Energy Modelling Initiative — Initiative de modélisation énergétique
Bringing the Tools to Support Canada's Energy Transition — Outiller le Canada pour réussir la transition

Energy Modelling Initiative Central Workshop Synthesis Report

Prepared by:

Environmental Energy Institute

Presented to:

l'Institut de l'énergie Trottier and Natural Resources Canada

October, 2019

environmental energy institute

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Acknowledgements

This report was funded through the Energy Modelling Initiative, launched by Polytechnique Montreal and sponsored by NRCan. The workshop hosts would like to thank all workshop participants for their insightful contributions. We would also like to thank our presenters who provided diverse perspectives on energy modelling in the Canadian context. We also thank our notetakers and moderators for capturing the lively discussions that took place throughout the workshop.

About the Environmental Energy Institute

The Environmental Energy Institute (EEI) at the University of Windsor is a cross-cutting institute that links people with ideas to improve life on our planet through energy solutions. EEI's mission is to develop a new generation of holistically equipped energy professionals by providing a broad spectrum, inclusive, and diverse energy education. In collaboration with the Turbulence and Energy Lab, a sample of research themes at EEI include energy storage, energy optimization for agriculture, investment decision support for renewable energy, and energy demand modelling. EEI has an established network, The Climate Led Energy Evolution Network 2040 (CLEEN2040), of energy researchers including leaders in energy systems modelling, consumer behaviour dynamics, energy storage technology, energy market dynamics, electrified transportation systems, and other relevant areas. In addition to this strong and dynamic team of researchers, CLEEN2040 has over 30 utility and industry partners all working together to advance the preparedness of the energy sector for industry-shifting disruptive changes likely to occur between now and 2040.

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Context

The objective of the Energy Modelling Initiative (EMI), launched by Polytechnique Montréal and sponsored by Natural Resources Canada (NRCan), is to convene a dialogue with Canada's electricity and energy modeling community with the intention to ultimately establish a national energy system modelling network. To achieve this, specific objectives were outlined, one of which is foster collaboration through regional workshops. The EMI Central workshop was the first in a series of three regional workshops taking place across Canada between September and November 2019.

The main objectives of the EMI Central Workshop were to:

- Convene the central regional modelling community including modellers, users, and policy makers.
- Explore how to strengthen the community through collaborations and enhanced policy relevance.
- Capture an overview of models and range of applications.
- Identify gaps in modelling approaches.
- Identify region-specific needs.

This report provides a summary of presentations, panel discussions, case study collaborative analyses, and overall themes resulting from the Central workshop.

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Workshop Activities Summary

The workshop was divided into three sessions: Presentations & Panel 1 – Model Users, Presentations & Panel 2 – Modellers, Case Study and Collaborative Analysis. Summaries of these sessions are provided below.

Presentations & Panel 1 – Applications & Perspectives from Model Users

Presenters were selected to cover the spectrum of users from generators, utilities, system operators, and the government. Key messages from these presentations can be grouped under three themes:

Granularity

There were questions concerning how granularity would be captured in a national energy modelling platform (i.e. transmission level, distribution level, etc.) and how a platform could transcend interconnections from system operator to local distribution company to consumer.

Consultation & Coordination

Users expressed concerns over their level of involvement in the development of a modelling platform. For example, different renewable energies provide various ancillary services such as regulation and frequency response which have yet to be appropriately valued in existing models. Utility perspectives highlighted the need to consult with LDCs in order to map a future for distributed energy resources (DERs). Furthermore, there was discussion on modelling coordination between LDCs and transmitters.

Regional Variability

It was mentioned by several presenters that there are strong regional differences between provinces and even between individual LDCs. The challenge of capturing interests and achieving consistency across local and regional levels was highlighted.

Panel Discussion

Following the presentations from model users, a panel discussion took place and the following key questions were raised and discussed:

Are there any existing interfaces between a national model and more detailed (i.e. utility level) models?

- Modellers and users only seemed aware of the models that they were using / developing and were not aware of interfaces between models.

Can utilities / system operators make their data available?

- They are interested in making their data available. There are security and privacy concerns to address. Furthermore, there is so much data to gather and it is cost prohibitive to gather it all. Data exists in different pieces and packages and it is a challenge to put it all together.

If access to unlimited data were possible, could we use / process it?

- Modellers and users agreed that too much data could also be an issue. Supercomputers would be required to process it. Also, data on its own might not be that useful. Modellers would need assistance with interpretation, etc.

