

Communicating Net-Zero Climate Policy and Energy Modeling Results via an Interactive
Visualization Dashboard

by

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B.Eng., Toronto Metropolitan University, 2022

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ABSTRACT

The Canadian Government has pledged to achieve net-zero greenhouse gas emissions by 2050. To achieve this target, energy modeling is required to evaluate different decarbonization pathways and possible policy options, however, its impact is currently stunted due to a communication gap between energy modelers and stakeholders. This thesis presents the development and testing of the Integrated Dashboard for Energy transition Analysis (IDEA), an open-sourced tool used to address the communication gap and promote evidence-based decision making. IDEA enables policy makers to evaluate decarbonization pathways and complex policy decisions through the use of visualizations and an interactive dashboard. A Human Centered Design process was implemented to develop a prototype dashboard and evaluate its functionality and applications. Key stakeholders including Environment and Climate Change Canada, Natural Resources Canada, the David Suzuki Foundation, Clean Energy Canada, BC's Ministry of Energy, Mines and Low Carbon Innovation and BC's Climate Action Secretariate were involved in the development and evaluations. An output of this thesis is a fully tested visualization dashboard that is adaptable to multiple models and visualization types. The major contributions of this thesis include insights and guidelines surrounding the needs of stakeholders, a detailed discussion on the current and future applications of IDEA, and a call for further communication tools that can advance data-driven decision making. IDEA successfully operates as a results analysis tool, enabling modeling teams and stakeholders to evaluate complex policy decisions. Future applications include expanding IDEA to a key insights tool, supporting decision makers with the most pertinent information, and a modeling tool, allowing stakeholders to implement their own assumptions and model formulations to conduct independent evaluations. Future work includes implementing the discovered improvements to strengthen IDEA as a results analysis tool and further investigating the feasibility and impact of the other tools uncovered.

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List of Acronyms

AB	Alberta
BAU	Business as Usual
BC	British Columbia
CAS	Climate Action Secretariate
CEC	Clean Energy Canada
CER	Clean Electricity Regulation
COPPER	Canadian Opportunities for Planning and Production of Electricity Resource
DSF	David Suzuki Foundation
ECCC	Environment and Climate Change Canada
EMH	Energy Modeling Hub
EMLI	Energy, Mines and Low Carbon Innovation
FAQ	Frequently Asked Questions
FOM	Fixed Operation and Maintenance
GEA	Global Energy Assessment
GHG	Greenhouse Gas
HCD	Human- Centered Design
IAMC	Integrated Assessment Modeling Consortium
IDEA	Integrated Dashboard for Energy transition Analysis
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt Hour
NGFS	Network for Greening the Financial System
NRCan	Natural Resources Canada
NGO	Non-Governmental Organization(s)
PRAS	Probabilistic Resource Adequacy Suite
SILVER	Strategic Integration of Large Capacity Variable Energy Resources

TCD	Task Centered Design
VOM	Variable Operation and Maintenance
WEC	World Energy Council

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Author Contributions

Chapter 2 of this thesis will be submitted as a peer-reviewed manuscript. Below the contributions of each author are clarified.

Attard, E., Perin, C., McPherson, M. Communicating Net-Zero Climate Policy and Energy Modeling Results via an Interactive Visualization Dashboard

E. Attard developed the methodology, collaborated on the prototype development and wrote the manuscript. M. McPherson supervised, contributed to manuscript editing, and provided insights on the prototype content. C. Perin provided insight and guidance on the methodology development and contributed to manuscript editing.

While Jonas Kraasch is not listed as an author of Chapter 2, he contributed by assisting in the software development of the visualization dashboard.

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Chapter 1: Introduction

The Canadian Government has pledged to reduce Greenhouse Gas (GHG) emissions by 40% below the 2005 levels by 2030 and to achieve net-zero emissions by 2050 [1]. Achieving these targets is a complex and multifaceted challenge requiring (1) energy modeling, to evaluate decarbonization pathways and support net-zero policy decision making, and (2) communication between various levels of government (federal, provincial, municipal), non-governmental organizations (NGOs), utilities, researchers, and communities. On an international level, energy modeling has been used to inform climate action and policy makers. These collaborations have shown that decision makers have a significant interest in employing energy models to gain insights from their outputs. Additionally, these models have the potential to greatly impact decision making and policy implementation when appropriate analysis and visualization tools are used to close the communication gap between energy modelers and policy makers [2][3][4].

Several obstacles currently exist that cause a communication gap and impede the impact of energy modelers. Some obstacles include [5][6][7]:

- Ineffective or incomplete communication of model formulation
- Lack of transparency and reproducibility of model results
- Lack of accessibility of input and output data
- Lack of engagement with stakeholders throughout the modeling process

Without transparency and accessibility of the model and its formulation, stakeholders may not have full trust in their outputs or may misconstrue the insights if appropriate information about the assumptions and implementation is not readily available. Similarly, other researchers cannot compare and validate model results using their own tools if reproducibility is not achieved. Facilitating cross model comparison opens opportunities for more trustworthy and impactful results that evaluate a wider variety of pathways and tradeoffs.

Another obstacle stunting the impact of energy models is the long lead times associated with model formulation, results preparation, and analysis. Having large amounts of time required to process and showcase the model results poses a challenge for impacting federal and provincial policy, which often has a short commentary window before changes are accepted and the policy is published.

This thesis is focused on bridging the communication gap and reducing the time required for results presentation through the use of visualizations and an interactive dashboard. The key objectives of this thesis are

- (a) to build an open-source and extensible tool that will be used to communicate energy modeling results to a variety of stakeholders, and
- (b) to evaluate the tool through a series of usability tests and stakeholder engagement session. The evaluations aim to uncover feedback, improvements and potential future applications.

The objectives were achieved through the following milestones:

1. **Dashboard Development.** The Energy Modeling Hub (EMH) has a reservoir of existing models that span spatial and temporal scales and provide insights for different levels of the energy system. The visualization dashboard was designed with these models in mind to ensure flexibility and extensibility. The primary focus of the initial prototype development was to display model results from a capacity expansion model called COPPER [8]. The dashboard was later expanded to include results from SILVER [9], a production cost model, and PRAS [10], a resource adequacy model. The development methodology selected allows seamless integration with the existing model code and outputs.
2. **Usability Testing.** This testing was conducted to ensure all desired tasks outlined in the dashboard development stage were fully functional before presenting the dashboard to stakeholders. A task-execution based test was conducted with participants who had previous energy modeling and energy policy knowledge. A wealth of improvements were gathered and implemented in preparation for the third milestone.
3. **Stakeholder Engagement Sessions.** A series of stakeholder engagement sessions were conducted to get feedback from critical entities in the Canadian energy policy space. The sessions aimed to simulate a stakeholder group analyzing energy modeling results using the dashboard. Relevant feedback was collected that outlined short-term improvements and longer-term alterations for the dashboard.

These milestones culminate into the manuscript presented in Chapter 2. A major output of this research is the developed and tested visualization dashboard that is open-sourced and adaptable to multiple types of energy models. The dashboard is available via a GitLab repository which has been linked in chapter 2. The major contributions of this research include:

- Insights and guidelines surrounding what information researchers must provide stakeholders to facilitate a successful collaboration and impactful discussion supported by energy modeling
- Identification of current and future applications for the visualization dashboard developed, including their suitable users
- A call for additional tools and a shift in energy modeling to better serve a wide variety of stakeholders

The insights provided in this research outline opportunities for future developments and tools that can support decision makers in implementing effective energy policy and moving the needle towards achieving Canada's GHG targets.

Chapter 2: Communicating Net-Zero Climate Policy and Energy Modeling Results via an Interactive Visualization Dashboard

2.1 Abstract

Energy models are essential tools used to explore ‘what if’ scenarios and assess decarbonization pathways, however their impact on decision making has been impeded due to poor communication of model results and a lack of transparency. This paper presents the Integrated Dashboard for Energy transition Analysis (IDEA), an open-source visualization dashboard that aims to remove the communication barriers between energy modelers and stakeholders. IDEA is a flexible, Python-based dashboard that facilitates interactive analysis of complex policy decisions. A Human Centered Design process was used to design and evaluate the dashboard, which hosted energy modeling results from three distinct models evaluating the Clean Electricity Regulations and an interprovincial transmission expansion. Key stakeholders in the Canadian climate landscape were involved in the design and evaluation process including Environment and Climate Change Canada, Natural Resources Canada, the David Suzuki Foundation, Clean Energy Canada, BC’s Ministry of Energy, Mines and Low Carbon Innovation and BC’s Climate Action Secretariate. The current implementation of IDEA successfully serves as a results analysis tool for users including the energy modeler, stakeholders soliciting external modeling work, and the advisory team of decision makers. For users consisting of ministers and decision makers, the current tool provides an overabundance of information and would need to present only key insights and pivotal decision-making milestones. The next steps for IDEA include integrating various inputs and adding clarifying terminology, among other additions discovered in this study.

2.2 Introduction

Models are essential tools that are used to understand the intricacies and relations within complex systems, such as the energy system. For decades, models have been used to explore ‘what if’ scenarios during times of transition and uncertainty [5]. In recent years, energy models have been used to assess decarbonization pathways and policy options, providing insights for the World Energy Council (WEC), the Global Energy Assessment (GEA), and the Intergovernmental Panel on Climate Change (IPCC) [11]. These initiatives highlight the desire of decision-makers to employ energy system models and gain insights from their outputs. However, more importantly, these assessments showcase the impact energy system models can have to enhance decision-making when appropriate analysis and visualization tools are used to bridge the communication gap between energy modelers and stakeholders [5].

Today, several obstacles exist that impede the impact energy models and their results can have on decision-making. Many obstacles originate from ineffective or incomplete communication of model formulation and analysis [5]. Huppmann et al. describe the need for transparency and reproducibility throughout the modeling development and execution processes [6]. Nikas et al.

highlight the need for transparency, accessibility of input and output data, and synchronization of modeling parameters [12]. Howells et al. state the importance of engaging stakeholders throughout the entire modeling process [7]. DeCarolis et al. discuss the development of energy system modeling best practices including open-sourcing modeling and its software [13].

The obstacles stated above, along with the current demand for deep decarbonization and the Canadian Government's pledge to achieve net-zero emissions by 2050 requires another paradigm shift in energy modeling: to focus on energy system integration and to remove the communication gap between energy modelers and policy makers [14]. The M3 Modelling Platform has been developed in response to this need by taking a holistic approach to energy system modeling that incorporates multiple disciplines (engineering, economics, public policy), levels of government (municipal, provincial, federal) and stakeholders (government, non-governmental organizations (NGO), utilities, academic) [5]. The modeling platform consists of three pillars. Pillar 1 improves the accessibility of Canadian energy modeling input data with CODERS [15], Pillar 2 provides multi-scale, multi-vector and multi-sector insights via an integrated modeling suite, and Pillar 3 addresses the complex nature of single and multi-model results analysis through a visualization dashboard. The platform delivers these integrated insights through a stakeholder engagement process which allows energy modelers to inform holistic policy development [5].

This paper presents the third pillar of the platform, the Integrated Dashboard for Energy transition Analysis (IDEA). IDEA is a flexible, Python-based dashboard that provides a holistic and interactive view of complex policy evaluations carried out by various energy models [5]. Given the intricacy and interdisciplinary nature of the energy transition, many considerations must be accounted for to ensure IDEA strengthens the dialogue surrounding net-zero policy and is adaptable to multiple applications, including the breadth of users, jurisdiction of decision making, flexible analysis, and adaptable outputs. Policy evaluation and decision making require the collaboration of stakeholders across various sectors and disciplines, therefore, this tool aims to effectively communicate model insights to a variety of stakeholders with different levels of knowledge and expertise [16]. Although decarbonization pathways require multi-sector and multi-disciplinary collaboration, decisions are formed at smaller, discrete scales, such as the provincial or municipal level of government. Therefore, the dashboard must present "big picture" insights as well as insights pertaining to each jurisdiction [17][18]. With this level of system complexity, a variety of visualization techniques must be applied in unison to develop these multi-faceted insights [19]. Given the variability in outputs of energy-economic models compared to sector-specific models, there is a need for a flexible, multi-purpose visualization dashboard that is adaptable to many energy models [5][12].

