THE UNIVERSITY OF WESTERN ONTARIO
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Water Resources Research Report

Use of an integrated system dynamics model for analyzing behaviour of the social-economic-climatic system in policy development

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Executive summary

Climate change remains one of the most critical issues that humans and the natural world face today. Yet while a strong body of scientific research has identified the risks if mitigation and adaptation measures are not taken, there still remains a policy lag. This leads researchers to pose several questions: is there an identified need by the policy domain for more or different science? Is the science that is conducted made policy-relevant? If not, are there tools to better link science to policy? This report will explain the process of science-policy communication related to the development of an integrated system dynamics model of the social-economic-climatic system at the University of Western Ontario under NSERC strategic grant program funding. It will describe the science-policy interface and outline the main challenge to developing science tools for policy, and will then explain how the UWO research team overcame such challenges. Finally, it explains (a) briefly the proposed model and (b) the process of policy scenarios development. The main objective of the research presented in this report is to bring the model closer to policy makers and emphasize how useful this tool is specifically for the Canadian federal government.

The science policy communication process has been established through the set of interviews and workshops. Interviews were used (a) to identify the issues of importance to be incorporated in the model development and (b) to formalize a set of policy scenarios that will provide input for policy making. Workshops were used to communicate science to policy developers and discuss the issues of importance for policy development. The research was fundamentally based on a multi-disciplinary approach that assisted in bridging the research domain to the policy domain. Ultimately, the feedback from the interviews and workshops was embedded in the development of the model and its scenarios, and made it possible to transform policy questions into model scenarios. In other words, by linking science and policy domains, the research team was able to produce a science-based and policy-relevant tool.

Limitations to the work mainly reflect the current stage of research and model development. As the strategic research continues on the *integrated system dynamics model of the social-economic-climatic system*, these limitations are likely to be overcome. The other key limitation is in the selection of the government partners. While the current group of partners has provided valuable insight, further research will aim to expand the group of partners across different departments. This will not only reflect a broader range of interests, but will also more accurately represent a systems view of government. Furthermore, a broader range of disciplinary biases will be consulted, including government policymakers who work more intimately with science and policy research.

Keywords: science, policy, science-policy interface, climate model, policy tools, integrated systems dynamics

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1.0 Introduction

While scientific knowledge is generally only one input in government decision making, it plays an underlying role specifically in environmental policy and management (Environment Canada 2009, 1). In the context of international and transboundary environmental challenges, scientific knowledge has formed the basis of several treaties and regimes, such as the stratospheric ozone and acid rain conventions (Haas 2004, 576-577). In these cases, a combination of timely, credible and accessible scientific knowledge adequately informed the policy domain of the causes of the issues and the impacts particularly to human beings. While the stratospheric ozone and acid rain issues are not resolved in their entirety, a concerted international policy effort stands as an example of the influence of science in the decision making process (Dimitrov, 2006).

Climate change, however, remains one of the most critical issues that humans and the natural world face today. While the full range of impacts are difficult to predict, the Intergovernmental Panel on Climate Change (IPCC) has affirmed that warming is 'unequivocal' and that the,

> Major advances in climate modelling and the collection and analysis of data now give scientists "very high confidence" – at least a 9 out of 10 chance of being correct – in their understanding of how *human* activities are causing the world to warm (emphasis added; UN News Centre, 2007).

As such human-influences ripple through the entire Earth-system, biophysical sectors such as water quantity, water quality and the global carbon system, as well as socioeconomic sectors such as our economy, energy use and production, land use planning and population are all impacted. Thus it is clear that climate change is not an isolated issue but rather one that impacts and is impacted by the entire Earth system. Yet despite strong scientific findings, climate change is yet to experience the required international and domestic policy efforts. This brings two key questions to the fore: is the connection between socio-economic and biophysical systems adequately understood? And if so, is the science being communicated in a policy-relevant manner?

The work under the strategic research grant entitled *An integrated system dynamics model of the social-economic-climatic system*, funded by the Natural Sciences and Engineering Research Council (NSERC) addresses this dual challenge. The research includes two mission statements. First, we must understand the vital feedbacks that connect human activities to the global climate system and the carbon cycle. Climate modeling plays an essential role in this regard. Second, and more fundamental, there must be an effective science-policy interface to (a) understand the requirements that policy imposes on science, and (b) to provide a useful tool for support of policymaking. This can be conceived as 'policy for science' and 'science for policy'.

This report reviews the latter, and explains the process of science-policy communication in the development of the integrated system dynamics model of the social-economic-climatic system named ANEMI. First, it briefly describes the science-policy interface and provides the justification for research conducted under the NSERC Strategic Grant.

Second, it describes the ANEMI model and identifies its applicability as a policy tool. Third, it reviews the science policy communication process in which federal government project research partners were consulted to provide the guidance for developing the model's policy scenarios. Fourth, it briefly reviews the policy scenarios (to be simulated by the ANEMI model) that are developed through the interdisciplinary work of UWO's team. It concludes with key findings and lessons learned.

