illustrated by the California Energy Commission's gathering of energy-related information for use in its modelling efforts. It must be stressed that any organization responsible for data should have the legal right to collect it and the legal obligation to protect it, which was perhaps most clearly observed in the case of the EIA. Finally, it is also important that data be made publicly available, which not only facilitates modelling analysis, but also ensures public accountability. By default, for example, all information gathered by the EIA is public and data providers must make substantiated cases to remove it from the public eye.

We have also seen movement towards open modelling, most clearly in the case of the 2050 Energy Calculator in the UK. Available in varying levels of sophistication (for beginners, those with intermediate interest, as well as access to the full spreadsheet for technical experts), the 2050 Energy Calculator offers an unparalleled degree of transparency about the modelling process. Such an approach has the advantage of retaining a sophisticated model in a user-friendly way, with considerable supporting documentation to probe assumptions and cultivate deeper understanding.

4.2/Trust: Modelling Forum for Discussion, Validation and Comparison

In order for policy-makers, civil society and the private sector to have faith in modelling results, modelling methods and their outcomes must be openly discussed, validated and compared with a high-level of academic rigour. Models need to be tested and compared to verify that the results they produce are reasonable. In fact, having a critical mass of models whose outputs are similar to each other increases confidence in model outcomes. The Energy Modelling Forum (EMF) in the US is undoubtedly the best example of such an institution, although model comparisons have also been undertaken in the UK and Sweden.

4.3/Sustainability: Dedicated Knowledge Infrastructure

Modelling activities are much more than mere mathematical equations. They also include data validation and analysis that requires sophisticated computing power and human expertise. Energy models are never developed in isolation; they need informal and formal venues for experts to discuss methods among themselves, to build understanding of new technologies and policy developments, and to cultivate dialogue between different academic disciplines.

Knowledge infrastructure must also include dialogue with policy-makers, the civil society and the private sector. This needs to be a two-way street: where modelling experts make efforts to communicate their findings and also listen to community needs and concerns about assumptions and research practices.

Energy models and their associated data sets need not only to be developed, but also to be continually maintained, improved and updated. A dedicated infrastructure is needed for this purpose in terms of data access, computational resources and skilled people who will develop, maintain and run the models. Importantly, a venue must be available where modelling techniques and findings can be discussed among experts, as well as with decision-makers, civil society and the private sector. Sustained funding is required to maintain such a structure and to prevent loss of the knowledge acquired.

4.4/Clear Policy Linkages: Institutional Framework Linking Modelling to Policy

A clear institutional framework linking energy systems modelling to energy and climate policy processes was noted in the UK, Sweden and California. The Committee on Climate Change in the UK is the best example of such an institution. While modelling is not the sole factor driving public policy decisions in any of these jurisdictions, the fact that energy systems modelling is required to be considered in the policy process offers a number of advantages. First, it improves accountability by requiring policy-makers to acknowledge the findings of modelling in their decision making. Second, it builds bridges between modellers and policy-makers, improving mutual understanding of the nature of the professional activities of each. Improved communication between modellers and policy-makers facilitates the communication of modelling uncertainties. Third, a link between modelling and policy processes allows for more timely updates on policies and thus increases their effectiveness.

5/The Canadian Situation

5.1/Canadian Federalism

Canada is a federation with constitutional responsibilities shared between federal and provincial and territorial governments. Provinces tend to possess significant constitutional powers over matters related to natural resources and the environment within their borders (Morton, 1996). The Canadian federal government is responsible for interprovincial and international affairs, including energy transport (interprovincial pipelines and electric grids), energy efficiency regulations and standards, and for bearing primary responsibility for supporting research and development.

In the UK, Sweden and California, government bodies responsible for energy and climate policy are the same as those responsible for modelling efforts and data acquisition, even though California's efforts are supported by federal agencies including the EIA. The reality of Canadian federalism (described in Table 1) makes both the actual modelling of energy systems and the design of organizations responsible for this modelling more complex than in unitary systems, as in the UK, Sweden and California, thus increasing the need for modelling insights at both the federal and the provincial level.