What are the privacy policies concerning data sharing in Ontario?

- Modellers commented on their various experiences using / sharing data in Ontario but there was no clear answer on what specific policies are in place.

Why is there such a diversity in data availability (i.e. IESO in Ontario, vs. Quebec and Manitoba)?

- IESO is mandated to provide data. If other jurisdictions are not mandated, they would have no reason to collect and publish information (which is costly).

It is important to note that the model user panelists expressed apologies for not knowing / using proper modelling vocabulary. This suggests that modellers should focus on providing clear explanations and interpretations of their modelling results to users to improve understanding.

Presentations & Panel 2 – Overview of Current Modelling Activities from Modellers

Key takeaways from the modeller presentation session can be grouped under three themes:

Data Availability & Privacy

The modeller group expressed interest in obtaining credible data to build and validate their models. There was discussion on how data could be made available via a national platform while still protecting IP of individual researchers. The value of big data analytics in improved forecasting was another topic of discussion. One challenge that was highlighted is the regional differences in data availability. For example, the IESO in Ontario provides comprehensive data sets via their publicly accessible website, however, similar information is not made publicly available in Quebec.

Impact of Consumer Behaviour

Most modellers mentioned challenges surrounding the incorporation of consumer behaviour in their models. There was discussion on how modelling could be applied to explore the links and gaps between adoption of innovations in energy services and sustainability transitions. The question “how can consumer behaviour be accounted for in electric power system models” was echoed throughout the presentations and it was often remarked that it is challenging to model something for which no history exists (i.e. consumer uptake of EVs, etc.). The question was posed “how can we capture the diverse opportunities and challenges the customers will face when attempting to model energy systems of the future”?

Incorporating Economics

The modeller group also focused on the economic impacts of energy choices and how these can / cannot be accounted for in current models. Commodity price uncertainty, technology price uncertainty, and uncertainty surrounding incentives and carbon pricing were all mentioned as challenges when incorporating economics into energy decision support modelling. There was also discussion on how current power system cost-of-service models might not provide appropriate structures for utilities of the future. Integration of changing market pricing into models was also brought up for discussion.

Panel Discussion

Following the presentations from modellers, a second panel discussion took place and the following key questions were raised and discussed:

In energy modelling, assumptions and approximations are made and aggregation takes place. How do you assess the accuracy of this?

- Modellers responded that, when possible, they check parameters with a real case (i.e. a model of a specific industry – go to that industry to check details). They also use multiple scenarios for the distribution of assumptions and try to come out with a possible range of outcomes.

How do you factor the change in the behavior of customers in the modelling?

- It was agreed upon that this is very difficult to model. Benefits, costs, and risks for users will all be factors. The other issue is that the data we do have is based on voluntary action and this cannot be extrapolated to a population. There is a lot of uncertainty surrounding future prices, responses, and changes in consumer demand. The responsibility of the modeller is to list the factors involved and the uncertainties and then create possible scenarios. For better understanding, we need what-if scenarios.

What do you think about the idea of a common platform?

- Modellers supported the development of a common platform but had concerns over how to store and share data. There was also discussion on the concept of having “handshakes” between models rather than working with one (or more) common models. It was also mentioned that agreeing on a common platform could potentially limit future innovation.

If data were to be shared on a common platform, would you know how the data was collected?

- Discussion focused on technology that has been developed where you can ask a question of data without actually seeing the data. You can encrypt the data, manipulate the data, get the answer you want, and never actually know what the data was. This could potentially be used to address some of the concerns people have in sharing the data.

How can models adapt to technological changes?

- Modellers referenced starting with a "base case" that assumes a future that incorporates the known regular changes of things (i.e. furnaces get old and need to be replaced) and building upon this with what-if scenarios for less certain technological changes.

Case Study

The case study was selected due to its regional relevance and the connection to a diverse range of stakeholders. The objective of the case study was to discuss how modelling can be applied to develop strategic solutions to enable the planned expansion of the Leamington-Kingsville greenhouse sector.