2.0 The science-policy interface

The development of environmental policies is a complex process, underpinned by the need for an effective science-policy interface; without an effective link between the two domains, sound evidence-based policies are difficult to achieve. The importance of science in policy is specifically recognized in the Canadian federal government context, in which a federal framework entitled *A Framework for Science and Technology Advice: Principles and Guidelines for the Effective Use of Science and Technology Advice in Government Decision Making* explicitly quotes:

> Science advice has an important role to play by contributing to government decisions that serve Canada's strategic interests and concerns in areas such as public health and safety, food safety, environmental protection, sustainable development, innovation, and national security. The effective use of science advice may also contribute to Canada's ability to influence international solutions to global problems (Government of Canada 2000, 2).

For the purpose of research for the NSERC strategic grant, the science-policy interface is schematically presented in Figure 1.

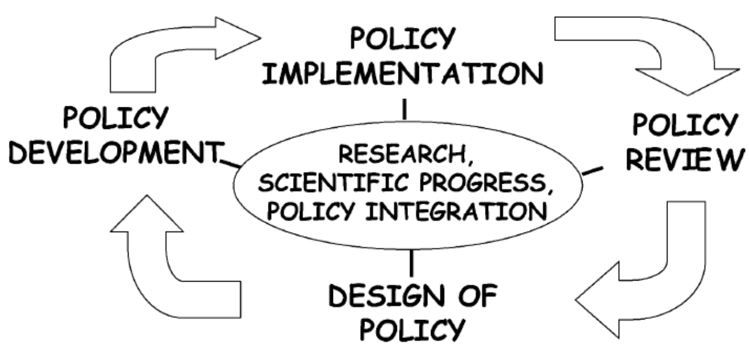

Figure 1: Science-policy link (source Quevauvillier *et al.,* 2005, 204)

Figure 1 offers two main insights. First, it generally outlines the policymaking process by the outer ring (Design of Policy, Policy Development, Policy Implementation and Policy Review). Second, and more importantly, it demonstrates that science plays a role in *every stage* of policy development. Recognizing this fundamental integration then makes it necessary to evaluate the effectiveness of science-policy communication. Some elements of effective communication can be inferred from Figure 2.

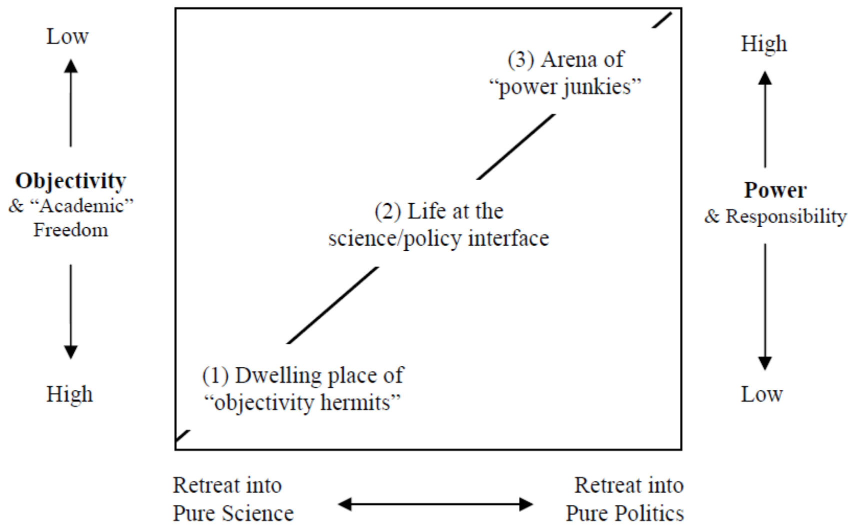

Figure 2: Conceptual space of the science-policy interface (source Roux *et al.* 2006, 8)

As the above figure demonstrates, science and policy domains must forgo their natural inclinations towards pure scientific objectivity or political power in order to meet at the science-policy interface. Without forgoing elements to which they are naturally inclined, an effective bi-directional communication cannot be established. Moreover, science must be expressed, communicated and adequately channeled if it is to affect policy decisions. This requires mutual efforts by both science and policy domains in order to be successful. However, the literature suggests that for a number of reasons, there is sometimes a lack of mutual engagement in this two-way communication. As Roux *et al* (2006, 8) explain, science and policy domains 'push and pull' information "without an appreciation of the complex nature of tacit knowledge, and of the effort required to achieve bi-directional knowledge flows between diverse worldviews". While there are many possible reasons for the barriers between science and policy domains, Table 1 points to some that are recognized in academic literature.

The NSERC-funded research work under the title "*An integrated system dynamics model of the social-economic-climatic system"* is trying to overcome the science-policy barriers in two ways. From a scientific perspective, the development of the ANEMI model has contributed to an increased understanding of climate change by building on the modeling done by other researchers; it has improved representations of the physical processes involved in the climate system and carbon cycle, and included the socio-economic sectors and activities that govern interactions with the biophysical system, especially those that influence or control anthropogenic emissions. It has also added to the number of approaches available for climate change modeling; it applies the *System Dynamics* simulation methodology, since it can both deal with long term delays, multiple feedback processes, and other elements of dynamic complexity and also provides for easy integration of scientific concepts of social, natural and engineering sciences.