As such, IDEA must encompass a wide range of users and applications, therefore a human-centered design (HCD) approach was taken [20]. HCD aims to produce a system that satisfies the user's needs by focusing the development on the user. Users are integrated at the start of the design process and their feedback is iteratively incorporated throughout subsequent development [21][22]. For the first stage of the HCD process, the Task Centered Design Method was applied to define the users and intended tasks [23][24][25]. A prototype was then produced and iteratively evaluated via internal usability testing [26] and external stakeholder engagement sessions. Taking into

consideration proximity, existing relationships, potential interest in this study, and the study's timeline, the following stakeholders were selected as users and to contribute feedback: Environment and Climate Change Canada (ECCC), Natural Resources Canada (NRCan), British Columbia (BC)'s Ministry of Energy, Mines, and Low Carbon Innovation (EMLI), BC's Climate Action Secretariate (CAS), the David Suzuki Foundation (DSF), and Clean Energy Canada (CEC).

The purpose of this paper is first, to describe the development of IDEA in collaboration with the stakeholders listed, second, to present the feedback collected via the usability tests and stakeholder engagement sessions, and third, to discuss future applications, strengths, limitations, and stakeholder engagement framework for IDEA.

The remainder of the paper is organized as follows. Section 2.3 presents an overview of existing visualization dashboards for energy model analysis. Methodology follows in Section 2.4 describing the HCD and evaluation processes. The prototype development is detailed in section 2.5. The evaluation results are showcased in Section 2.6 and discussed in Section 2.6. The paper ends in section 2.7 with conclusion and future work.

2.3 Existing Visualization Dashboards for Energy Modeling Results Analysis and Communication

Multi-model comparison and multi-model analysis have the capacity to impact policy by uncovering consistencies and discrepancies between multiple models in scenario evaluations and assessing the impact on populations and infrastructure systems using various macro- and sectoral models, respectively. The influence of these insights can significantly increase with the addition of a visualization dashboard which hosts multi-model results in a transparent way. Using a single visualization platform to showcase insights and compare multiple models cultivates discussion surrounding model formulation and associated scenarios. This promotes trust and confidence in decision-making [16].

Several groups have developed visualization dashboards to facilitate communication and display energy modeling insights. Most dashboards fall into three main categories: narrative-based, model comparison, and live simulators. Narrative-based dashboards guide users through model outputs using words and storytelling, with narrative visualizations [27] integrated throughout the dialogue to help communicate insights. The Network for Greening the Financial System (NGFS) created a narrative-based website showcasing projections of climate risks, allowing users to scroll through narrative supported by visualizations [28]. The narrative-based approach provides context for the visualizations, however, this approach risks integrating bias into the narrative, persuading users towards a specific conclusion, and devaluing certain insights [29].

Model comparison dashboards facilitate comparison of scenario and multi-model-based analysis. The Integrated Assessment Modeling Consortium (IAMC) and the International Institute for Applied Systems Analysis (IIASA) developed the IAMC 1.5 °C Scenario Explorer focusing on model comparison between various emissions pathways [30]. Model comparison dashboards apply the exploratory data analysis method [31], leaving all analysis and decision-making to the users by strictly visually presenting numerical results with minimal explanation or narrative. While it is

less likely with the model comparison approach that the analysis of the results can be biased, many dashboards of this nature are coupled to proprietary modeling software. These tools are rigidly designed for their associated model and therefore, are not customizable or adaptable for other energy system models [5].

Live simulators [32] allow users to select modeling parameters via a series of buttons and sliders and generate live model results. The live simulator approach is advantageous for user's understanding regarding dependencies and trade-offs of decarbonization but can only represent a pre-selected subset of the possible pathways for decarbonization.

The categories above highlight an existing gap in the available dashboards. The model comparison approach addresses the shortfalls of both the narrative-based and live simulator dashboards by transparently showcasing model results without narrative and analyzing a large volume of pathways, respectively. However, existing proprietary dashboards create a challenge for flexibility and adaptability.

2.4 Methods

2.4.1 Dashboard Approach Selection

Based on the approaches discussed in Section 2.3, there is a need for a flexible and open-source tool with minimal narrative that can support multi-scenario and multi-model comparison. The model comparison approach reduces the risk of integrating modeler's bias while expanding the breadth of the scenarios presented which will mitigate bias brought by the users and lead them to new conclusions. Creating an open-sourced model comparison dashboard fills the gap discussed and addresses the pitfalls of current model comparison dashboards.

2.4.2 Human-Centered Design Process

The HCD Process can be broken down into three stages: user requirements, prototyping, and evaluation, as depicted in figure 2.1. The user requirements stage sets out to define the user, their needs for the intervention, and their intended tasks. In prototyping, designers select features and an interface design that focuses on accommodating the most important tasks identified. The user requirements and prototyping stages were conducted in collaboration with ECCC in two workshops, to establish a viable prototype before presenting it to the remaining stakeholders. In the evaluation stage, testing is conducted to confirm the intended tasks can be completed with the dashboard by the identified users. Feedback is collected and several issues are commonly uncovered. The evaluation stage was conducted using two methods, usability testing and stakeholder engagement sessions. Based on the issues identified, the three stages are repeated until all tasks are incorporated and a satisfactory design is developed [20][22].

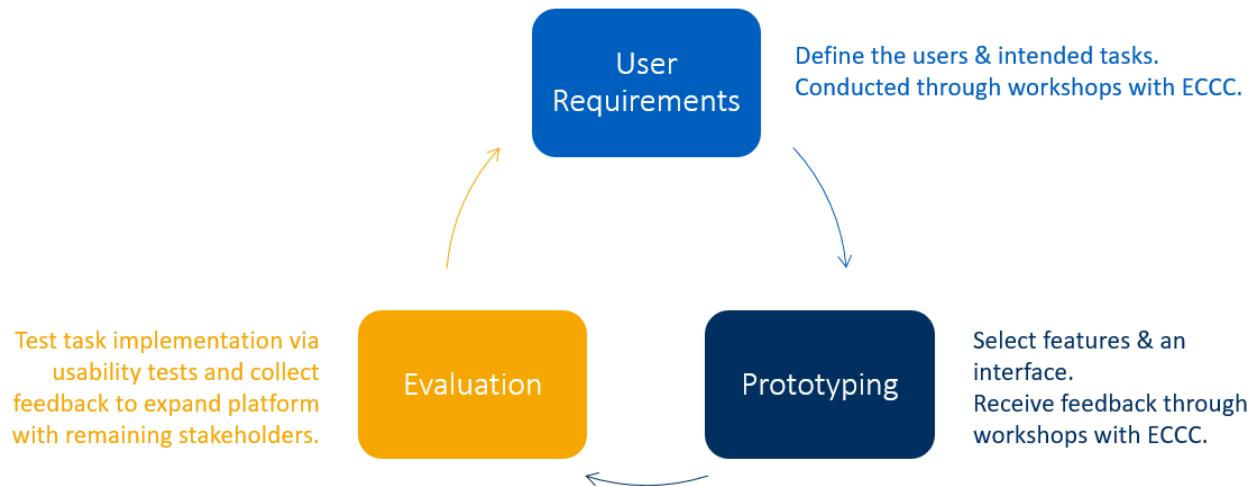


Figure 2.1: Human Centered Design Process used to develop the user requirements, prototype and test IDEA.

2.4.2.1 User Requirements Methodology

To define the user requirements, a Task Centered Design (TCD) approach was taken. TCD is a HCD methodology used to design user interfaces that prioritize quick learning, efficiency, and comfortability. The methodology is useful in identifying the needs of users, the intended tasks that the interface should support, and conducting usability testing. The first step, identification, is used to identify all real end users and discover their desired tasks. The second step, user centered requirements analysis, determines which tasks will be included, excluded and possibly included in the interface design [24][25].

The ultimate purpose of IDEA is to facilitate dialogue between stakeholders with a wide range of experience levels, education backgrounds, and involvement in Canada’s climate action. The following stakeholders were of top priority to participate in the engagement sessions due to their role in climate action in Canada: the federal government, the provincial government, non-governmental organizations, and academic organizations. In Canada, the federal government has jurisdiction over pollutants in the context of national targets and interprovincial trade and commerce. This includes setting regulations on greenhouse gas (GHG) releases from various facilities and emitters. Alternatively, the provincial government has jurisdiction over energy generation and supply, resource development, infrastructure for transportation, and land use. Therefore, provincial leaders have a vital role in targeting and reducing GHG emissions through the expansion of clean energy sources and infrastructure [33]. Along with the federal and provincial governments, a multitude of NGOs and academic organizations are active in working to reach Canada’s GHG emissions targets. These organizations conduct independent research, engage with stakeholders and communities, and investigate alternative pathways that will achieve a just transition. With the considerations above, the stakeholders presented in section 2.2 were selected.

The initial prototype of IDEA was designed in collaboration with ECCC to display model outputs generated by the Energy Modeling Hub evaluating the Clean Electricity Regulation (CER) [34][35]. These results used a capacity expansion model, called the Canadian Opportunities for

Planning and Production of Electricity Resources (COPPER) [8], to evaluate a business as usual (BAU) and a CER scenario for both low and high demand projections. To develop the list of tasks the prototype must accommodate and collect feedback, two workshops were held with ECCC. The methodology for these workshops is describe in section 2.4.2.1.a below. Table A.1.1 in Appendix A.1.1 shows an exhaustive list of the initial tasks desired by ECCC. The specified tasks include the model outputs of interest, data representation specifications, and other necessary functionality.

Table A.1.1 was analyzed, and any duplicated or unnecessary visualizations were removed to reduce computational load and information overload [36]. Tasks 1G, 1J, and 1L were removed due to repetition or lack of data and the final tasks were documented in Table A.1.3 in Appendix A.1.3.

2.4.2.1.a Workshop Methodology

The premise of the workshops was to use an existing collaboration with ECCC as an opportunity to conduct the first two stages of the human centered design process using a relevant and current project. Two workshops were held: (1) To develop the list of tasks for IDEA, as documented in Table A.1.3 and (2) to get feedback on task implementation to develop a high-fidelity prototype. Eight individuals were present in the workshops, all with extensive energy modeling experience and detailed knowledge on energy policy and climate change in Canada. In the workshops, IDEA was displayed on a projector and manipulated by the developer. All model outputs were showcased and analyzed by the researchers, with the implemented visualizations and features supporting questions as they arose. Feedback and comments were documented as well as observations regarding which visualizations and features were most used. This feedback was then integrated to ensure IDEA meets all identified tasks before the usability testing and stakeholder engagement sessions were conducted.

2.4.2.2 Evaluation Methodology

Two evaluation methods were used to test the usability and collect feedback on IDEA. Following the workshops with ECCC, formal usability testing was conducted to evaluate the newly implemented changes. The product of this testing was a high-fidelity dashboard that met all required tasks outlined in tables A.1.1 and A.1.3.

The dashboard was then tested in a series of stakeholder engagement sessions to expand the flexibility and impact of IDEA. The purpose of these sessions was to (1) obtain feedback on the current dashboard from the perspective of different stakeholders beyond ECCC, (2) better understand the stakeholder's interest and intended applications for a visualization dashboard, and (3) curate a list of improvements to guide future dashboard development.

To ensure the sessions were relevant for each stakeholder, the dashboard was expanded to display two additional sets of results that evaluated provincial specific results for the CER and an interprovincial transmission expansion between BC and Alberta (AB), respectively. This incorporated two new models into IDEA, SILVER [9] and PRAS [10].