Table 1 – Distribution of responsibilities regarding energy in Canada

Federal Responsibility	Shared Responsibility	Provincial Responsibility
• International and interprovincial energy trade	• Environmental regulation of energy projects	• Ownership and management of energy resources
• International and interprovincial energy infrastructure	• Trade and investment	• Royalty design and collection
• Regulation of nuclear energy and uranium	• Management of uranium mining safety	• Uranium mining
• Energy resources on federal Crown land, offshore and North of 60°	• Management of offshore under Accords	• Electricity production, distribution and regulation
• Regulations and standards relating to energy efficiency	• Energy efficiency and scientific research and development	• Land-use planning and allocation
		• Laws and regulations on exploration, development, conservation and energy use

Source: (IEA, 2016: 23)

5.2/The Council of the Federation

The political legacy of the 1980 National Energy Program is such that the Canadian federal government continues to be sensitive to anything hinting at a national energy strategy (Doern et al., 2015: 149). It was therefore left to the Council of the Federation (CoF), a body that brings together provincial governments, to announce a Canadian Energy Strategy in 2015 (CoF, 2015). Key themes and areas of focus of the strategy are presented in Table 2. Since the rights of First Nations peoples in natural resource management are increasingly being recognized, First Nations peoples and representative organizations will have to be partners in developing Canada's energy future (Krupa, 2012).

Table 2 – Themes and areas of focus of the 2015 Canadian Energy Plan

Sustainability And Conservation	Technology and Innovation	Delivering Energy to People
1. Promote energy efficiency and conservation. 2. Transition to a lower carbon economy. 3. Enhance energy information and awareness.	4. Accelerate the development and deployment of energy research and technologies that advance more efficient production, transmission, and use of clean and conventional energy sources. 5. Develop and implement strategies to meet energy sector human resource needs now and well into the 21st century. 6. Facilitate the development of renewable, green and/or cleaner energy sources to meet future demand and contribute to environmental goals and priorities.	7. Develop and enhance a modern, reliable, environmentally safe and efficient series of transmission and transportation networks for domestic and export/import sources of energy. 8. Improve the timeliness and certainty of regulatory approval decision-making processes while maintaining rigorous protection of the environment and public interest. 9. Promote market diversification. 10. Pursue formalized participation of provinces and territories in international discussions and negotiations on energy.

Source: (CoF, 2015: 9)

5.3/Energy Systems Modelling in Canada

Vaillancourt et al. (2014) provide an overview of current energy systems modelling in Canada (Table 3). They identify three main federal entities that have undertaken modelling activities: the National Energy Board (NEB), Environment and Climate Change Canada (ECCC) and National Resources Canada (NRCan). The models used are generally employed to forecast trends in energy and GHG emissions. The NEB has used a private bottom-up and top-down model together in a common, integrated framework to project Canadian energy supply and demand: Energy 2020 and TIM (The Informetrica Model), respectively. ECCC has employed a modelling framework referred to as the Energy, Emissions and Economy Model for Canada (E3MC), which is based on Energy 2020 and in-house models, to project future emission trends (Environment Canada, 2014). NRCan has used MAPLE-C (Model to Analyze Policies Linked to Energy in Canada), an equilibrium model designed to forecast energy supply, demand and emissions — although this model is no longer used to provide outlooks, the last dating back to 2006. Energy systems modelling of Canada's situation is also performed internationally by the EIA and IEA when producing global energy outlooks (Vaillancourt et al., 2014).

While the above Canadian government bodies have acquired a certain degree of modelling capacity, it has generally been limited to the production of outlooks based on modelling codes developed and generally run by consulting firms. More advanced modelling competence has been developed at Canadian universities and related consulting firms:

- The CIMS model was developed at Simon Fraser University's Energy and Materials Research Group, with numerous applications undertaken by the related consulting firm of Jaccard and Associates, now known as Navius. CIMS is a hybrid model integrating both bottom-up and top-down approaches (Rivers and Jaccard, 2005).
- The Canadian Energy Research Institute (CERI) has developed a stock-rollover module, which we have called Canada Pathways, similar to the PATHWAYS model developed in California (CERI, 2017-9; Williams et al., 2012a, b).
- The Canadian Energy Systems Simulator (CanESS) has been developed by whatIf? Technologies in Ottawa with assistance from the Canadian Energy Systems Analysis Research (CESAR) initiative at the University of Calgary (CESAR, 2017a). The CanESS is an integrated, multi-fuel, multi-sector, provincially-disaggregated energy systems model for Canada that enables bottom-up accounting for energy supply and demand (CESAR, 2017a; Trottier Family Foundation, 2016: 40). It is currently being used in the CESAR Pathways Project (2017b).
- The EnviroEconomics consulting group in Ottawa has also used the CIMS model in tandem with the R-GEEM in a recent analysis for Canada's contribution to the Deep Decarbonization Pathways Project (Sawyer and Bataille, 2016).