Table 1: Possible explanations for the science-policy gap (after Saner 2007, 5)

Science	Policy
	Concepts & Foundations
Understanding the world	Managing the world
"Is" (facts) – Description	"Is" combined with "ought" (values) – Prescription
Reductionism	Holism
Truth and reproducibility	Rightness and practicality
Uncertainty is a fact of life	Deciding "Yes" or "No" is the goal
	Methods & Perspectives
Problem oriented	Service oriented
Clientele diffuse, diverse or not present	Clientele specific, immediate, and insistent
Investigation	Justification
Experiment and observation	Dialogue and judgment
Inquiry and discovery	Imagination and mission
Precision and selection towards the truth	Reconciliation of viewpoints and compromise
Replication asserts independence from context	Context-specific, situational solutions desired
"Know what and how"	"Know why and whether"
Risk: "right answer, but wrong question"	Risk: "unsupported answer to the right question"
Absolutism in the concept of truth	Absolutism in ethical concepts
Inequality is a scientific observation	Equality is moral goal
Sharing within a world-wide network	Focus on domestic interests
Very open to external expertise	External input is evaluated as "an agenda"
Long-term focus or open-ended	Time horizons are often fixed (e.g., next election)
Resources are almost never sufficient	Resource needs can often be defined
Failure and risk accepted	Failure and risk intolerable
	Toward Ignorance & Mutual Arrogance
Scientists, engineers … are first segregated in universities from …	*lawyers, historians, philosophers*
Use technical terminology and jargon	Use socio-economic and political jargon
Praise innovation	Are weary of innovation
Often underestimate the complexity of policy-making	Often overestimate the precision of science
	… and then thrown back together in the workplace …
Derogative term: "lab coats, techies"	Derogative term: "policy wonks"
Favourite statements about the other side: "They should learn some science and statistics" "They ignore the hard evidence" "Over there, they don't appreciate our value"	Favourite statements about the other side: "They should learn about the process and context" "They think they are the high priests of truth" "Over there, they always want more resources"
The world of progress	**The world of power**

From a decision-making perspective, work presented in the report allows policymakers to compare the ANEMI simulation results of multiple policy-dependent scenarios in order to clarify the variables that policy can affect, helping the government to accentuate the beneficial effects of climate change, improve the ability of society to adapt to detrimental effects, and avoid the worst of the possible outcomes.

The innovative aspects of the research on science policy communication include the *process* by which the research team collected policy related information and interacted with the policy domain. While the technical model development proceeded at the University of Western Ontario, key partners in the Canadian federal government were involved from the departments of Environment, Finance, Natural Resources, Fisheries and Oceans and Agriculture. These partners were engaged throughout the entire process of ANEMI model development and provided useful guidance and feedback. Science policy dialogue is established through the consultation sessions, workshops and direct interviews.

The consultation first took the form of interviews, in which a representative of the UWO research team traveled to Ottawa and conducted face-to-face interviews with a selection of government partners. As a preliminary stage of engagement, the focus was on highlighting key policy issues to be translated into ANEMI model inputs, parameters and ultimately the development of model simulation scenarios. The diversity of interviewees (ranging from various levels of seniority, science-policy biases, and departments) was useful as it gave a broad overview of government policy priorities. Not only did it introduce the ANEMI model in greater detail than previous interactions, but it discussed more practical policy issues and how they could be integrated into the modeling work.

The next form of consultation with federal government partners was a workshop hosted by Environment Canada and held in Ottawa, Ontario. During the workshop, the entire research team presented an update of the ANEMI model development, highlighting the technical additions to the model as well as describing the scenarios in detail. The representation of the entire research team (including engineers, economists and political scientists) allowed for an in-depth description of the ANEMI model, as well as an enhanced ability to engage with the partners. The feedback gained from the workshop was significant, as the project partners discussed and debated the details of the scenarios, suggested ways to make them more policy-relevant and provided useful feedback for further study.

The development of the *integrated system dynamics model of the social-economic-climatic system ANEMI* relied heavily on policy interaction. Direct communication with policy partners from the Government was not only useful for developing the technical aspects of the model, but also for demonstrating the value in science-policy interaction. By establishing a two-way dialogue, both domains were better able to understand the other's approaches and foster a synergy that led to the creation of a useful policy tool.

3.0 The ANEMI model

3.1 Methodology

There are several different approaches to modeling, in which one can understand and analyze biophysical and socioeconomic systems under changing climatic conditions. One widely employed approach involves the use of Global Circulation Models (GCM's). A key characteristic of GCM's is the way that they artificially separate biophysical and socioeconomic systems through technical structuring (Simonovic and Davies, 2006). Each system is treated as independent, allowing the scientist to study each system in great detail and resolution. While this approach is useful for certain objectives, it does however have some significant limitations (Simonovic and Davies, 2006, 432). At a fundamental level, GCM's do not contain or capture the feedbacks that are critical to understanding how the systems *interact* and how these interactions influence the overall system behaviour.

In this regard, the research reported here employed a *system dynamics* simulation approach to capture important interactions between climatic, biophysical and socioeconomic systems. While the more inclusive nature of a system dynamics approach sacrifices the high resolution that GCM's provide, it does enable a more complete analysis of the entire system. Rather than predicting future events, the system dynamics simulation approach "improve(s) the understanding of the vital connections and relationships within a system that determines its behaviour" (Davies and Simonovic, 2010).