Introduction & Context (provided to participants):

- The Leamington-Kingsville area is home to the greatest concentration of greenhouses in North America.
- Over 2800 acres of under glass agriculture accounts for $1B in economic activity in the Province.
- The sector is undergoing rapid transformation and expansion and is looking for innovative flexible energy system solutions to meet future load growth in the most timely and economic manner.
- Ontario growers are increasingly integrating LED lights to extend daily and seasonal growing periods.
- Operations are also becoming automated, from packing processes to harvesting routines.
- Many are looking to increase production density and expand.
- These load increases are being multiplied throughout the expanding sector.
- Planned expansions have future load growth expected to increasing 5-fold over the next 5 years. This poses some challenges:
- CAPACITY

    - To meet the new demand with grid-supplied electricity will require buildout of new transmission infrastructure.

- ENVIRONMENTAL FOOTPRINTS
    - Growers want to expand while minimizing their carbon and water footprints.

- COST
    - Energy costs have a substantial impact on profit margins in this sector.
    - It is unrealistic to expect completion of a transmission project of this magnitude in the timeframe required.
    - Innovative and strategic transmission deferral solutions are an option to enable expansion without delay.

Relevance to Ontario's Long-Term Energy Plan:

The following points, taken from Ontario's LTEP were presented to demonstrate that the challenges associated with the case study selected are likely to be faced by others and are of utmost importance to energy system planning:

- *Ontario's approach to grid modernization is to create the right environment for LDCs to make the best decisions for their systems and their customers*.
- *To get there, the government and its partners need to address the barriers to innovation.*
- *To meet the challenges of the future, LDCs may need to adopt more flexible and innovative approaches to service delivery than have been allowed in the past.*
- *To encourage change in the energy sector, the government will work with utilities and other partners to build a culture of innovation, and will look to the OEB to explore, where cost-appropriate:*
- *The deployment of renewable distributed generation and other distributed energy resources that provide value to customers;*
- *The use of innovative, non-wires solutions that could, among other things, allowing utilities to manage their systems better and encourage customer choice including the principles of efficiency and cost-effectiveness;*
- *The regulatory treatment of LDC capital and operational expenditures, which can inhibit the uptake of these non-wires solutions;*

- *Opportunities for utilities to partner with their customers to use in-front and behind-the-meter applications to address system needs.*

Stakeholder Panel Discussion

Following the presentation of the case study, a panel discussion amongst the stakeholders, including a representative grower, an LDC, the system operator, and energy consultant, took place. The following questions were raised and discussed:

If the region is facing capacity challenges, why are new operations not going elsewhere in Ontario?

- Stakeholders cited existing marketing expertise and infrastructure (water, electricity, and natural gas), as well as high solar irradiation as the reasons for operations wanting to stay in this region.

What is the end-use of natural gas and electricity in the greenhouses?

- Natural gas is used for boilers and to produce CO_2 for the plants. The majority of the electricity goes to pumps and lighting.

How much additional capacity is anticipated to be required?

- The system operator informed participants that they currently have 300 MW in the area and they have 1800 MW of connection requests currently.

Do you foresee any social issues with acceptance of increased development?

- The plan for increased transmission is to twin the lines, so there shouldn't be any social issues. The region has also already gone through this with the expansion of wind, so there shouldn't be any surprises.

Following the panel session, participants were divided into tables (pre-determined to achieve mixed representation), and the following objective was put forth:

OBJECTIVE: To develop strategies to enable this planned expansion without reliance on new transmission infrastructure, considering the needs of all stakeholders.

Questions for discussion were provided on poster sheets and responses were synthesized by a table moderator. Summaries of these are provided in Appendix A.

Synthesis of Table Discussions

During the discussion presentations it was evident that all groups felt that energy models would be highly valuable when developing strategies to address this specific case and similar situations that the sector is, and will be, facing in the future. Although the same questions were posed to each group, different groups had slightly different interpretations. Much of what was discussed during the panel sessions was echoed during the table discussions. Key takeaways included:

- Energy modelling faces challenges surrounding incorporating consumer behaviour and social acceptance.
- Modelling must take a true interdisciplinary approach and incorporate policy and regulatory effects, environmental impacts, and economics.
- To build better models, an integrated system modelling approach is required. While, models are required at a system level, they will need to be fed by more granular data (time and space). Finer details will need to be linked to the next coarser level.

The groups also identified several exiting models / elements that could be applied to address the stated objective, including: energy demand forecasts, peak load analysis, future scenario modelling, life cycle assessment, storage models, economic models, commodity pricing, carbon market models, and opportunities to daisy-chain models together.