The methodology for the usability testing and stakeholder engagement sessions are documented in sections 2.4.2.2.a and 2.4.2.2.b, respectively.

2.4.2.2.a Methodology for Usability Testing

Usability testing was conducted with a group of seven researchers, all of which had some knowledge of energy systems and energy system modeling. A task execution-based usability test was conducted, and a think-aloud protocol was implemented to support the findings [26][37]. Participants were provided with a laptop that had IDEA pre-loaded and were expected to complete 18 tasks, which are detailed in appendix A.2.1. The tasks were designed to test the implementation of each feature in table A.1.3 by requesting users to find an answer to the given questions. Screen recordings were reviewed to ensure the participants used the intended feature without issues and found the correct answer. The time taken for each task and if it was completed correctly was documented. At the end, participants were encouraged to provide comments and feedback via an interview-style question period. Screen and audio recordings were collected for each participant. Participants were not told if they provided the correct answer to each task and were not given a time limit to complete the tasks, however the entire session was limited to an hour and a half. The percentage of participants that completed each task correctly was calculated for each usability task. Additionally, the median time taken for each task amongst all participants was reported, as the average time is more sensitive to outliers, therefore the median provided a more robust representation of the central tendency [38]. Thematic analysis was used to uncover themes and categorize think-aloud data from the usability tests. Thematic analysis consists of four steps: data familiarization, coding, forming themes, and reporting [39]. This analysis was conducted on the verbal transcribes and the transcribed screen recording collected during the usability testing.

2.4.2.2.b Methodology for Stakeholder Engagement Sessions

Each stakeholder was engaged in a stakeholder engagement session, exclusive to their respective organizations, with one to six participants. All participants work in the energy, energy policy or environmental policy sectors, however participants significantly varied in experience level, expertise, and education. The number of participants in each session can be found in table 2.1 below. Some participants had prior knowledge of the modeling work and capabilities of the EMH, but no participant had interacted with IDEA prior to the sessions.

Table 2.1: Number of participants included in each stakeholder engagement session.

	Stakeholders				
	CEC	DSF	NRCan	EMLI	CAS
Number of Participants	1	2	4	6	5

The structure of the sessions consisted of four stages:

Prelude: The prelude introduced the session, IDEA, and the model results being shown. The intent with the prelude was to provide context for the model results, to avoid questions during the session that did not pertain to IDEA or its visualizations.

Training: Participants were then given access to IDEA and encouraged to follow along with the training portion. During training, the primary author walked users through the platform, highlighting key features and content.

Exploration: During exploration, participants had free rein to explore the dashboard and attempt to analyze the model results presented. This stage simulated the intended use case of IDEA, which is to investigate an energy modeling study.

Feedback: In the last stage, users were asked a series of interview-style questions to elicit feedback. Questions focused on what was missing, the future applications of IDEA, and how participants would use the dashboard in their daily roles. The feedback session concluded with a survey that asked participants to rank how important various content, features, and applications were to them as a perspective user. The survey used the Likert scale which can measure individuals' opinions, attitudes, and perceptions. Participants decide on their level of approval of each question using the scale and options provided [40]. The following scale was used in this survey: (1) very unimportant, (2) unimportant, (3) neutral, (4) important, and (5) very important. The survey can be found in appendix A.3.1. To analyze the Likert scale results, the median was found for each question and categorized according to the respective organizations. The median was used as the mean does not provide any meaningful significance when using the Likert scale while the median better represents the participants attitudes and tendencies [41][42].

Three sessions were conducted virtually and two were conducted in-person. For the virtual sessions, participants remotely controlled laptops with the dashboard pre-loaded using Chrome's Remote Desktop application. During the exploration stage, facilitators watched the screens of each participant and asked appropriate questions to determine participant's interests and thoughts. For the in-person sessions, participants were paired up with a facilitator who was knowledgeable about IDEA and the model results shown. To assist with driving engagement, a challenge, similar to the tasks presented in the usability test, was given to all participants at the beginning of the exploration phase. Audio and video recording of the participant's screens and field notes were collected throughout the sessions.

Thematic analysis, as described in section 2.4.2.2.a, was applied to analyze the qualitative feedback collected in all engagement sessions. The verbal transcripts collected and transcribed screen recordings were analyzed. Common and diverging themes across all five sessions were identified.

2.5 Results

2.5.1 Prototype Development

Python and the *Bokeh* package were selected as the development tools to adhere to DeCarolis et al.'s best practices of open-sourcing and Huppmann et al.'s need for transparency [13][6]. With the *Panel* application, *Bokeh* visualizations can be displayed on a dashboard and interactive widgets can be integrated to enhance the comparability of model results [43].

Dashboard development was broken down into two stages. The first stage consisted of data pre-processing, where model outputs were transformed into a common format and manipulated to ensure congruence between data. The common format selected was the *Pyam* format [44], which categorizes model outputs into the following columns: model, scenario, region, variable, unit, and value. This format has been used in various integrated assessment modeling studies and aligns well with the models developed at the EMH [44]. Model outputs produced by COPPER may have multiple data dimensions including time (year, day, month or hour), region (Canada or provincial), and technology. Technology refers to the type of resource used to generate electricity. Some common examples include solar, wind, nuclear, fossil fuel, and hydro. In the model's backend, technologies are represented by acronyms or short forms that are often unintelligible by individuals outside of the modeling team. Therefore, results were aggregated into common technology names often seen in the energy sector (task 10A) to reduce the number of items and colours required in the figure (task 8). The aggregated and disaggregated technologies names can be found in table A.1.2 in Appendix A.1.2. In this stage, unit conversion was performed to ensure a consistent unit system and appropriate multipliers were used (task 3).

The second stage included visualization and dashboard development. Due to the data's multi-dimensional nature and intended users, visualizations commonly used in energy modeling and data analysis were adopted [45][46]. The initial prototype and total capacity tab can be seen in figure 2.2. The dashboard consists of a series of tabs showcasing various visualizations. Given studies have shown that decision-making is impacted by the limitations of an individual's working memory, each tab hosts only one model output to minimize information overload [36]. At the top of each tab are the correlating dropdown menus allowing users to select their data of interest. Scenarios can be selected using the first dropdown menu and multiple scenarios can be selected and shown at once. The scenarios are distinguished using patterns and labels in the plot (task 4). Users can view the Canada-wide results or results per province using the region dropdown menu (tasks 2A and 2B). If users wish to compare provincial results side by side, a second figure is included on each tab that shows the output for all provinces for a selected year (task 2B). The year can be changed using a slider, which offers the functionality to view how results change over time (task 9). The "per Region" plot showing the side-by-side provincial results can be seen in figure 2.3.

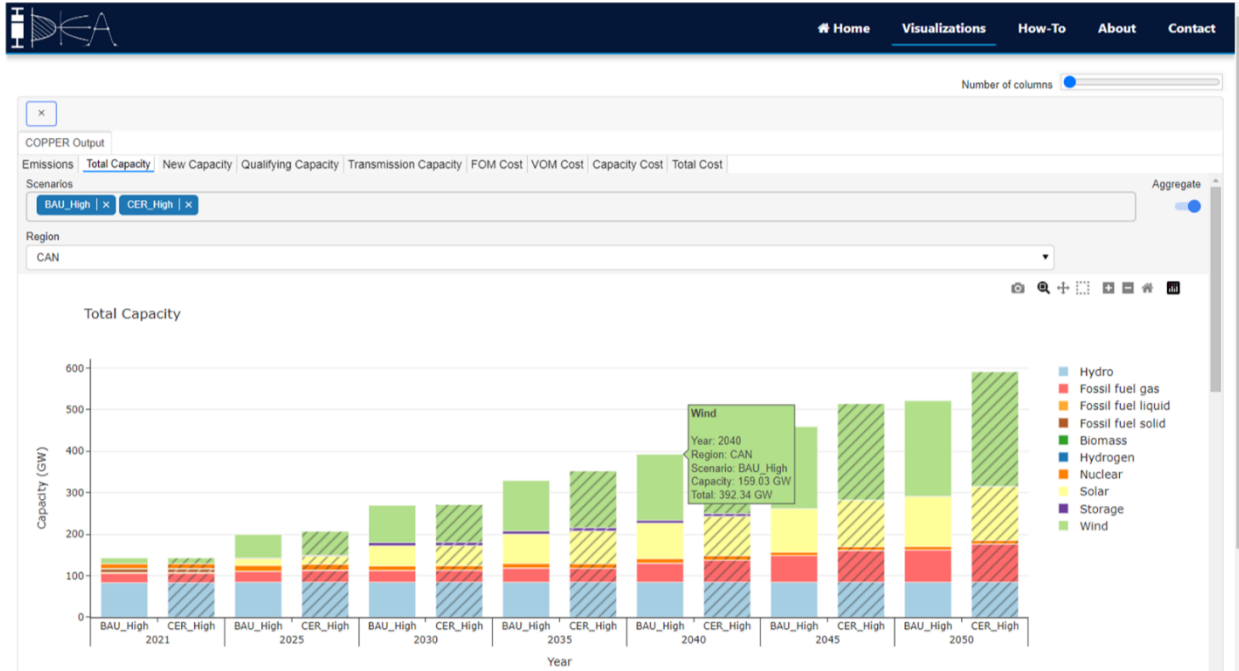


Figure 2.2: The initial prototype and total capacity tab showcasing the total capacity model outputs for all of Canada. The hover tool is shown providing numerical information for the wind technology in 2045 for the BAU high scenario.

Each figure is fitted with a hover tool that provides additional information when the user hovers over a specific data point. The hover tool commonly displays the technology name, time period, region, scenario name, value and total value (in that time period or region). This feature facilitates numerical comparison that supports the visual comparison enabled by the plot (task 5). A tool bar has been integrated that facilitates panning, zooming, saving, and refreshing of the figure (task 7). The hover tool and tool bar can be seen in figure 2.2. Additionally, users can hide data with a single click of an item in the legend, and with a double click, users will see only the data associated with that technology name (task 6). While showing aggregated technology names is advantageous in reducing clutter and the number of required colours, this design decision results in a loss of granularity in the data presented. To avoid this pitfall, a toggle labelled “aggregate” was added to show the aggregated or disaggregated technology names and their associated data (task 10B). The aggregate toggle can be shown next to the scenario dropdown menu in figure 2.2. The interactive legend can be seen in figure 2.3.

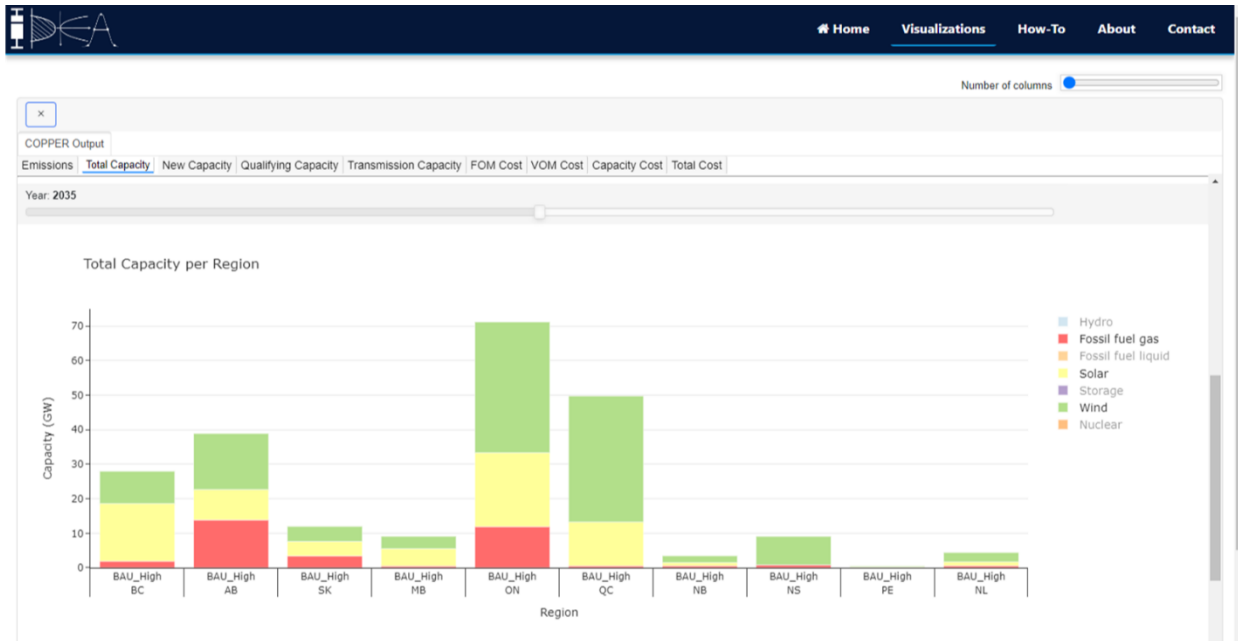


Figure 2.3: The total capacity per region plot on the total capacity tab showing provincial side by side results. Here, the grey technology names have been single clicked to remove their data and only the data pertaining to fossil fuel gas, solar and wind remain on the plot.