Specifically, the main innovative feature of a system dynamics approach is that the emphasis is placed on understanding the *feedbacks* within the system, in which the endogenous relationships between model sectors are accounted for and brought to the fore. From a technical perspective, this is important because:

> An endogenous theory generates the dynamics of a system through the interaction of the variables and agents represented in the model. By specifying how the system is structured and the rules of interaction (the decision rules in the system), you can explore how the behaviour might change if you alter the structure and the rules. In contrast, a theory relying on exogenous variables…explains the dynamics of variables you care about in terms of other variables whose behaviour you have assumed. Exogenous explanations are really no explanation at all; they simply beg the question, What caused the exogenous variables to change as they did? (Sterman, 2000, 95)

From a more practical perspective, understanding feedbacks is important because:

> Most real-world *events* are a consequence of the internal structure of a potentially larger, and perhaps unrecognized system. In other words, observed events are not external to the systems they affect, but instead stem from unforeseen interactions between system components (Davies and Simonovic, 2010).

In the case of climate change, industrial and land-use based emissions from socioeconomic activity cause radiative forcing, which in turn influence the climate system and eventually change the behaviour of other natural systems. In other words, a change to one system has (un)intended consequences for another. Since anthropogenic effects form one of the largest uncertainties in climate prediction efforts, it makes scientific sense to include them in our models (Simonovic and Davies, 2006).

3.2 ANEMI model structure

ANEMI model is developed using the system dynamics simulation modeling approach. Figure 3 gives a visual representation of the 10 individual model sectors included in the model, the related variables and whether positive or negative feedbacks are at play.

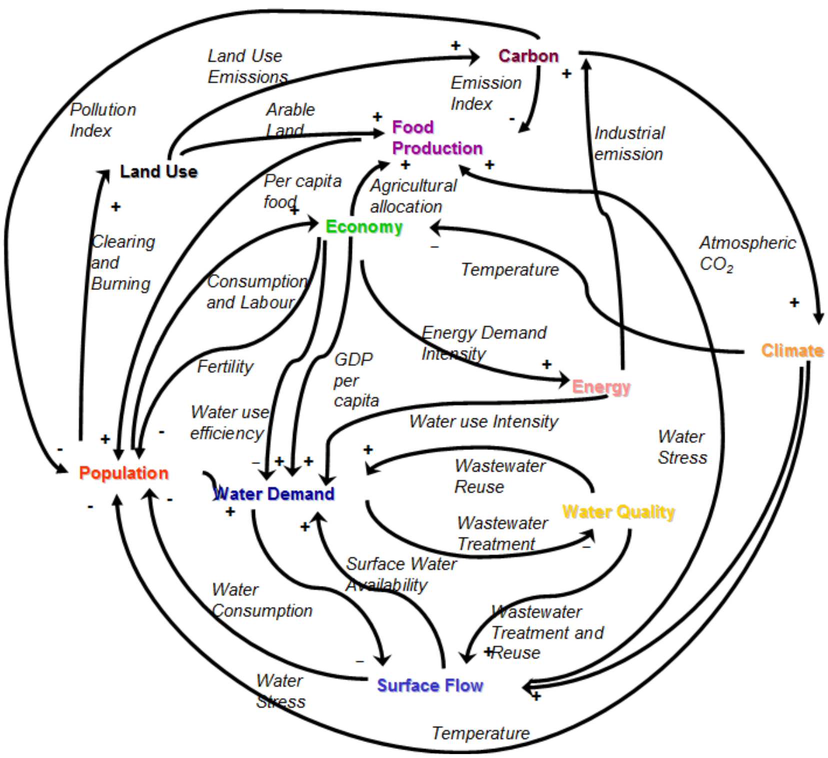

Figure 3: ANEMI Model

Four important points of clarification are necessary. First, the model's ten sectors can be divided into five biophysical sectors (Water Quality, Water Demand, Surface Flow, Climate and Carbon) and five socioeconomic sectors (Population, Land Use, Economy, Energy and Food Production). As mentioned, incorporating both types of systems together within the model's structure is innovative, as it captures the fundamental interactions between sectors and the behavioural change imposed upon them.

Second, the complexity of the model differs depending on whether it is examined as a whole or as individual sectors. If studied as a *whole*, the model contains approximately 740 state variables, 600 mathematical equations and thousands of feedbacks. Yet because each sector is affected by a different set of internal feedbacks and external variables, their complexity can range. For example, the Energy and Economy sectors contain 204 state variables while the Population sector only contains 10 state variables.

The third point of clarification is with reference to the direction and interpretation of feedbacks within the ANEMI model. There are two kinds of feedbacks, positive (+) and negative (-). A positive feedback is ‘reinforcing’ and can be understood by the simple example of interaction between the Land Use and Carbon sectors. If land use is defined as the clearing and burning of forests, then as it continues, the ability of forests as a carbon sink diminishes, ultimately increasing the level of carbon dioxide. Put simply, an increase in Land Use stimulates an increase in Carbon.

A negative feedback is ‘balancing’ and can be understood by the following example and interaction between the Surface Flow and Population sectors. If surface flow is reduced, then the amount of available water for human consumption is reduced, ultimately contributing to a reduction in the human population over time. Put simply, if there is less available water, population growth cannot be sustained.

The above represents a simplistic way to describe how feedbacks function, as they only capture the basic interaction between two isolated sectors. Since thousands of feedbacks are at play within the model, it is clear that they play a significant role in influencing system-wide behaviour.