Workshop Synthesis

The EMI Central Workshop successfully convened the regional modelling community and had representation from energy generators, utilities, system operators, large consumers, consultants, government, and academia. Participants were eager to participate in the development of a national modelling platform. From the presentations, panel discussions, and case study, the following key opportunities and challenges emerged as priority items:

Opportunity 1 – Data Storage & Sharing

A national platform could present a means for data storage and sharing amongst modellers and model users. This could expedite model development and provide validation for models in existence.

Opportunity 2 – Collaboration & Coordination

A national platform would connect the modelling community allowing for increased collaboration and coordination. Modellers expressed interest in participating in such a platform and discussed ways in which their own models could potentially interact and connect with others. Linking models to provide more comprehensive outputs and analysis presented collaboration opportunities for workshop participants.

Opportunity 3 – Access to Expertise

A national platform would provide access to expertise and answers for model users and policy makers. The case study demonstrated that energy system stakeholders have many questions about how to make the best decisions and that a centralized group of experts could greatly assist by providing the technological tools and intellectual support for scenario analyses.

Challenge 1 – Data Sharing

While modellers and model users were excited about the opportunity to share data, there were many concerns raised about intellectual property and privacy. Specifically, there was a lack of clarity on existing privacy policies in the region and concerns over who would own the shared data. Modellers also expressed an interest in knowing how shared data was collected. This seems to pose the greatest obstacle in moving towards a shared platform.

Challenge 2 – Unique Uses / Needs

"Energy modelling" means something different to various stakeholders. Participants shared concerns over how one platform could consider their individual needs due to vast differences between and within regions and industries. Spatial and temporal granularity were also discussed as unique factors. For some utility applications, modelling can be on time scale of seconds, whereas energy demand forecasts can be on the time scale of years. Incorporation of economics and consumer behaviour were highlighted as being important for some, but not all modelling applications.

Challenge 3 – Rate of Change of the Sector

A national platform and modelling toolbox would need to dynamically respond to a sector that cannot quite keep up with itself. Electric vehicles, electrified heating, solar shingles, participation in demand response are a few examples of change in the sector which pose modelling challenges. It was echoed throughout the day that it is difficult to model when there is a lack history for uptake and adoption.

Closing Remarks & Recommendations

This workshop was a successful and productive start that opened the discussion on the mobilization of Canadian modelling expertise. Participants from various backgrounds were supportive of the big picture objective to convene the modelling community and develop a national modelling platform to enable collaboration and access to common data and tools. The key takeaway from this workshop is an understanding that the modelling community is vast and that the stakeholders involved have diverse needs and concerns. To move this initiative forward in the most productive way, inclusive representation from industry, government, consulting, and academia, across all regions is necessary. Going forward, focus should be paid to addressing the challenges identified above so that data and models can be shared amongst the modelling community and unique needs are incorporated into the platform development. It is also recommended that the development is supported not only by energy modellers and model users, but also by researchers in various fields such as energy economics, consumer behaviour, technology development, and others with expertise on the variables that the models depend on.

Appendix A – Collaborative Analysis Sheets

Table 1.

How can modelling be applied to demonstrate a pathway to reach the stated objectives?

Reference case → business as usual

Forecasting energy demand, growth by plant type

What existing modelling elements can be applied?

Scenarios, load curves, peak load analysis, LCA + supply chain, energy usage/unit area, fuel switching + waste to fuel, risk analysis

What other factors affect potential pathways and need to be considered in modelling?

Assumptions? GHG intensity, policy / regulatory effects, economic → how is money earned / spent, input-output, forecast future of industry

What specific objectives should be pursued to support the overall objective?

Increase greenhouse efficiency, enable on-site (renewable) generation → electricity, heat, waste to fuel, diversification of output

How can these be integrated with a higher, systemic objective?

Growth of greenhouse industry → economic growth, job creation, circular economy

How are objectives interrelated?

Supply = demand, relations between energy use and environmental impact, relations between infrastructure growth and job creation.

In pursuit of the objectives, what impacts needs to be considered in policy development (use +/- to indicate positive or negative outcomes)?

Electricity, gas, water consumption, electricity services

Industry optimization? → infrastructure, locations, processes, heating, light, waste management, environmental footprint

Are there additional effects and consequences to consider?

Social, employment, urbanization, food security, land use / zoning / classification / safety

What are the prospects of new modelling approaches for political decision making?

Drivers for growth of industry, end use for energy, tragedy of the commons

Sectors not covered that need attention?

Mushrooms → no light requirements

How do other electricity users affect this industry?

Opportunity costs, robotics + AI, pairing the industry with complementary energy users

Policy aspects not covered/ignored by modelling?