For more complex results, alternative figures were designed and various widgets were added. For the transmission capacity model output (task 1K), a map was used to provide a geospatial representation of the provinces and transmission lines. A “combine” dropdown menu was added allowing users to view total transmission capacity (combined) or new and existing transmission capacity (separated). The “separated” option distinguished new transmission capacity from existing and planned capacity using a dashed line. Additionally, the hover tool provided directionality, to specify the available capacity in each direction between the two provinces. The transmission capacity tab can be seen in figure 2.4.

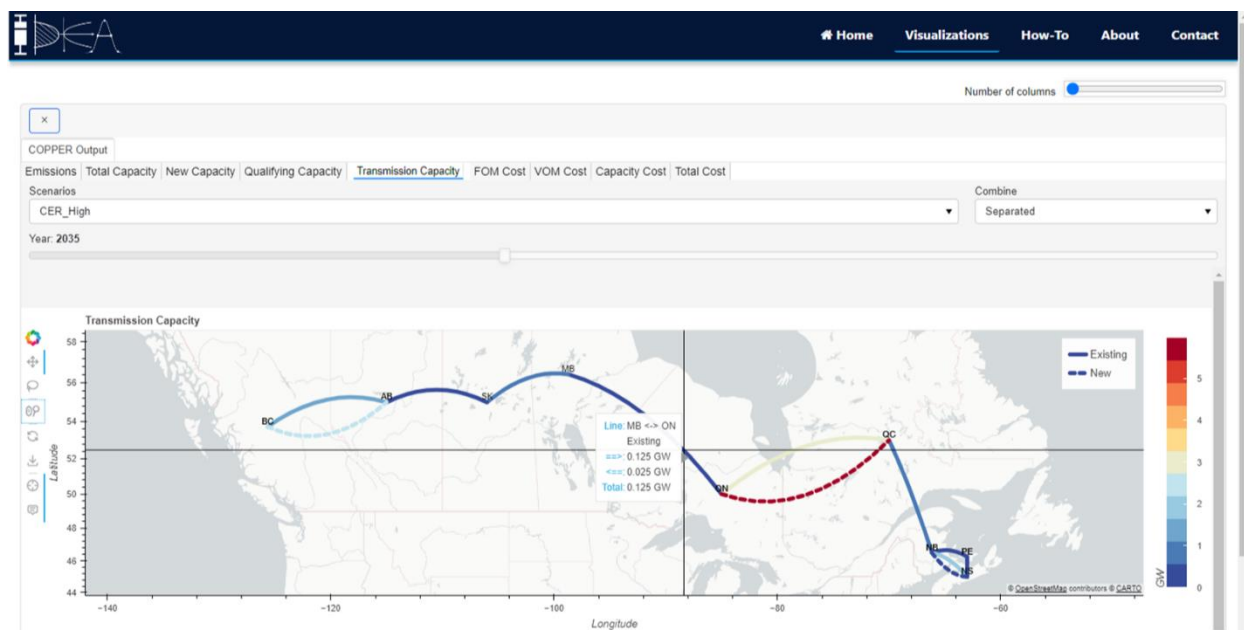


Figure 2.4: The transmission capacity tab, showing the transmission capacity results for all of Canada. The "combine" dropdown has been set to "separated" to showcase the new and existing transmission lines separately.

In the workshops, ECCC requested the addition of various model outputs, including dispatched electricity, generated electricity, transmission flow, and backup generation, as well as model inputs, including demand, technology costs, and extant capacity. Leveraging existing visualization code, a stacked bar chart was selected for the generated electricity and net new capacity plots (task 1K and 1L), a map for the transmission flow (task 1J) and a stacked area chart for dispatched electricity (task 1M).

Another major request was the overview tab, which supports Canada wide results and facilitates quick, high-level comparisons between scenarios. Total capacity, total emissions, total cost and new capacity figures are featured on this tab. The overview tab can be seen in figure 2.5 below.

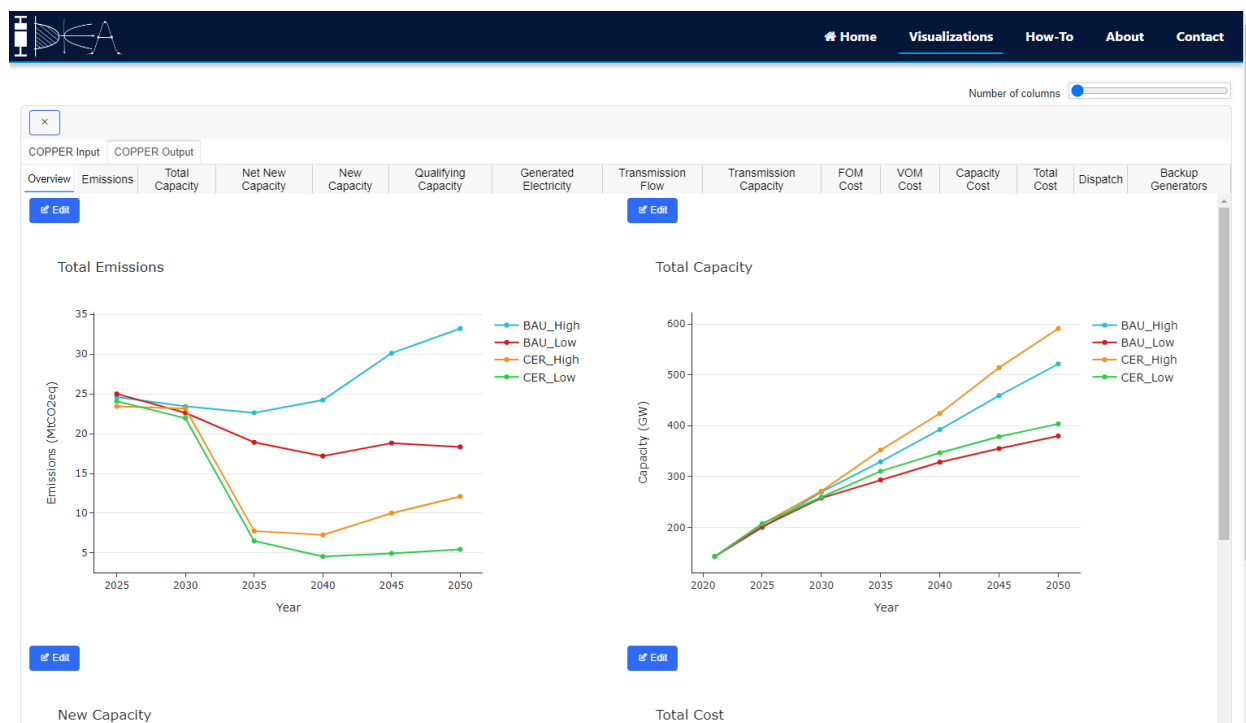


Figure 2.5: The overview tab, showcasing the total emissions and total capacity plots for all four scenarios run.

To better facilitate comparison, participants suggested adopting a standard colour allocation for each technology, maintaining a consistent order for the stacked bars, and presenting all costs as undiscounted annuities. Specific colours were selected and standardized across all visualizations for the aggregated technology names that match existing mental models associated with these technologies (task 11 & 14) [47][48]. Participants requested functionality for side-by-side comparison of different outputs (for example: cost and emissions). An “add card” button was added at the bottom of the dashboard allowing users to create another instance of the entire dashboard. The number of instances can be adjusted using the “number of columns” slider at the top right, allowing users to add up to four instances of the dashboard. With this feature, cross-variable comparison was achieved (task 16). Additionally, edit and data buttons were added to allow users to change colours, titles and axis labels, and download the exact numerical data for each figure, respectively (task 17 and 18). The features mentioned can be seen in figure 2.6 below.

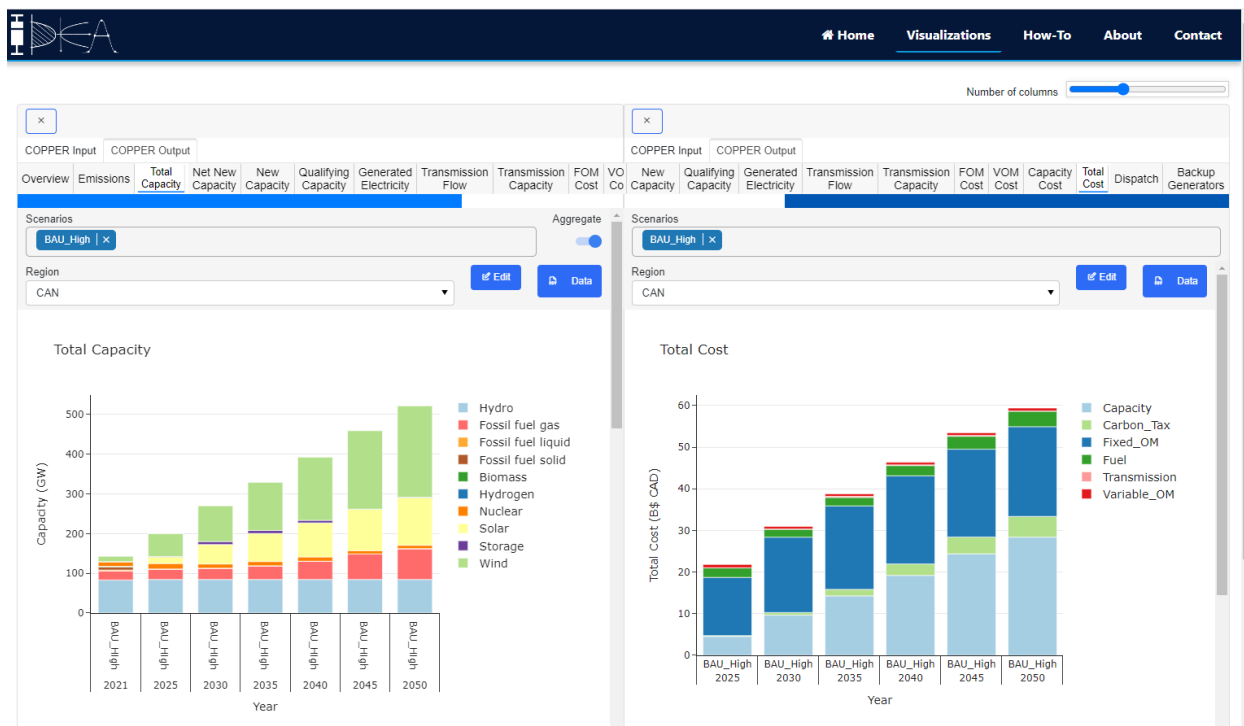


Figure 2.6: IDEA, showing two instances of the dashboard arranged side by side. The left shows the total capacity tab, and the right shows the total cost tab. Additionally, the edit and data buttons can be seen on the right.