The final and most important point of clarification is that the development of the ANEMI model has proceeded along two lines: a global version and a regionalized version. Each version has benefits and drawbacks, but both serve as useful policy tools for certain contexts. In the global version of the model, data is globally aggregated and gives a spatially less precise but overall more holistic understanding. On the other hand, the regional model gives a more context-specific understanding of different regions of the world. The work on the regional version of ANEMI is still in progress. Figure 4 gives a visual representation of the geographic regions chosen for the ANEMI model regionalization.

3.3 ANEMI model as a policy tool

The research conducted with the ANEMI model addressed the following research question: "How do the expected paths of climate, environmental, and economic variables change when feedbacks between the economy and the environment are more fully modeled than in previous work?" The question was addressed by integrating climate change science with government policy, through the frameworks of sustainability and systems analysis.

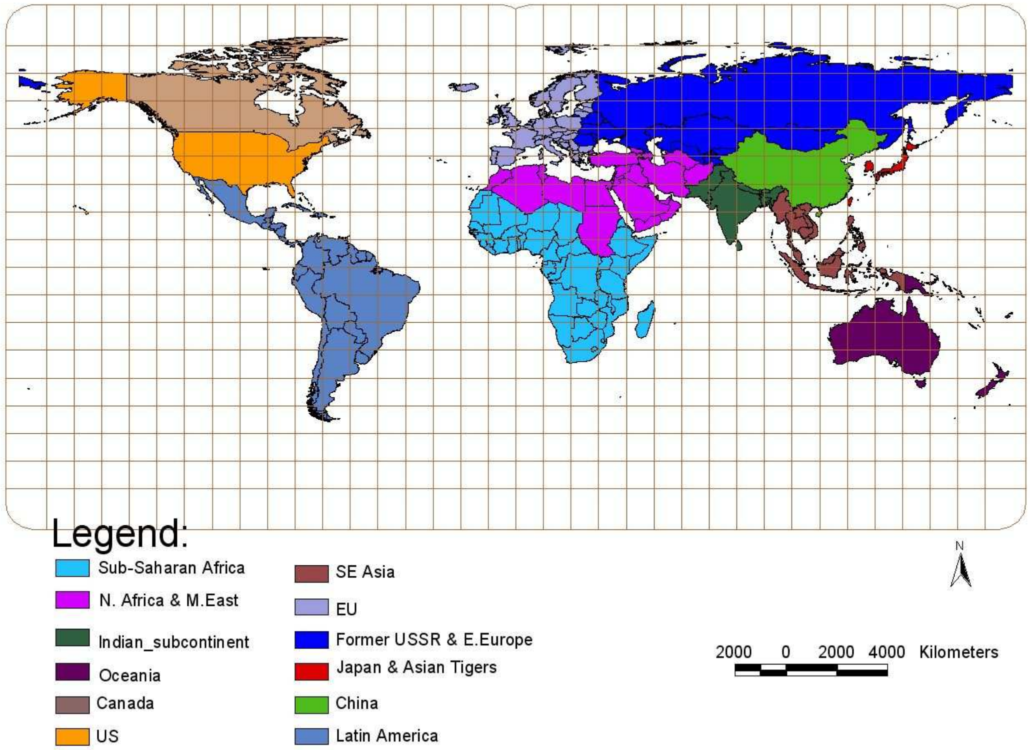

Figure 4: Geographic Representation of the Regionalization of ANEMI

Furthermore, while building on previous climate-economy models, the ANEMI provided improved representations of the physical processes involved in the climate system and carbon cycle, and included the socio-economic sectors and activities that govern interactions with the biophysical system, especially those that influence or control anthropogenic emissions. This is important because the major policy questions identified by the government research partners required a comprehensive analysis of how environmental and natural scientific issues relate and affect those that are socioeconomic in nature. For instance, how will the impacts of climate change impact Canadian economy in the future? Or similarly, how will a proposed carbon tax reduce or mitigate the impacts of climate change in the future?

Finally, the model balances simplicity and comprehensiveness with complexity and detail. It is simple enough for an analysis of its behaviour, for identification of major feedbacks, and for studies of model sensitivities. It is also complex enough to provide value for the scientific and policy-development communities. This makes the ANEMI model a time-efficient and easily comprehensible policy tool.

ANEMI can be used to focus on 'what if' simulations – in other words, through simulations with the model, to investigate outcomes of changes in chosen model parameters that represent either policy options or uncertain physical characteristics, such as carbon taxation rates, the delay in establishing wastewater treatment facilities, changes in the thermal diffusivity of the oceans, higher CO_2-fertilization factors, and any number of other options or combinations of options. The best parameters to manipulate include those representing policy variables or corresponding to uncertain natural characteristics.

For a more comprehensive look at the effects of parameter manipulation, sensitivity analysis is available. Sensitivity analysis allows a user to determine the effects on key variables in the model to changes in a parameter or group of parameters – sensitive parameters cause large variations in key variables for small parameter value changes.

Regardless of the simulation approach used, whether comparisons between individual model runs or more comprehensive sensitivity analysis, the aim of any experimentation is the exploration of model variable behaviours between different simulation runs. The desire is to see how the modelled system behaves normally, and then how changes in policies or physical parameters alter that behaviour. From a policy perspective, model sensitivity to a parameter change means that a 'high-leverage' point has been discovered – such parameter changes may represent useful intervention points in the real-world. For example, enacting a carbon tax policy that results in little economic cost, but large environmental benefits in the model may be an intelligent option.