History of the industry, behaviour, light pollution, social considerations, globalization & trade, consumer interest / marketing, distributional justice, employment → workforce diversity

Any new modelling approaches / methodology that could help?

Interdisciplinary → technical + social + economic

Table 2.

How can modelling be applied to demonstrate a pathway to reach the stated objectives?

Assess load flexibility, technical feasibility, price assessment, scenarios for energy and capacity requirements

What existing modelling elements can be applied?

Coordination of loads, consider regulatory sandbox

What other factors affect potential pathways and need to be considered in modelling?

Social acceptance, grid stability, global emissions, global markets

What specific objectives should be pursued to support the overall objective?

Support fuel switching, consideration of load flexibility, focus on end-uses and surrounding factors

How can these be integrated with a higher, systemic objective?

Social acceptance, rate / equity, managing social impacts

How are objectives interrelated?

Light + heat time profiles, time, space, system based objectives (not technical, user perceptions / preferences

In pursuit of the objectives, what impacts needs to be considered in policy development (use +/- to indicate positive or negative outcomes)?

Lower average rates, grid impacts / constraints, Price → impacts on location and time of use decisions, environmental impacts

Are there additional effects and consequences to consider?

Land use, GHG emissions, noise / light pollution, life cycle assessment of projects, waste management → bio-waste + energy

What are the prospects of new modelling approaches for political decision making?

Show need for new regulations / institutions, must by quick (need answers yesterday)

Sectors not covered that need attention?

Shift in manufacturing sector to offshore plants → freed up capacity, opportunity for industrial ecology

Policy aspects not covered/ignored by modelling?

Who pays for non-wires solutions? Community identity (i.e. Leamington and French's ketchup)

Any new modelling approaches / methodology that could help?

Agent-based models, financial risk + uncertainty, comparison of alternative solutions

Table 3.

How can modelling be applied to demonstrate a pathway to reach the stated objectives?

Consider all complexities

What existing modelling elements can be applied?

Storage, life cycle analysis, methanol production

What other factors affect potential pathways and need to be considered in modelling?

Interconnection requirements, climate extremes, carbon capture, different types of storage

What specific objectives should be pursued to support the overall objective?

Policy development

How can these be integrated with a higher, systemic objective?

How are objectives interrelated?

In pursuit of the objectives, what impacts needs to be considered in policy development (use +/- to indicate positive or negative outcomes)?

Economical inclusion by all local interest groups, storage (seasonal), getting customers on board, balance interests of many diverse stakeholders

Are there additional effects and consequences to consider?

Time of year, federal policy vs. provincial interests, electrification → all eggs in one basket?, stay diverse

What are the prospects of new modelling approaches for political decision making?

Sectors not covered that need attention?

IT infrastructure – can we process all of this data?

Policy aspects not covered/ignored by modelling?

Public opinion – social (i.e. grow marijuana)

Any new modelling approaches / methodology that could help?

Table 4.

How can modelling be applied to demonstrate a pathway to reach the stated objectives?

Use calibrated technical models to perform optimizations for different operating scenarios (lit / unlit cases) → focus on efficiency.

What existing modelling elements can be applied?

Use parametric modeling approach, scale existing 1 acre models → larger models → validate, use elements of existing economic modeling approaches

What other factors affect potential pathways and need to be considered in modelling?

Environmental / climate factors, transient loads analysis, optimal growing conditions (model constraints / plant requirements).

What specific objectives should be pursued to support the overall objective?

Bio-digester and approaches that support a circular economy, energy storage to capture off-peak use times, fuel flexibility (NG, H2, electricity)

How can these be integrated with a higher, systemic objective?

Modeling at system level rather than using individual models (integrated models with gas and electric, as an example), balancing multiple objectives (environment, community, economics) → multi-disciplinary design optimization.

How are objectives interrelated?

In pursuit of the objectives, what impacts needs to be considered in policy development (use +/- to indicate positive or negative outcomes)?

Government incentives for reducing energy consumption / emissions (+), water tariff, carbon tax (+/-), economic / employment incentives (+), regulatory constraints (+/-).

Are there additional effects and consequences to consider?

Yes.

What are the prospects of new modelling approaches for political decision making?

Integrated system modeling approach, socio-economic impact modeling

Sectors not covered that need attention?

Labour (local vs. offshore hiring), waste diversion, future regulations (environmental)

Policy aspects not covered/ignored by modelling?