2.5.2 Usability Test Results

Thematic analysis identified the following common themes: accessibility, aesthetics, data errors, features, functionality, text content, and layout.

Accessibility: Font size was an important design item that significantly impacted accessibility. One participant struggled for accessibility reasons and mentioned they “had to bring their head close to the screen” in order to view the text in the hover tool, legend, and tab names, indicating a more inclusive font size should be chosen.

Aesthetics: All seven users identified the importance of distinguishing between the visualizations on one tab. For example, Participant 3 pointed out, “since the background is white, ... there is not really a clear distinction that [the scenario bar] is a header,” leading to users misinterpreting which drop down menus and widgets were for each figure.

Features: Three participants identified the data button as useful, but Participant 5 stated the downloaded files “should have an indicator of what scenario and region are downloading...instead of the same file name...otherwise it increases my work to double check in each file what province it is.” This button should also support data downloading for multiple regions at once.

Functionality: Throughout the tests, it was clear that participants could not fully identify all the functionality that was available without verbal explanation. Participant 1 stated they were “searching around for buttons for a while,” specifically for tasks involving the aggregate toggle

(task M) and the interactive legend (task G), resulting in a low percentage of correct responses in figure 2.7. Additionally, Participant 1 stated “the panels weren’t intuitive...that you could have more than one panel at a time.” This, coupled with the high completion time for task R, indicates that the process for *adding a card* to view two side by side instances of the dashboard was not innate for users and requires further clarification.

Text Content: It is vital that the costs figures are clarified using text on all cost tabs, as five participants were confused regarding what cost metrics were being shown (discounted or undiscounted, annualized or not annualized) and what currency the results were in.

Layout: The default zoom was challenging for participants when viewing the figures, dropdown menus, and sliders all on one page. This resulted in high completion times for tasks E and F which required users to scroll down to view the full figure, in turn, hiding critical menus.

More significant suggestions included allowing users to select the scenarios of interest on the overview page and adding pie charts showcasing the generation mix for each province. Additional feedback from the usability tests can be found in Appendix A.2.2.

Overall, correctly responded tasks took users less time to complete. All participants were able to successfully complete tasks A, B, F, I, J, K, L, and Q. Referencing table A.3, these results confirm that the following design tasks are effectively facilitated by the dashboard: 1, 2, 4, 5, 7, 10, 13, and 16. Participants expressed that with the addition of training and after becoming aware of the features available, they would be able to successfully complete all tasks.

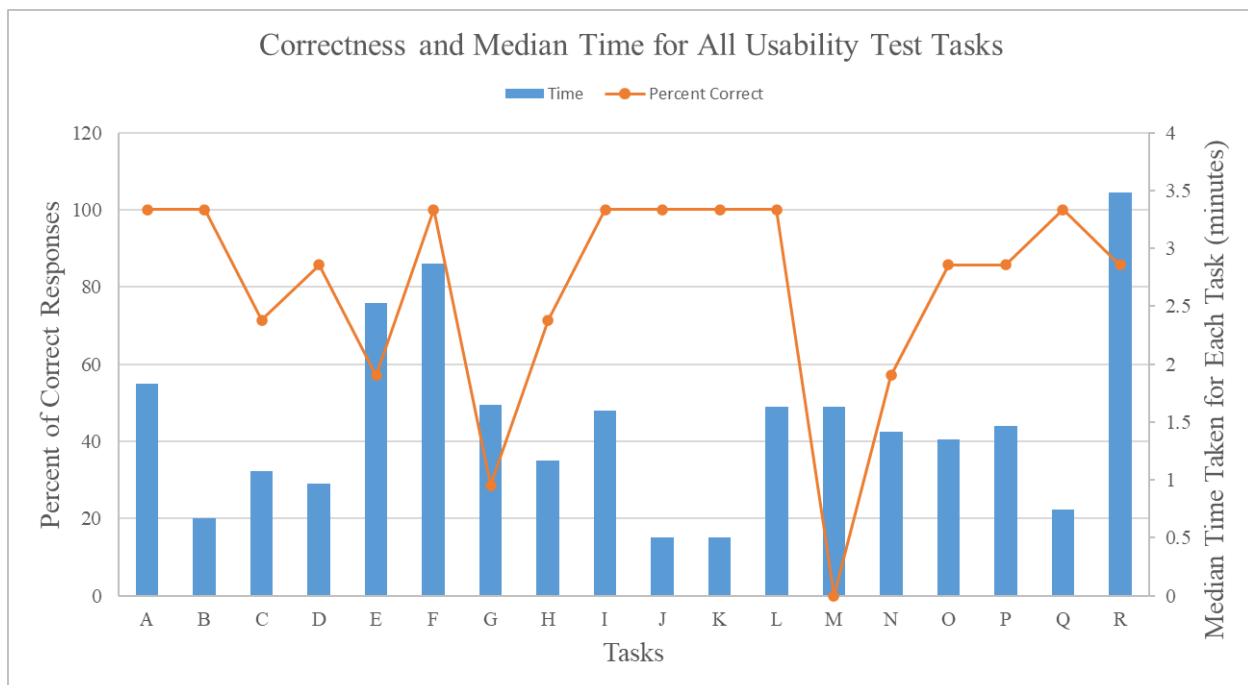


Figure 2.7: Percentage of correct responses and median time taken for each usability test task.

2.5.3 Stakeholder Engagement Session Results

2.5.3.1 *Constructive Feedback and Improvements*

A thematic analysis was conducted to analyze all data collected in the stakeholder engagement session. Table A.3.2 in Appendix A.3.2 summarizes the feedback and improvements for IDEA. Major similar and diverging feedback between stakeholders is discussed below.

Expand Inputs. A common point of discussion in each session surrounded expanding the inputs presented in the dashboard, as shown in table A.3.2. Participants expressed the importance of understanding the model formulation and governing assumptions to accurately interpret the model results. The Ministry of EMLI stated, “to really understand the model and feel comfortable with it, we need to know what the inputs are.” Individuals that work closely with decision makers also highlighted that the majority of the questions they are approached with when discussing energy modeling results involve the assumptions and inputs of the model, which is supported in figure A.3.1. The expanded range of inputs should include reserve margin allocations, life span of each generator type, system reliability metrics, technology evolution over time, wind and solar capacity factors, capacity factors per unit or average capacity factors for each generator type for a given region, information regarding curtailment, cost assumptions (annualized, carbon tax growth, discount rates, interest rates), and policy assumptions.

Add Terminology and Definitions. All participants also expressed the need for definitions and additional documentation via verbal feedback and in the survey responses (figure A.3.2). Participants agreed that while avoiding information overload on the dashboard was important, definitions for the tab names, visualizations, technology types, and scenarios are critical. Participant 2 at the Ministry of EMLI said, “If I have to go back [to another tab], I find it disrupts my train of thought when I’m exploring. Also, users may lose interest at that point,” and suggested to implement plain language definitions as a pop up when a user hovers over a specific term. This was echoed by participant 4 at NRCan who said, “the problem with a glossary is that we keep forgetting it's there.” Participants at NRCan suggested providing more detailed documentation on the model formulation, policy implementation, scenario development, model limitations and data sources as a searchable frequently asked questions (FAQ) tab that users can go to if they seek more detailed information beyond the pop ups. Also, users requested additions to all visualizations that indicate when the policy being evaluated has been implemented. This enables better comparison of the Canadian and provincial landscapes before and after policy implementation.

Feature Improvements. There were some features that hindered the usability of the dashboard for stakeholders. The double scroll bar and pre-set zoom provided challenges to view the entire figure with the appropriate drop-down menus, leading to confusion and users forgetting to select the appropriate scenarios during operation. Participant 2 from the Ministry of EMLI stated “sometimes I forgot to click BC instead of Canada and using the slider. I think there was a lot of components to be aware of,” highlighting the need for better distinction between visualizations and menus. The highlighted tab, indicating which tab users selected, was often incorrect, resulting in longer navigation times between tabs. The slider was also challenging for users to click and drag, as it is relatively long and requires a certain amount of mouse travel before a new selection

is made. Additionally, when the slider is used, the y axis is re-scaled to the new data rather than having a fixed scale and adjusting the trend line. This nonobvious visual change led users to assume the data did not change over time and hindered the comparison.

Present Levelized Data. To strengthen comparison DSF and NRCan suggested providing the data in levelized metrics. Key desired metrics are a levelized cost (cost per kWh) and capacity factor per unit or technology, in each region.

Reduce Visualizations on Each Tab. Although covered in the training portion, participants often forgot there were multiple figures on each tab providing Canada-wide and provincially specific data. The current interface has no indicator that additional figures are present. Having a simpler tab with one visualization and set of menus would be more intuitive for the users.

Expand High-Level Results. CEC, DSF, and NRCan all ranked the federal and provincial governments as their primary audience (figure A.3.3). Communication between the government and these stakeholders is often conducted via briefing notes or PowerPoints that only contain high-level information. CEC requested a shift to showcasing a suite of scenarios and better highlighting key insights and required decisions that are necessary to secure Canada's energy future. This would allow CEC to clearly communicate to the government an array of pathway options and upcoming decision milestones. Similarly, DSF stated they commonly analyze six to eight scenarios at a time, so appropriate overview and high-level figures should be implemented to support this volume of scenarios. NRCan and EMLI work closely with the provincial government and requested provincially focused overview plots to compare the trends for each province. Feedback to expand the key insights presented was often collected from participants with a policy-focused background or that worked very closely with decision makers. From figure A.3.1, it was evident that all stakeholders value high level results for emissions and generated electricity, as they were attributed the highest importance. New capacity results also had a relatively high importance among all stakeholders. To assist with the communication of high-level results, the addition of a summary page with text explanation of the key findings was also suggested.

Contextualize Model Results. NRCan is often asked by decision makers how presented modeling results compare to recent policy announcements, published modeling work or "the latest new views and projects," as stated by participant 2. Therefore, expanding IDEA's capacity to include externally relevant modeling results or information would help ground the user and lead to stronger result interpretation. A similar intervention was suggested by EMLI to indicate directly on the visualizations when a specific policy comes into effect so users can accurately analyze the impact before and after policy implementation. CEC suggested to present this additional information in a "Where are we now" tab that would, "communicate to decision makers, here's where we are today, here are the diverging paths, and this is the trajectory we are on." This would provide metrics for where Canada is currently, in terms of generation capacity and emissions, so users can compare to historical values as well.

Flexibility in Visualization Representation. With the diverse backgrounds of the stakeholders included, individual opinions varied on how data should be represented in each figure. Some stakeholders agreed with the bar and line charts with the Ministry of EMLI stating "I do like bar

charts, I think they are easy to read.” This opinion was commonly shared amongst technical individuals experienced in modeling or engineering and economic analysis. Other participants desired more graphic visualizations, such as pie charts or maps. This provided a more holistic view for these users and the spatial component of the map helped with their results interpretation. Participant 1 from the Ministry of EMLI stated “sometimes with the bars, I just see a bunch of bars. With a map, I see this is BC, and this is AB.” CEC suggested adding in the functionality to change the chart type of each figure to allow “data to be presented in a different form of graphic to solve for different problems.”

2.5.3.2 Positive Feedback

Participant 1 from DSF highlighted the data button as a critical feature, stating “I think [it’s] going to be really powerful for folks who turn it into a report for briefing notes.” This was also reflected in the survey results (figure A.3.2) and verbal feedback (table A.3.1). Similarly, having consistent units and providing numerical data via the tool tip improved comprehension and stood out in the survey. The edit button was also highly regarded in verbal feedback, specifically by DSF who identified they have internal colours they commonly used for various technologies.