- The Canadian MARKAL optimization model was first developed by the Group for Research and Decision Analysis (GERAD) at Université de Montréal (Loulou et al., 1992), which was later updated and replaced by a Canadian TIMES (the Integrated MARKAL-EFOM Systems) model (Vaillancourt et al., 2014). The most advanced TIMES model for Canada today is part of the NATEM (North American TIMES Energy Model) platform developed by ESMIA Consultants used in several policy analysis projects (Vaillancourt et al., 2017) and refined through academic projects at Université de Montréal (Levasseur et al., 2017). The MARKAL/TIMES model generators are supported by the Energy Technology Systems Analysis Program of the IEA and used in some 70 countries (ETSAP, 2016).

Table 3 provides an overview of energy systems modelling performed in Canada. Finally, it should be pointed out that influential forward-looking reports about crude oil markets and transport produced by the Canadian Association of Petroleum Producers (CAPP) are not based on modelling but rely instead on surveys of its membership and their own forecast techniques (CAPP, 2015: 1-2).

Table 3 – Overview of energy systems modelling in Canada

	Canadian Govt. Bodies			Canadian Universities/Consulting Firms				
Model type/ Organization	National Energy Board	Environment Canada	Natural Resources Canada	Simon-Fraser/ Navius (Vancouver)	CESAR/ WhatIf? (Calgary/ Ottawa)	CERI/ CESAR (Calgary)	EnviroEconomics (Ottawa)	Uni. Montréal / ESMIA (Montreal)
Top-Down	The Informetrica Model (TIM)		MAPLE-C	R-GEEM			(R-GEEM)	
Bottom-Up	Energy 2020				CanESS			MARKAL / TIMES / NATEM
Hybrid		E3MC		CIMS			(CIMS)	MERGE
Stock-Flow						Canada-PATHWAYS		

The above models have been harnessed in a number of recent Canadian climate-energy systems modelling initiatives (ECCC, 2016: 13-14). A 2015 assessment from the Council of Canadian Academies concluded that Canada can significantly reduce emissions by using commercially available technologies and identified many existing technologies able to achieve further reductions. The assessment, carried out by an eight-member expert panel, did not undertake primary research but rather sought to clarify issues that civil society and the private sector are generally unfamiliar with or may be confused about, but that are widely understood and accepted by energy and climate experts and supported by the literature (CCA, 2015: 5). The Deep Decarbonization Pathways Project (Sawyer and Bataille, 2016) identified six decarbonization pathways for Canada, suggesting that Canada can make significant progress through the decarbonization of the electricity grid using mainly renewable energy sources, some fossil fuels with CCS, and replacement of combustion-based energy sources with electricity in many sectors. Emissions reductions were driven by a policy package of performance-based technology regulations and carbon pricing. The Trottier Energy Futures Project (Trottier Family Foundation, 2016) looked at 11 different scenarios for Canada to achieve different levels of GHG reductions by 2050, using one optimization model and one simulation model. The main pathways for reducing emissions included expanding the use of non-emitting electricity, increasing the use of biofuels in the transportation sector and improving energy conservation and efficiency. The report also noted that further research is needed on ways to achieve net-negative GHG emissions.

5.4/Gaps in Current Canadian Energy Systems Modelling

Lack of Support for Open Energy Systems Modelling

As opposed to other jurisdictions, Canada does not have a program that supports energy systems modelling or integrates it into policy design. Although modelling capacity exists in Canada, it is spread across various government bodies, university research institutes and consulting firms.

Without institutional support, however, much of the energy systems modelling in Canada is performed by private consulting firms using proprietary models and data sets raising concerns about a lack of transparency. This inhibits civil society and private sector trust in results because decisions about modelling, such as policy assumptions and key parameters, are often made only by those experts capable of running the models. While we recognize the considerable expertise of those responsible for running models, concerns about "optimism bias" and the "planning fallacy" (see Flyvbjerg, 2013) suggest that opening up the modelling process would be beneficial.

Data Gaps and Relatively Limited Modelling Efforts

In contrast to observed best practices for data collection and management in other jurisdictions, there are considerable delays in the production of Canadian energy information. The last two outlooks produced by the NEB date from 2013 and 2016 (NEB, 2016), with very limited scenarization, while the latest from NRCan goes back to 2006 (NRCan, 2006). These delays substantially limit the impact of modelling on policy evaluations and design. Similarly, the last emissions projections by Environment Canada date from 2014 (ECCC, 2017). Yet we know that much can change in three years.