4.0 From model development to policy communication

The main focus of this report is on the presentation of research results obtained through the use of ANEMI in policy communication. The main goal of the communication process was the development of a number of policy scenarios that capture interest of research partners from various Government departments.

The key partners in the project were representatives of the federal Departments of Environment, Finance, Natural Resources, Fisheries and Oceans and the recent addition of Agriculture. The partners were engaged in the form of preliminary interviews as well as workshops (two conducted up to now and one more left to be conducted before completion of the research). While the focus of interviews was on highlighting key policy issues to be translated into model inputs, parameters and ultimately the development of model scenarios, the workshops were used (i) to present the model development methodology and (ii) to present the model structure and preliminary simulation results that will lead to clear formulation of policy questions to be answered by the end of research project. Policy questions will be answered through the simulation of a final set of formulated policy scenarios.

This section will present the summary of the findings obtained during the preliminary interviews, which provided the foundation for development of scenarios. It is organized in three sub-sections: interview format, challenges pertaining to partner interests and key policy questions.

4.1 Interview format

A total of seven face-to-face interviews were conducted, in which a researcher (the first author of the report) from the research team traveled to Ottawa to consult with the government partners. Some interviews were one-on-one while others included groups of participants. This diverse approach to interviewing allowed the research team to investigate a broad set of policy questions using slightly different methods, as well as the opportunity to interact with approximately twenty federal government officials.

The oldest and most highly regarded method of survey research, face-to-face interviewing, has many advantages (Singleton Jr. and Straits 2005, 238). For example, the researcher was able to use visual aids such as model descriptions and diagrams that helped to clarify technically complex structure of the model. Furthermore, the face-to-face interviewing permitted unobtrusive observations related to the sensitivity of some policy issues (Singleton Jr. and Straits 2005, 238). These were useful in scenario development because the special notes were made about some policy issues that were top-of-mind, controversial, unsettled, or yet to be fully determined. For those issues that were top-of-mind, it was a direct signal that a scenario reflecting the issue would be useful to policymakers in the current political climate. At the same time, those issues that were reflected with ambiguity and uncertainty allowed development of potential future scenarios not of the interest at the current moment. Finally, for policy issues that were described more reluctantly or for those that reflected controversy, it allowed the research team to respect partner's interests and omit them from further analysis.

While face-to-face interviewing has many other advantages, there were also disadvantages that introduced some limitations to the research. For example, the interviewer may have introduced bias into the data by "fail(ing) to follow the interview schedule in the prescribed manner or by suggest(ing) answers to respondents" by the way questions were posed (Singleton Jr. and Straits 2005, 239). Bias may have also been introduced by the respondents, depending on how they reacted to certain questions, or how they personally or professionally related to potential policy issues. The main disadvantage to face-to-face interviewing, however, was cost. The budget had to provide for recruiting, training the interviewer, as well as the travel expenses, lodging and meals (Singelton Jr. and Straits 2005, 239). Despite the disadvantages, face-to-face interviewing provided unique and useful insights in the wide range of policy question and demonstrated significant advantages over other methods, such as secondary research or telephone interviewing.

While most of the interviews conducted were one hour long, some went much longer. Each interview began by the interviewer describing the ANEMI model, the purpose of the research and what is being specifically investigated. The interviewees were then asked whether they had any specific questions about the model to ensure a complete understanding of it and the research context. Next, the interview posed a more general question, asking the interviewee to describe their professional position and the context in which they work. This was important to identify areas of bias and the closeness to which interviewees were to the political realm (the higher in the bureaucracy the interviewees were, the more intimately connected with politics they would be, therefore potentially reflecting a greater degree of reliability as to the importance of policy issues). The questions then proceeded to ask the respondents what the key climate change-related issues for their respective departments were, what the most important one was, and how often or by what standards the issues change in importance. Other questions included: What emphasis do you place on the Arctic region?; What type of information (from each model sector) will be of value to you in addressing the policy needs?;What factors determine and prioritize these issues?; Etc.

The diversity of interviewees (ranging from various levels of seniority, science-policy biases and departments) was useful as it gave a broad overview of the government policy priorities.

4.2 Challenges pertaining to partner interests

Departmental Biases
When asked about specific climate change-related issues that would be desirably represented in scenarios, the participants predictably commented on interests within their respective departments. One example that was cited dealt with the representation of specific crops and their particular albedo effects. Another example included the representation of different natural resource sectors, such as forestry. Furthermore, several comments pointed to the impacts of rooftop agriculture. Such interests were well received and are important for the consideration of policy implications, especially in the Canadian context. However, the scope for which our globally aggregated version of the model is designed cannot include such details.

Sub-national, Sub-sector Data
Participants also placed high value upon regional data, particularly in the Canadian context. Since our project partners consist of Canadian federal departments, this comment is understandable. While participants were keenly interested in the detailed representation of the model's water sectors, they commented on the value of representing the specific water stressed or water endowed regions of Canada. This included the particular drought concerns on the prairies (and consequently agricultural production) as well as the effect of reduced glacier runoff on major rivers and lakes. Some participants commented that in playing to the strengths of our water sectors, that Canada be divided into watershed regions. Although we are not confident that such detail could be incorporated into the model, the suggestion to possibly divide Canada into three broad regions (East, West, and North) is being considered.