In the sessions, CEC commented “the things that immediately struck me ... was just the smoothness... This has been relatively seamless. The functionality on doing anything is pretty straightforward.” When using the dashboard as a results analysis tool, Participant 2 from DSF stated “I’m beginning to answer my own questions...the tool makes it easy for me to ask the kinds of questions I would of the policy and to quickly assess the results.” Other participants highlighted the interactivity, the ability to select and deselect data via the legend, and the figure save button as key features. In the final session, CAS highlighted the importance of the input table. “I really like this [the input table] ...A lot of times results will be shared with the ministries, and they will be like what are the assumptions behind it?” The input table provides the necessary assumptions and background information to answer questions posed by ministries. The overview tab was also highlighted as it provided a quick and comprehensive way to see the net effect of the simulated policy.

2.6 Discussion

2.6.1 Applications

Throughout the sessions, the potential applications and users for IDEA were thoroughly discussed to identify how the current platform could serve stakeholders and what modifications would be needed to serve other applications. Three major use cases were identified in this study: a results analysis tool, a key insights tool, and a modeling tool.

Results Analysis Tool: IDEA was conceived as a results analysis tool used by energy modelers to facilitate exploration and discussion of energy modeling results. Within this use case, IDEA facilitates scenario comparison, multi-model comparison, and multi-model analysis. Based on the feedback collected, the current version of IDEA successfully meets the needs of two users within this application: the modeler and the partnering stakeholder. The modeler uses IDEA to comprehend the model results, extract key insights, and evaluate policy options. The partnering

stakeholder collaborates with a modeling team to analyze scenarios or pathways of interest. Throughout the collaboration, IDEA is used in meetings between the stakeholders and modeling team to discuss model implementation, constraint development, input selection, output analysis and major insights. By engaging with stakeholders using this dashboard, IDEA allows non-technical groups to leverage modeling results to make an impact on climate policy in Canada. This is particularly influential when it comes to organizations who do not have the modeling capabilities or resources to evaluate a proposed policy in the commentary window provided. Clean Energy Canada and the David Suzuki Foundation would be categorized in this user group. Additionally, two other users within the results analysis tool application were uncovered in this study: the decision maker's support team and First Nations. The decision maker's support team are not modelers or ministers themselves but have strong technical knowledge and provide advice and direction to decision makers. These individuals are often responsible for answering specific questions from ministers and having IDEA to support the answers improves their level of detail, accuracy, and confidence. There is also a desire for these individuals to compare modeling studies conducted by independent groups with announced policies to evaluate how the simulated scenarios fit within the Canadian climate context. For example, facilitating comparison between the EMH's CER modeling study to the Canada Energy Regulator's Energy Future Report [49]. The BC Ministry of Energy, Mines and Low Carbon Innovation and BC's Climate Action Secretariate would be identified in this user group. Regarding First Nations, this tool allows community driven engagement and decision making. With this use case, more comprehensive training may be required to communicate how to interact and interpret the platform. The suggested terminology additions in table A.3.1 would also improve engagement and intelligibility.

Key Insights Tool: Ministers and decision makers were another user that was commonly discussed. Information being communicated to ministers and decision makers is often presented in briefing notes or PowerPoints and only includes the key insights that pertain to the pertinent decisions or questions of the minister. The current design of IDEA provides too much information and requires a certain level of technical literacy for result interpretation. The level of detail and research provided by IDEA is not required for the current process for government officials to make decisions or exceptions. Therefore, when considering ministers and decision makers as users, participants highlighted some key changes. A narrative-based approach would be more suitable for this application as it allows one to guide the decision maker through the key insights and directly relate them to upcoming decisions. The dashboard would also have to be extremely user-friendly and intelligible by an individual with a high school degree.

Modeling Tool: Some participants expressed interest in using IDEA as a modeling interface where users could change the inputs provided, develop their own scenarios, and output new model results. These users have strong technical literacy but do not have the background or resources to develop and operate complex energy models. This application provides users with increased autonomy over the scenarios simulated, however it significantly increases the computational complexity of IDEA.

With the variability of the applications and users above, participants suggested the implementation of profiles. The profiles could be customized to a layperson, decision maker, or expert, and would

allow users to tailor the visualizations to their needs. It was clear through the engagement sessions that decision maker's priorities focus on emissions, capacity and cost, therefore a decision maker profile should include these metrics and decision items. The expert profile could take a form similar to the current implementation of IDEA, providing all model results and allowing the user to draw their own insights and conclusions.

2.6.2 Strengths

IDEA successfully facilitates results analysis and multi-model comparison for energy modeling results from the integrated models. Expanding the available models can be done easily by creating a new model profile and leveraging the existing visualization code. Having a library of visualizations available specific to energy models significantly decreases the turnaround time to analyze and interpret results.

As depicted in section 2.6.2, stakeholders identified some key strengths of the platform. The data and edit button provide functionality required by NGOs to prepare briefing notes and conduct their own analysis. Facilitating visual and numerical comparison improved comprehension of the trends and data presented. Users were able to use IDEA to explore the energy modeling results, find data of interest, and investigate the model formulation via the input table.

Integrating the inputs and outputs into one user-friendly interface increases transparency and accessibility of model results [6][12]. IDEA also ensures stakeholders can be involved in every stage of the modeling process by providing a comprehensive and intelligible dashboard for stakeholders to interact with [7]. Additionally, IDEA is open source, which contributes to its transparency and adaptability [13].

2.6.3 Limitations

IDEA is subject to limitations that should be considered when interpreting modeling results using this communication tool.

IDEA has been developed for a subset of models, with visualizations and features optimized for these specific results. Effort is underway to expand to others, including economic and agent-based models. If a user wanted to visualize results for a new model, it would require experience with Python to expand the visualization capabilities. Similarly, IDEA is not currently hosted on a server and is only accessible via a public GitLab repository. This may create a barrier for non-technical users when attempting to independently operate the dashboard without support from the EMH or other modelers.

By selecting the model comparison approach, presenting all available results, and implementing the additions in table A.3.1, information overload becomes a major limitation for users interacting with the platform. If users are not aware of the available content or are overwhelmed with the content presented, the engagement and impact of IDEA will suffer. Appropriate training and documentation are required to supplement this limitation as well as strategic layout design. Additionally, targeting specific users and implementing profiles, as suggested in section 2.6.1, could reduce the impact of this limitation.

Creating an open-source visualization tool that can facilitate results analysis and multi-model comparison creates the opportunity for users to misuse the results or create false comparisons. If users are not provided with details regarding the assumptions and model formulation, they may not have enough background information to make an educated comparison and unveil appropriate key insights. This concern was raised in the engagement sessions in reference to policy makers who may not have the technical literacy to correctly interpret the data as well as individuals who intend to manipulate model results to push forward a designed narrative. Additionally, when comparing model results from two distinct models, there can be a plethora of differences between the model formulations, resulting in a false parity developed from the results analysis. To address these limitations, appropriate model documentation can be implemented as well as warning messages if users attempt to compare two incomparable data sets or models.

In regards to the study, as stated in table A.3.1, the number of participants ranged from one to six, resulting in a relatively small population. Therefore, while the results provide insight into the needs and expectations of different stakeholder groups, more feedback and sessions would be required to generalize the results to specific organizations or entire stakeholder groups.

2.6.4 Identified Gap in Energy Modeling

Through the stakeholder engagement sessions, a pertinent gap in the energy modeling landscape was unveiled. All stakeholders suggested moving away from two to four discrete scenarios and attempting to specify the “perfect” future. This is not an effective way to communicate with stakeholders, as a small subset of scenarios cannot address the diverse needs and questions of all individuals present for these discussions. Instead, it was suggested to pivot to an array of scenario options or a scenario suite that can showcase what variables modelers are confident in and where the uncertainty and major decisions culminate. Adapting this modeling technique allows stakeholders and researchers to identify the common trends and minimum thresholds needed to achieve federal and provincial emissions targets, resulting in a more direct pipeline to effective decision-making.

2.6.5 Stakeholder Engagement Session Recommendations

Several lessons learned were extracted from the workshops with ECCC regarding stakeholder engagement and model comparison. Aligning expectations on cost metrics was a big point of discussion, specifically regarding how costs are calculated (discount factor, interest rate, annuity values) and visualized. Similarly, how technology types were represented in the platform significantly impacted the user’s understanding of the results. The workshop also highlighted the need for strong communication between the modeling and visualization development teams, to ensure model results are represented accurately and with all the necessary dimensions.

Regarding the methodology presented in section 2.4.2.2.b, overall, the stakeholder engagement sessions elicited a large amount of engagement and feedback. It was evident that participants with a stronger technical background had higher engagement with the dashboard. Individuals with a policy heavy background had significantly more questions about the model formulation and assumptions. Participants expressed the need for more time with the dashboard to explore all the visualizations, test its limitations, and get comfortable with the features and functionality. Some

users would require more training to understand and be comfortable with devising insights from the dashboard. Having multiple participants in the sessions, compared to a single participant, elicited more engagement with the platform possibly due to the decreased pressure of observing and engaging with a single participant. The in-person sessions provided significantly more verbal engagement and participants were more prone to ask questions and express feedback. However, some participants expressed it was intimidating being paired with an expert watching over them while engaging with the dashboard.

Reflecting on previous collaborations between the EMH and other stakeholders, IDEA is likely to primarily serve as a results analysis tool in stakeholder partnerships. In this application, the following stages are recommended to ensure a smooth and effective collaboration:

Scenario Development: Modeling team and stakeholders develop a scenario suite that represents the policy and possible pathways to be evaluated.

Model Alignment: Modeling team and stakeholders align on the implementation of the policy and pathways, including how constraints are realized, to ensure model assumptions are realistic and the policies are correctly implemented.

Installation & Training: IDEA is installed for the stakeholders, allowing individual access to the model results and visualizations. Training is conducted to highlight the features and functionality of IDEA.

1-on-1 Results Analysis: Modeling team and stakeholders meet to discuss the first impressions of the results. Key insights are identified, and data outliers are addressed. The modeling team is available for direct questions from all stakeholders.

Individual Results Analysis: After an introduction to the results, stakeholders have the opportunity to do an independent deep dive using IDEA. Stakeholders can develop their own list of key insights, questions and concerns that can be addressed.

Final Engagement: Modeling team and stakeholders convene to discuss final key insights, impacts of the model results, and their influence on decision making.

The entire process is iterative and can be repeated as new policy interests arise and modeling results are delivered.

2.7 Conclusion

This paper presents the open-source, energy modeling visualization dashboard IDEA. It includes the motivation and requirements, prototype design, usability testing, stakeholder engagement feedback, and applications.

A human centered design approach was used to develop a prototype dashboard and conduct evaluation. Several key entities in Canadian climate action were engaged in the development and to provide feedback on the dashboard. A multitude of feedback was collected regarding current successes and future improvements. Overall, IDEA's interactivity, comprehensive suite of visualizations and user-friendly interface were highly regarded. Major feedback from stakeholders

includes expanding the model inputs available in the dashboard, adding terminology and additional text to support results interpretation, and improving the dashboard layout.

The potential applications, strengths, and limitations of IDEA were discussed in detail. IDEA successfully operates as a results analysis tool for modelers and stakeholders partnering with modeling teams to evaluate decarbonization pathways and policies. With the modifications suggested in section 2.6, IDEA could also support advisors to decision makers and First Nations. To communicate with decision makers, IDEA would need to be adjusted to a key insights tool that provided only high-level information pertinent to decision makers. A narrative-based approach may be best for this application.

IDEA is open-sourced and can be accessed through a GitLab repository: <https://gitlab.com/sesit/idea-dash>. Current efforts are underway to integrate the feedback uncovered in this study into the current version of IDEA and future work includes analyzing the identified applications and users to outline a roadmap for future development. Additionally, given the importance of discussions between stakeholders and utility operators as identified in figure A.3.3, additional engagement sessions should be conducted with this user group.