There are also recognized gaps and inconsistencies in Canada's energy data (EMMC, 2012). Moore et al. (2012) observe that Canadian energy-related data are gathered by a wide variety of agencies with varying standards, using different evaluation and analytic tools, and that the resulting data are spread through various portal and access points, often with considerable delay.

Lack of Planning Framework to Link Modelling to Energy and Climate Policy

While many modelling efforts aspire to influence climate and energy policy in Canada, they tend to lack a planning mechanism linking them to the policy process. Both the UK and California saw modelling used to a significant degree in energy and climate planning documents, often emerging as a link connecting the two policy issues. The UK has developed a comprehensive Low Carbon Transition Plan, while in California considerable planning exercises have been undertaken, including the CEC's biannual Integrated Energy Policy Report (IEPR) and the Scoping Plan and CARB updates. The emphasis on planning is not to suggest that these jurisdictions are succumbing to Soviet-style central planning. Rather, it suggests that state planning and liberal economic policy might be combined in interesting ways that might not have been imagined only a decade ago.

Historically, the National Round Table on the Environment and Economy (NRTEE), formed in 1988 as an independent policy advisory agency to the federal government, had a mandate to bring Canadians together to design and implement new sustainability tools, assess the options available and make recommendations to the Prime Minister and Cabinet (Page, 2013: 6). The NRTEE was unique in that it was able to develop its own modelling expertise, for example employing CIMS, TIM, and D-GEEM to investigate carbon pricing (NRTEE, 2009). It also has to be able to contract firms for specific modelling work, as it did in 2012 when it requested that Navius perform a reality check on the state of climate policy in Canada (NRTEE, 2012). However, the NRTEE ceased to exist in 2013 when its funding was cut (NRTEE, 2013).

Limited Analysis of Links between Energy and Pan-Canadian Emission Reduction Efforts

Another significant aspect of current energy systems modelling efforts is the limited effort to consider linkages between energy and emission reduction efforts. More work is indeed needed in the area of integrating electricity markets (Pineau, 2013) as potential synergies could be developed between provinces with clean energy surpluses and their neighbours to avoid GHG emissions (Amor et al., 2011). Integrated energy systems modelling focused on emission trading implications certainly deserves more attention. To the best of our knowledge, the economic impact of linking California, Quebec and Ontario through cap-and-trade has been the subject of only a handful of studies (CARB, 2012; Sawyer et al., 2016; WCI Economic Modelling Team, 2012). While numerous pan-Canadian studies of the costs of energy and reducing emissions are available for Canadian provinces and territories (for example, Rivers, 2010), as far as we know, no study has sought to consider interprovincial cooperation on reducing emissions through pan-Canadian emissions trading or harmonized carbon tax, with the notable exemption of Vaillancourt et al. (2017).[vii]

[vii] This study considers a Canada-wide GHG reduction target. The marginal reduction cost computed by NATEM corresponds to a harmonized carbon tax that should be imposed on each of the 13 Canadian provinces and territories (distinguished by the model) in order to globally achieve the Canadian target.

6/Moving Forward

It is clear from our review that Canada possesses world-class modelling expertise. However, two key items are lacking: (i) sustained and predictable long-term funding for the development, maintenance and operation of a variety of energy systems models; and (ii) a national setting that will allow experts to work together in dialogue with policy-makers and the broader public towards energy and climate goals in order to better include a systemic view in the policy process.

We therefore recommend that **the Canadian federal government commit resources to establish a permanent energy systems modelling initiative (ESMI) that would**:

1) **Acquire or commission energy systems models that are in the public space, and managed to be open access, open source and transparent to trained users across Canada.**

   The ESMI should be committed to building transparency, trust, sustainability, and policy clarity. To do this, the models need to be government owned and/or in the hands of a not-for-profit organization with a mandate and governance that is committed to open access and open source. This will democratize energy systems modelling and instil greater confidence in the tools while expanding their capabilities and generating insights that are useful to decision makers.

   At a minimum, we suggest that the funding be sufficient to establish a sustained program to help Canada achieve its 2030 and beyond emission reduction commitments under the Paris Agreement.

   While we are not recommending a specific governance model, we do recommend that this initiative be managed by ministries or agencies that have a specific interest in accessing these simulation tools and insights that they will generate.