In addition to the representation of regional data, most of the participants also wanted to see our model's Economy sector sub-divided to represent the various economic sectors. They commented on how this would provide a deeper outlook on what sectors will be specifically challenged as the climate changes and consequently, what tradeoffs would ensue. Furthermore, this would provide information as to what sectors are likely to be more lucrative in the future. Ultimately, participants noted that a detailed and disaggregated representation of the economic sector would provide key information as to future comparative advantages, and prove highly useful over a range of policy interests.

This suggestion is of importance for the project team's economists and their development of an aggregated economic model of Canada.

4.3 Policy questions

Domestic vs. International Focus
Several participants placed a high value on being able to represent a comparison between Canada's national context with other regions of the world. This specifically revolved around economic issues and the ability to identify comparative advantages, since Canada's natural resource-based economy is sure to be heavily impacted by the effects of climate change.

One participant specifically noted interest in showing the impacts of economic change in one region on another. For instance, if Africa's economy plummets, do Canadian exports fall? This would require additional resolution in the model's Economy sector as it relates to exports, imports, exchange rates, etc.

Participants also commented on the interest in identifying the comparative impacts of climate change and their possible effect on population migration. As one participant suggested, however, there would be great difficulty in representing a strong relationship between climate change and environmental migration due to the other factors also influencing population movements.

Ultimately, interest in such comparative work would prove the usefulness of the work in developing both, a global and regional model. While some details are beyond the scope of the aggregated model, suggestions of comparative analysis were considered because of the many policy implications that arise.

Arctic as a Priority
Interest was expressed towards the physical changes taking place in the Arctic region, specifically with reference to the enormous amounts of methane gas that are likely to be emitted due to melting of permafrost. Comments were also made that current lack of knowledge and a better understanding of interactions in the Arctic region will better position us for future 'transitions', such as moving into different markets or economic sectors.

However, participants did not place a high priority on developing the Arctic as a region – note that Arctic is not represented in the ANEMI due to the challenges of obtaining the necessary data.

Land Use Changes
Participants expressed interest in different aspects of land use, fitting nicely with the current updates and additions to this model sector. Suggestions arose over the ability of ANEMI to produce in climate extremes, the impact of a loss in coastal lands, the impact of losing wetlands due to human actions, melting permafrost in the Arctic and possibly taking account of the effect of rooftop agricultural production. Some of these suggestions

are out of the scope due to the spatial and temporal resolution of the model. Consideration was given to the connection between climate extremes (or increased temperature) and available land for potential food production.

Water
Participants saw the model's water sectors as the major strength and suggested scenario development to assess important implications of climate change on water resources. In specific, due to the ubiquity of the issue, water was identified as a major issue of interest to the project partners. One participant explicitly stated, "Both globally and regionally, there's nowhere water won't be an important issue".

Water pricing in particular arose from the discussion with several representatives of the project partners, in which interest was placed on whether water use behaviour would change with the implementation of water pricing. Participants expressed concern over water used for irrigation, and suggested modeling the impacts on the water supply if current irrigation practices were sustained. Interestingly, one stakeholder suggested developing a scenario to consider 'multiple objectives'. For instance, the participant noted a recent experiment in which a U.S. state-level government compared the impacts of increasing the capacity of water treatment through the maintenance of wetlands (a *natural* water treatment process) for which the farmers will be compensated. In this regard, results could show the difference between humans *paying* for their environmental damage, and humans *preserving natural processes* – and benefiting economically from it.

Both global and national water concerns were emphasized. For instance, a comment was made in relation to the effects of Canada more heavily protecting its water from export. Potential exists in representing the effects of cross-border trade/pumping of water between Canada and the United States. Future modeling work will entail fully capturing the feedbacks related to water issues identified during the interview process.

Energy
Energy has been identified as one of the high priority issues. It was described as a development issue, an equity issue, critical to the economy, and simply put by one participant, its "hard to say anything is more important than energy."

Several specific issues arose with respect to energy. Most foreseeable in being assessed by the model was the ability to represent a change in the mix of energy supply. The participant noted interest in factoring in increasing peak energy demand and whether some sources are more suitable for meeting peak demand. Furthermore, interest was expressed in the ability of meeting peak demands when we shift to more renewable energy sources. Another energy-related issue that arose was cross-border energy transfer between the United States and Canada and how increasing energy demand, increasing energy dependence, and cross-border transfer will impact the system. Whether or not the model's Energy sector could capture 'energy trade', it is suggested to consider this for future development, as energy concerns are likely going to factor highly on government agendas.

Other participants drew a link between the energy and water, noting a special interest in their interplay. For instance, in order to pump out Alberta's dirty and viscous oil, vast amounts of water (turned steam) must be injected at high temperatures to make the oil more fluid and able to be piped. This type of local issue scenario, however, would be out of the scope of the model due to the aggregation of data.

Economic Costs of Action vs. Inaction

Finally, a major interest from the partners concerned the economics of climate change. This was expressed through a variety of suggested scenarios, but ultimately reflected the salience of the issue of cost. As put by one participant, 'climate change is just as much an issue of economics as anything else, and since it influences our behaviour, we must utilize it as a tool'.