To conclude, IDEA successfully facilitates the results analysis and multi-model comparison of energy modeling results that evaluate decarbonization pathways for Canada. This tool is very powerful for communicating results to stakeholders and advisors to decision makers. With some modifications, the user groups can be significantly expanded. Overall, IDEA supports evidence-based decision-making and can make a significant impact in achieving Canada's GHG emissions reduction targets.

Chapter 3: Conclusion

In order to achieve Canada's greenhouse gas emissions targets, effective communication between stakeholders and energy modelers is required. The purpose of this thesis was to develop a tool to address the communication gap between these groups and understand its strengths, limitations, and applications. A prototype dashboard was developed using a human centered design approach to outline the necessary tasks and functions. Task-based usability tests were executed to validate the implementation of the desired tasks and identify possible failures in the prototype. Several stakeholder engagement sessions were conducted with a variety of groups in the Canadian energy space to test the dashboard, collect feedback for improvements, and understand how IDEA could be implemented in their work.

As demonstrated in Chapter 2, the current version of IDEA successfully supports model results analysis, which strengthens opportunities for researchers and modeling groups to collaborate with ministries and NGOs in policy evaluations. The work presented also outlines future versions of the dashboard that can support decision makers and provide them with more autonomy over results analysis and data driven decision making. Individuals higher up in the decision-making process requested a paired down tool that presents only key insights that directly relate to prevalent decisions. Additionally, many stakeholders were eager to adjust the assumptions and model formulation to uncover new findings that could support current challenges in energy policy. This resulted in the request for a modeling tool, which would provide a user-friendly interface for non-modelers to conduct their own modeling.

To address the obstacles impeding the impact of energy models, IDEA achieved transparency and accessibility by completely open sourcing the development code, allowing individuals to understand how results are being presented and add in their own models or visualizations. Additionally, model inputs, such as technology costs, capacity factors, and emissions allocations were transparently presented on the dashboard's inputs tab, allowing stakeholders to determine the key tradeoffs of each metric and confirm the model assumptions align with their expertise. The guidelines presented in section 2.6.5 ensure stakeholders are integrated throughout the modeling process, ultimately strengthening the model outputs and improving stakeholder trust.

In terms of future work, this thesis outlined many achievable improvements to strengthen IDEA's functionality as a results analysis tool. These improvements have been collected and shared with the development team at the EMH to be implemented. More significant modifications would be required to transform IDEA into a key insights tool. For this application, further consultations with ministers and decision makers would be required to outline the key metrics of interest. However, with the current visualization infrastructure developed for IDEA, a key insights tool is a realistic future application. Transforming IDEA into a modeling tool would require diaristic functionality changes and could introduce the need for surrogate modeling to provide modeling results within a reasonable time frame for users. Further canvassing would be required to understand the practicality and usefulness of this application for stakeholders before development is considered.

This research and IDEA advance data-driven decision making by addressing decarbonization issues that are multi-disciplinary, multi-sectoral, and multi-scale. The contribution of this research unveils the needs of stakeholders in different disciplines (engineering, economics, policy) and different sectors (federal government, provincial government, NGO, academic). Understanding these needs is key to progressing decarbonization as successful policies must be equitable and address climate change vulnerabilities in multiple populations. The needs of each group are also bound to be distinct and based on their knowledge and lived experience. This data is often hard to collect, highlighting the value of the presented work. While it may not be possible to have all stakeholders completely align, this work also sets out to find common and diverging needs among stakeholders, which is critical in establishing a starting point for conversation surrounding decarbonization policy and helps to identify key challenges for policy implementation. On a multi-scale perspective, climate action is being implemented on the municipal, provincial and federal level, however the size and priorities of these climate action strategies varies largely. The work presented facilitates cross jurisdiction analysis which opens opportunities for better alignment between climate action plans and provincial/federal targets. Better understanding these three key principles and their relation to decarbonization issues is key to more productive discussion on prevalent policies and topics surrounding Canada's energy future.

Throughout the engagement sessions, the impact of IDEA and its applications on each stakeholder varied:

Federal Government – Using IDEA as a communication tool to evaluate a prevalent federal policy currently being discussed showed IDEA's capability to influence real regulation. With IDEA providing a solution for key issues of the communication gap, including lack of transparency and long lead times for model analysis, the federal government can leverage IDEA to create data-driven decarbonization policy and easily engage with other stakeholders to collect feedback on the policy. Evaluating more decarbonization pathways and a wider breath of scenarios strengthens future policy and ensures the views of more stakeholders can be considered during the commentary window.

Provincial Government – Many divisions of the Provincial Government have their own internal models that are used to evaluate pathways and policy options. These models are often not compared with external models due to a lack of resources, time, and capability. IDEA provides the functionality to conduct multi-model comparison, therefore raising the awareness of provincial government officials regarding other models and model results that exist. This breeds future opportunity for collaboration and comparison, which will inherently strengthen the models of all parties and highlight the key diverging principles in model assumptions.

Non-Governmental and Academic Organizations – IDEA offers NGOs and academic organizations the ability to support and enhance their analysis with quick and detailed model results that can be easily transferred to briefing notes or PowerPoints for delivery to decision makers. This greatly widens the impact NGOs and academic organizations can have on promoting data-driven policy decisions, as the time for results analysis and presentation is substantially reduced with the use of IDEA.

Energy Modelers – IDEA offers energy models the functionality to take a holistic approach to model debugging and results analysis. Having all results seamlessly visualized enables modelers to ensure constraints are correctly implemented, results are properly correlated, and outliers can be targeted. Similarly, IDEA provides a full picture of the results, rather than a small subset of graphs or excel sheets, strengthening the opportunities for deep analysis and insight discovery.

IDEA has been developed with an extensible framework allowing quick and easy integration with other models and modeling teams. With its code completely open-sourced, users can integrate new models, expanding to integrated assessment models, transportation models, agent-based models, and more, as well as new visualization to effectively showcase the results of each model. With this adaptable framework, modeling teams across Canada can make a bigger impact on energy policy decision making and promote more dialogue surrounding possible decarbonization pathways for Canada.

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Appendix

A.1: Prototype Development

A.1.1: Initial Task Table for the Prototype Design using TCDM

Table A.1.1 Initial Tasks Identified

No.	Task
1	View various model outputs including:
1A	Total Generation Capacity
1B	New Capacity
1C	Qualifying Capacity
1D	Emissions
1E	Total Cost
1F	Capital Cost
1G	Total Operations and Maintenance Costs
1H	Fixed Operations and Maintenance Costs
1I	Variable Operations and Maintenance Costs
1J	Transmission Investment Cost
1K	Transmission Capacity
1L	Location of New Variable Renewable Energy Generators
2A	Explore results for all of Canada
2B	Explore results produced per province
3	Have units across all visualizations be consistent
4	Facilitate side by side comparison of multiple scenarios
5	Facilitate numerical comparison
6	Facilitate selection/deselection of data in the figures
7	Facilitate zooming, panning and saving
8	View model results for each technology type
9	View model results for the entire simulation period
10A	View technologies as common aggregated energy types
10B	View disaggregated technologies as simulated in the model

A.1.2: Aggregated and Disaggregated Technology Names

Table A.1.2 Aggregated and Disaggregated Technology Names

Aggregated Technology Names	Disaggregated Technology Names
Hydro	Hydro Daily
	Hydro Monthly
	Hydro Run of River
Fossil Fuel Gas	Fossil Fuel Gas
	Carbon Capture and Storage
	Renewable Natural Gas
	Backup
Fossil Fuel Liquid	Fossil Fuel Liquid
	Bio
	Backup
Fossil Fuel Solid	Fossil Fuel Solid
	Carbon Capture and Storage
Biomass	Biomass
Hydrogen	Blue Hydrogen
	Green Hydrogen
Nuclear	Nuclear
	Small Modular Reactors
Solar	Solar
Storage	Battery Storage (Lithium Ion)
	Pumped Hydro Storage
Wind	Onshore Wind
	Offshore Wind

A.1.3: Final Task Table for the Prototype Design using TCDM

Table A.1.3 Final Task List

No.	Task
1	View various model outputs including:
1A	Total Generation Capacity
1B	New Capacity
1C	Qualifying Capacity
1D	Emissions
1E	Total Cost
1F	Capital Cost
1G	Fixed Operations and Maintenance Costs
1H	Variable Operations and Maintenance Costs
1I	Transmission Capacity
1J	Transmission Flow
1K	Generated Electricity
1L	Net New Capacity
1M	Dispatched Electricity
1N	Backup Generator Operation Hours
2A	Explore results for all of Canada
2B	Explore results produced per province
3	Have units across all visualizations be consistent
4	Facilitate side by side comparison of multiple scenarios
5	Facilitate numerical comparison
6	Facilitate selection/deselection of data in the figures
7	Facilitate zooming, panning and saving
8	View model results for each technology type
9	View model results for the entire simulation period
10A	View technologies as common aggregated energy types
10B	View disaggregated technologies as simulated in the model
11	Have standard colour allocations for technologies and provinces
12	View various model inputs including:
12A	Demand profile
12B	Technology costs
12C	Capacity factors

12D	Emissions Intensity
13	View Canadian results for each scenario on one figure for model outputs including:
13A	Total Cost
13B	Total Emissions
13C	Total Capacity
13D	New Capacity
13E	Technology Efficiency
14	Organize stacked bars in a consistent order
15	Minimize dashboard loading time
16	Facilitate side by side comparison of different model outputs
17	Allow users to see and or download exact numerical data used for each figure
18	Allow users to change colours in each visualization

A.2: Usability Testing

A.2.1: Usability Test Tasks

- A. Between the years 2035 and 2040, is there an increase in total solar capacity in Canada for BAU_low and CER_High scenarios?
- B. In 2050, how do the emissions compare between the BAU_low and the CER_low scenarios for Canada?
- C. How does the total cost of the CER_low scenario compare to the total cost of the BAU_low scenario for Canada over time?
- D. How much money is being invested in transmission in 2035 in Canada in the BAU_high scenario?
- E. How much new transmission capacity is built in 2035 between Saskatchewan and Manitoba and what direction is it flowing in the CER_low scenario?
- F. How does the total transmission capacity between Ontario and Quebec in 2050 compare between the CER_low and BAU_low scenario?
- G. In 2025, how much fossil fuel solid qualifying capacity is there in Canada for the BAU low scenario using the summer capacity factors?
- H. Download the following figure: The generated electricity for each province in 2030 for the CER_high scenario.
- I. In 2050, how do the transmission flows between BC and Alberta compare when looking at the BAU_low scenario vs the CER_low scenario?
- J. Which scenario results in the highest cost in 2050 for Canada?
- K. How many hours did the backup generators run in Canada in 2025 for the CER_High scenario?
- L. How does the amount of generated hydro electricity differ between Ontario and Quebec when looking at the BAU_low and CER_low scenarios in 2035?
- M. How much emissions are caused by fossil fuel gas CCS in Canada in the CER_low scenario in 2045?
- N. Are the trends over time of total capacity and total cost the same or different for all scenarios?
- O. For the CER_High scenario, on the Canada fixed operation and maintenance (FOM) cost figure, zoom into the years 2025 and 2030 and then pan to 2045 and reset the axes.
- P. Looking at the dispatch plot for BC on March 3rd, 2025, for the BAU_High scenario, how much electricity was generated by hydro and solar in the 18th hour?
- Q. What is the efficiency of green hydrogen (h2green_ct)?
- R. Add visualization cards and increase the number of columns to 3 to see 3 visualizations at a time, side by side

A.2.2 Usability Test Results

Accessibility: Line graphs with yellow data presented an issue for participants with visual impairments. The font size for the tab names and legends were also challenging to read on laptop screens. Additionally, the tool tip font and tool bar icons were also slightly undersized.