Social / community resistance, public opinion, political agenda / motivations

Any new modelling approaches / methodology that could help?

Net-zero operations modeling / optimization

Table 5.

How can modelling be applied to demonstrate a pathway to reach the stated objectives?

Look at variables, data, assumptions to predict / estimate.

What existing modelling elements can be applied?

Macroeconomic models, daisy-chaining model types

What other factors affect potential pathways and need to be considered in modelling?

Politics, recessions, social acceptances, international policy / trade agreements

What specific objectives should be pursued to support the overall objective?

Low cost, equity, reliability, sustainability, safety (personal + environmental)

How can these be integrated with a higher, systemic objective?

How are objectives interrelated?

Sustainability + equity + safety (public good)

In pursuit of the objectives, what impacts needs to be considered in policy development (use +/- to indicate positive or negative outcomes)?

Environmental (-, air quality), always compromises to make (in modelling), different factors are easy to model, some easier (safety vs. cost).

Are there additional effects and consequences to consider?

Electricity rates, vegetable market price, who shoulders the cost

What are the prospects of new modelling approaches for political decision making?

Better model = better decisions, transparency issues, models are complicated + hard to use by politicians).

Sectors not covered that need attention?

Pipelines, natural gas, water

Policy aspects not covered/ignored by modelling?

Politics, consistency between governments (i.e. carbon tax), modellers need time, politicians need answers now.

Any new modelling approaches / methodology that could help?

International / global model, chaining different types of models together (but can't have just one model), data access / sharing hard

Table 6.

How can modelling be applied to demonstrate a pathway to reach the stated objectives?

Model flexibility regarding gas / electricity – is full NERC needed? Need approximate model of greenhouse operations meshed with other models.

What existing modelling elements can be applied?

Demand forecast, optimization, behavioural, appropriate time scales / details

What other factors affect potential pathways and need to be considered in modelling?

Storage, flexibility, microgrid

What specific objectives should be pursued to support the overall objective?

Correct incentives needed

How can these be integrated with a higher, systemic objective?

Flexible design for transition

How are objectives interrelated?

All shape behaviour + increase efficiency + future system attributes (increase resiliency)

In pursuit of the objectives, what impacts needs to be considered in policy development (use +/- to indicate positive or negative outcomes)?

Flexibility + competing demand from vehicle charging, understand value proposition, social / environmental impacts, regulations around cogen.

Are there additional effects and consequences to consider?

Water treatment, demand risk, population / other forms of growth, new infrastructure

What are the prospects of new modelling approaches for political decision making?

Economic lens needed as well as social / environmental lens, build resilience to changes in political practices

Sectors not covered that need attention?

Impact (price, etc.) on other users, land use change

Policy aspects not covered/ignored by modelling?

Link fine details to next coarser level.

Any new modelling approaches / methodology that could help?

We need to communicate our results to policy makers, Game Theory

Table 7.

How can modelling be applied to demonstrate a pathway to reach the stated objectives?

Model demand of all energy sources, optimization model

What existing modelling elements can be applied?

Technological (uses of energy, market / commodity pricing, load curve (water / electricity / gas), gas constraints as well, seasonal data on top of daily, carbon markets

What other factors affect potential pathways and need to be considered in modelling?

Value of load, labours, local stakeholders, alternative “localized” energy source (wood, cogen)

What specific objectives should be pursued to support the overall objective?

Maximize ROI, profit, minimize to have GHG negative?, reliable system

How can these be integrated with a higher, systemic objective?

Community, provincial, national economics, environmental global emissions

How are objectives interrelated?

Backups and resiliency of power support systems, energy (limitations of supply / demand), local air pollution, local food supply / scarcity, biological risks of food transport

In pursuit of the objectives, what impacts needs to be considered in policy development (use +/- to indicate positive or negative outcomes)?

Power consumption trends (i.e. global adjustment formula), jobs, private investment, demand response programs, voter as a rate payer, political uncertainty

Are there additional effects and consequences to consider?

What are the prospects of new modelling approaches for political decision making?

Integrated supply – demand model, easier access, more data and analysis tools, spend money to quicken feedback

Sectors not covered that need attention?

Labour, fertilizer, transportation, consumption of fresh water

Policy aspects not covered/ignored by modelling?

NAFTA / trade disputes, political views may not align, individual behaviours (different values / needs)

Any new modelling approaches / methodology that could help?

Long term climate adaptation modeling