2) **Make use of existing institutions to establish and sustain energy systems modelling knowledge infrastructure in a manner that reflects Canada's varied regions.**

   Because Canada's federal nature is particularly important for energy and climate policy, it needs to be integrated into any design. The successful institutional designs observed in unitary states, including the UK and Sweden (and to a certain degree, California), are not directly applicable.

   Accordingly, we suggest that this new knowledge infrastructure be realized through a set of multidisciplinary, interacting, regional hubs at universities across Canada that would support modelling development and operation relevant to their region. These hubs would also train experts in (a) the development of new model capacity, (b) how to use of the models to address questions that are important to decision makers, and (c) how best to communicate the insights to decision makers and the general public who are critical to any energy systems transformation.

   These hubs would require permanent research staff able to develop, maintain and run models and databases, under the supervision of professors.

   These regional hubs would also be able to work in close proximity with provincial governments, the private sector and First Nations, institutionalizing iterative encounters between energy experts and decision-makers and relevant stakeholders at all levels.

   The proposed institutional context reflects energy systems modelling best practices observed around the world, while considering the particularities of Canada's unique geography and federal system. It promises to build on universities that are the model for the development of knowledge in Canada, and its use of existing institutions makes it easier to put in place.

3) **Support coordination of modelling, analysis and communication efforts across the country to ensure openness and independence, as well as collaboration, comparisons, exchanges and innovation.**

   Coordination between the various institutions supported by this initiative is essential to make sure that the diverse codes and data sets are available to all, can interoperate and can be compared.

   National coordination will facilitate exchanges and collaborations between institutions and researchers, increasing the weight of Canadian contributions to energy systems modelling on the international scene. It will also help the transfer of knowledge to various governments, agencies, industry and other civil stakeholders.

   In addition, national coordination will facilitate the identification of gaps in modelling approaches and highlight new needs in energy data.

Appendix

Table A1: Overview of Key Characteristics of the Versions of Participating Models Used in EMF 24

Model	Covered sectors	Number of US Regions	Covered Gases	Model Base Year	Model of Technology Choice
ADAGE	Energy, Rest of Economy (Limited Land Use)	6	CO2, CH4, N2O, HFC, PFC, SF6	2010	CESproduction function
CIMS	Energy	1	CO2, CH4, N2O	2005	Probabilistic choice model
EC-IAM	Energy, Rest of Economy (no Land Use)	1	CO2, CH4, N2O, Short lived F-gases, long lived F-gases	2000	Linear/Non-Linear programming (Electric supply Sector, Non-Electric Energy Supply Sector); CESproduction function (Rest of Economy)
FARM	Energy, Rest of Economy (no Land Use)	1	CO2	2004	CESproduction function
GCAM	Energy, Land Use	1	CO2, CH4, N2O, HFC, PFC, SF6	2005	Logit choice model
NewERA	Energy, Rest of Economy (no Land Use)	1*	CO2	2008	Linear/Non-Linear programming (Electric Supply Sector); CES Production Function (all Other Sectors)
ReEDS	Electric Supply	134	CO2	2010	Linear/Non-Linear programming
USREP	Energy, Rest of Economy (no Land Use)	12	CO2, CH4, N2O, HFC, PFC, SF6	2004	CESproduction function
US-REGEN	Energy, Rest of Economy (no Land Use)	15	CO2	2010	Linear/Non-Linear programming (Electric supply Sector); CES Production Function (all Other Sectors)

Model	Model Time Step (years)	Last Model Year without Climate Policy	Intertemporal Solution Approach	Bio w/CCS	Citation for Paper in this Volume
ADAGE	5	2010	Intertemporal Optimi-zation	No	Ross et al. (2013)
CIMS	5	2010	Recursive Dynamic	No	Jaccard and Goldberg (2013)
EC-IAM	10	2010	Intertemporal Optimi-zation	No	Zhu and Ghosh (2013)
FARM	5	2009	Recursive Dynamic	Yes	Sands et al. (2013)
GCAM	5 (but 2012 is included as an additional year)	2012	Recursive Dynamic	Yes	Wise et al. (2013)
NewERA	5	2010	Intertemporal Optimi-zation	No	Tuladhar et al. (2013)
ReEDS	2	2012	Sequential Myopic	No	Sullivan et al. (2013)
USREP	5	2010	Recursive Dynamic	No	Rausch et al. (2010)
US-REGEN	5	2010	Intertemporal Optimi-zation	No	Blanford et al. (2013)

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