Aesthetics: The aesthetics of the input table were dated and made comparison between numerical data difficult. The white background of the sliders and dropdowns resulted in them blending into the dashboard, causing users to miss their functionality. Given there are two to three plots per tab, participants also suggested to better distinguish these plots using lines or different background colours. Colour coding could also be used to distinguish tabs into intelligible groups.

Data Errors: Some technology names were incorrectly aggregated, resulting in disaggregated technologies displaying in the aggregated plots.

Features: The data button doesn't support downloading data for multiple regions at once. Also, the file name for the downloaded data is not unique, requiring users to open the file to determine the contained data. Engaging with the slider was difficult for some users as it requires dragging and holding the slider for a long distance before updating. When the scenario dropdown was clicked and all scenarios were selected, the dropdown remained open, blocking the other menus from the user. When attempting to save a figure, users were looking for a download icon (down arrow) as opposed to a camera icon. Additionally, the lasso tool did not allow users to exit their selection and reset the figure. The content in the tool tip, specifically the total provided, was not immediately intelligible to the user and participants suggested adding in a percentage of total to facilitate comparison in stacked bar charts. Additionally, the numerical values presented in the tool tip should be converted from exponential form to an appropriate number of significant figures. Regarding the interactive legend, it was not apparent to users that they could double click a legend name and have only the data for that item in the figure shown.

Functionality: The aggregate toggle has a slight lag after it was clicked. The transmission capacity bar graph was more useful compared to the map, as users could quickly determine where new transmission lines were being built and how the new capacity changed over time. Comparing two scenarios for the transmission capacity or transmission flow figures was a challenge, as it required the addition of a second instance of the dashboard, which was not an intuitive process for users. Participants requested functionality to rearrange the figures and dashboard to their preference, enabling comparison between their figures of interest. It was also of interest to select the scenarios on the home or overview page of the dashboard and have those scenarios propagate to all figures. A pie chart showcasing the generation mix for each province would align with common visualizations seen in practice. Additionally, users would like a reset button that reinstates the original colour palette for all visualizations in the dashboard.

Text Content: Units were missing in the input table for each column. Adding descriptions of each variable or tab name would also be beneficial for users. Disaggregated technology names were confusing to users, as they used acronyms only the modelers are familiar with. Cost metrics provided in the platform should have some context, specifically what is included in each cost, if

they are annualized or not annualized, and if they are discounted or undiscounted. Additionally, costs should be specified in Canadian dollars.

Layout: The default zoom was challenging for participants when viewing the figures, dropdown menus, and sliders all on one page. To view the full figure, users often scrolled down, which in turn hid the menus. Some figures also had the y axis scroll functionality automatically enabled, which caused users to struggle to scroll up and view the menus again. Placement of the "add card" button and slider to facilitate side-by-side comparison of different variables was not intuitive. Additionally, some users would fail to see the slider or dropdowns available due to these features being the same colour as the background or users getting lost when scrolling. One figure per tab would solve this challenge and reduce the mental load on users.

A.3 Stakeholder Engagement Sessions

A.3.1 Survey

Confidential

Page 1

Visualization Platform Feedback Form

Please complete the survey below.

Thank you!

1) Organization Name _____

Part 1: Figures

How important is it to have a figure of

	Very Unimportant	Unimportant	Neutral	Important	Very Important
2) Emissions	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3) Total capacity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
4) New capacity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
5) Net new capacity (showing new capacity and retired capacity)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
6) Qualifying capacity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
7) Generated electricity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
8) Transmission capacity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
9) Transmission flow	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
10) Dispatched electricity	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
11) Total cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
12) Fixed operation and maintenance cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
13) Variable operation and maintenance cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
14) Capacity cost	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
15) All scenario trends for one variable (as seen in the overview tab for emissions or total cost)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
16) All model inputs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
17) Demand over time	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
18) The generation mix per year (generated electricity per year divided by the electricity generated by each technology)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
19) Technology costs	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Part 2: Comparison**How important is it for you to be able to compare**

	Very Unimportant	Unimportant	Neutral	Important	Very Important
20) Model inputs for different scenarios	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
21) Multiple scenarios, side by side	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
22) Different variables, side by side (for example, emissions and cost)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
23) Multiple scenarios, in one figure?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
24) Simulation results to historical data (i.e. compare results to 2021 data)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
25) Results for multiple provinces	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Part 3: Presented Results**How important is it for you to see results for**

	Very Unimportant	Unimportant	Neutral	Important	Very Important
26) All of Canada	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
27) Each province	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
28) Interprovincial transmission (between provinces)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
29) Intra-provincial transmission (within a province)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
30) New transmission	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
31) Total transmission (new + existing)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
32) Cost in discounted (present) values	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
33) Cost in undiscounted values	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
34) Cost in annuity values	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
35) Fuel cost per technology type	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Part 4: Features**How important is it for you to be able to**

	Very Unimportant	Unimportant	Neutral	Important	Very Important
36) Zoom in on a figure	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
37)					

- | | | | | | |
|--|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Save a figure | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 38) Download the data used for a specific figure | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 39) Aggregated technology names to intuitive and comprehensive names | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 40) Disaggregate technology names to each technology type | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 41) Have a description of each figure (for example: explaining what the figure is and what it shows) | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 42) Have an aesthetic platform? | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 43) Change the title and axis titles of a figure | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 44) Change the colours used in the figures | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 45) Change the font size | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 46) Have consistent units across related figures | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 47) See the exact numbers from the data represented on the figure or with an interactive feature (as seen in the hover tool) | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 48) Select and hide data on a figure | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 49) Have each technology associated with a specific colour that is consistent across all figures | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 50) Have the y axis of two figures being compare have the same maximum and minimum values | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 51) Have the provinces occur in the same order on each figure | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |
| 52) Have the platform pages load quickly | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> | <input type="radio"/> |

Part 5: Application

How important is it for you to be able to use this platform to engage with

	Very Unimportant	Unimportant	Neutral	Important	Very Important
53) The public	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
54) The Canadian (Federal) Government	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
55) The Provincial Government	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
56) Non-government organizations (NGOs)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
57) Researchers	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
58) Utility companies or organizations	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
59) Private Sector	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

A.3.2 Verbal Feedback Collected from all Stakeholder Engagement Sessions

Table A.3.1 Collected verbal feedback from all stakeholder engagement sessions.

Category	Feedback	CEC	DSF	NRCan	EMLI	CAS
Number of Participants		1	2	4	6	5
Features	Double scroll bar provides issues for users scrolling between visualizations	X	X	X	X	
	Allow users to change the visualization type or data representation	X			X	
	Facilitate calculating the difference between scenarios	X				
	Selection/deselection feature in the legend didn't always work		X		X	X
	The tab highlighted did not always match the user's current tab	X	X	X	X	X
	The slider is challenging to operate		X		X	X
	Implement a reset button to reset the scenario and region dropdown options			X		
	Clicking and dragging table columns wasn't intuitive				X	
	Edit window unexpectedly opened when user selected a different tab					X
	Replace slider with an animation through time					X
Content	Add "Where are we now" tab that provides Canada's current state	X				
	Add high level, provincially focused plots to the overview tab	X		X	X	
	The time zone was not stated in the dispatch plots		X		X	
	Provide leveled cost		X	X		
	Expand inputs included		X	X	X	X
	Plot the demand for the entire simulation period on one plot				X	
	Patterns used in the visualizations are not in the legend				X	
Terminology & Background Information	Add terminology definitions	X	X	X	X	X
	Provide information on model formulation and limitations		X	X	X	X
	Provide links to documentation and sources			X		X
	Add minimal text explaining each tab in plain language			X	X	X
	Add a research question to each tab to assist users in determining the key insights			X		
	Add a summary page highlighting the key insights of the modeling work and the modeling work's motivation			X	X	X
	Improve descriptiveness of figure titles			X	X	X
	Tab names were not completely intuitive				X	X

	Provide information on the scenarios selected and their implementation				X	X
Layout	Location of dropdowns, sliders and toggles aren't always intuitive or clear to users		X		X	X
	Pre-set zoom and screen aspect ratio causes figures to be cut off			X	X	X
	The tool bar location was not obvious to users				X	
	Having multiple figures on one tab hides the data				X	X
Functionality	There was a 2-3 second delay between interactions		X			
	When engaging with the slider, users could not see the trend changing because a local y-axis was used				X	X
	A local y-axis makes side-by-side comparison using the "Add card" feature difficult				X	
	Having scenario dropdown menus when there was only one scenario option was confusing to users				X	X
	Interpretation of transmission capacity tab was not intuitive to users					X
	Allow users to select scenarios, region, scope, and other settings in the overview and home page for all tabs					X
Accessibility	Optimize platform for colour blind users					X

A.3.3 Feedback Collected from Surveys

Figure A.3.1: A heat map depicting median stakeholder responses to the survey question, *how important is it to have a figure of*, for each figure listed.

Stakeholders					Figures
CEC	DSF	NRCa n	EMLI	CAS	
5.0	5.0	5.0	5.0	5.0	Emissions
5.0	5.0	3.0	5.0	5.0	Total Capacity
5.0	5.0	4.0	4.5	5.0	New Capacity
4.0	5.0	3.0	4.0	3.0	Net New Capacity
3.0	3.5	3.0	4.0	3.0	Qualifying Capacity
5.0	5.0	5.0	5.0	5.0	Generated Electricity
4.0	5.0	4.0	5.0	4.0	Transmission Capacity
3.0	4.5	4.0	4.5	4.0	Transmission Flow
4.0	4.5	4.0	4.0	3.0	Dispatched Electricity
5.0	4.5	3.0	4.0	5.0	Total Cost
4.0	4.5	3.0	3.5	3.0	Fixed Operation and Maintenance Cost
4.0	4.5	3.0	3.5	3.0	Variable Operation and Maintenance Cost
4.0	4.5	3.0	4.5	4.0	Capacity Cost
5.0	4.5	5.0	4.0	3.0	All Scenario Trends for One Variable
5.0	4.0	5.0	4.5	4.0	All Model Inputs
5.0	4.5	4.0	5.0	4.0	Demand Over Time
4.0	4.5	5.0	5.0	3.0	The Generation Mix per Year
5.0	4.5	5.0	4.5	4.0	Technology Costs

Figure A.3.2: A heat map depicting median stakeholder responses to the survey question, *how important is it for you to be able to*, for the listed functionality and features.

Stakeholders					Features
CEC	DSF	NRCa n	EMLI	CAS	
3	4	4	4	4	Zoom in on a figure
3	4.5	5	3.5	5	Save a figure
5	4	5	4.5	5	Download data
5	4	4	4	4	Aggregated Technology Names
5	3.5	3	4	3	Disaggregated Technology Names
4	4	5	4	5	Figure Description
4	4	4	4.5	4	Have an aesthetic platform
4	3.5	3	4	4	Change titles
4	3.5	3	3	3	Change colours
4	4	4	3	4	Change font size
5	4.5	4	4	4	Have consistent units
5	4.5	4	4	4	See exact numerical data
5	3.5	3	4	4	Select and hide data
5	4	4	3.5	3	Associate specific colours to each technology
3	3.5	4	3.5	4	Have consistent y axes
4	3.5	4	3.5	3	Have a consistent provincial order
4	3.5	5	4	3	Quick loading times

Figure A.3.3: A heat map depicting median stakeholder responses to the survey question, *how important is it for you to be able to use this platform to engage with*, for the listed stakeholders.

Stakeholders					Applications
CEC	DSF	NRCa n	EMLI	CAS	
2	3.5	3	3.5	3	Public
5	4.5	5	3.5	3	Federal Government
5	4.5	5	4	4	Provincial Government
3	4	4	4	3	Non-governmental Organizations
4	4	4	3.5	4	Researchers
4	4	4	4	4	Utility Companies
4	3.5	4	4	3	Private Sector