Generally speaking, the participants wanted to see more direct connections made between the Economy and other sectors of the model; in this regard, the relationship between energy and the economy, the costs of using different energy sources, energy pricing, and the overall role that energy plays in the economy came up as an important issues. Moreover, participants put a strong emphasis on equating certain actions to a dollar figure. Participants also commented on the need to mitigate the dichotomy between 'environment' and 'economy', and therefore seek to connect the two. While many feedbacks are at play within the model, the inclusion of more or different strengths of such feedbacks should be considered.

More specifically, some participants stated an interest in pricing 'ecological goods and services', such as putting a value on the natural purification *process* of wetlands. While this particular example would fall outside of the scope of the model, others suggested pricing carbon. Falling within our model's limits, carbon pricing similar to that of the EU has been considered as a possible scenario. Ultimately, these suggestions arose out of the interest of putting a value on nature, 'just for being nature'. Participants advocated the need for such an approach due to the way in which economics mistreats or misrepresents certain relationships as 'negative externalities'.

Participants also expressed interest in comparing the impacts of economies in other regions, as previously alluded to in *Section: Domestic vs. International Comparison* of this report. With the completion of the regional version of the model this issue will be addressed.

Economic concerns clearly played a large role, yet the major issues that were repeatedly addressed were the ability to identify the costs and benefits of action, the ability to highlight economic comparative advantages, the ability to shed light on tradeoffs, identifying where the particular economic stresses of climate change will appear and, generally, the supply and demand changes due to climate change. To move forward with the economic concerns expressed from the partners, close collaboration will be essential between our team of economists, system modellers, and policy communicator.

5.0 Development of scenarios

This section describes the scenarios that were developed from the feedback obtained from the stakeholders. A brief context will be given, followed by an overview of the main policy question, the specific version of the model that was used (global or regional), where the main output is and what the implications are for the scenario. In each case, a figure is provided that represents what sector is being manipulated (highlighted in red) and what sectors are consequently affected (highlighted in green).

5.1 Scenario 1: Carbon pricing

Key Question: What carbon price allows us to achieve a given emission target?

There are several tools to assist countries in meeting their national emission reduction targets, including carbon trading schemes, specific regulations as well as carbon taxes. This scenario (Figure 5) adopts the approach of a carbon tax and tests what the abatement costs will be to Canada.

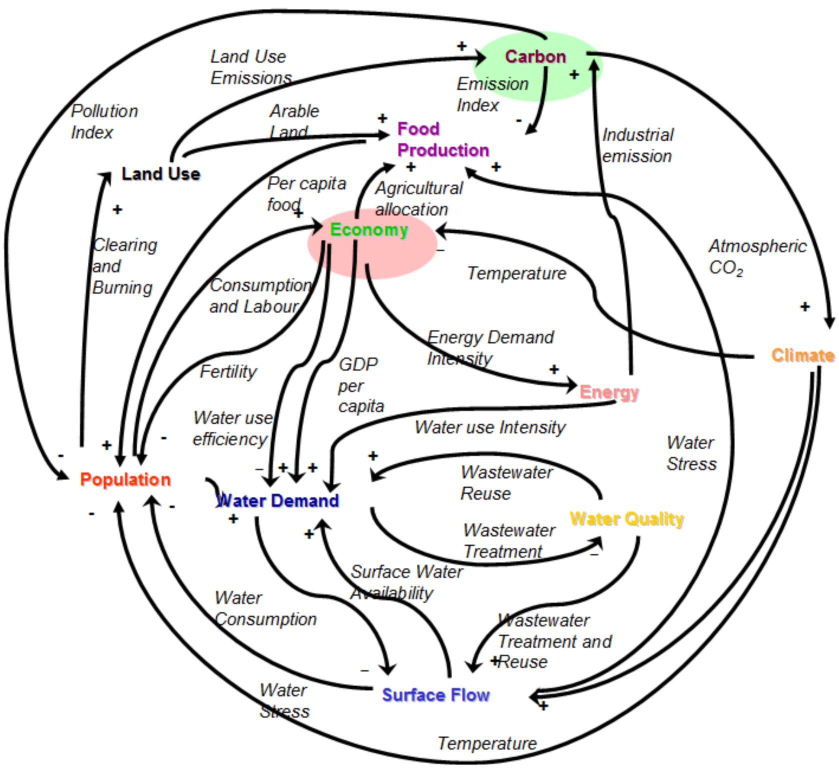

Figure 5: Scenario 1: Carbon Pricing

Due to the current status of development, this scenario tests isolated sectors and does not use the global or regional version of ANEMI previously described. Instead, it tests the Economy and Carbon sectors using two component models (global DICE model and a modified Canada model being developed by the economists on the research team) that will be eventually integrated into the larger ANEMI model. As model development continues, the distribution of output will eventually include other sectors to gain a more holistic systems view of the change in behaviour.

5.2 Scenario 2: Economic growth rate

Key Question: What are the impacts on emission levels from changing economic growth rates?

This scenario (Figure 6) examines various economic growth rates and the subsequent impact on the carbon sector. That is, if GDP continues to grow into the future, there is a reason to believe that a rise in economic production may have environmental consequences. This is important, because our economic system is based on perpetual growth; the impacts are therefore important to understand as many policy implications arise (i.e. tradeoffs between economic growth and environmental damage).

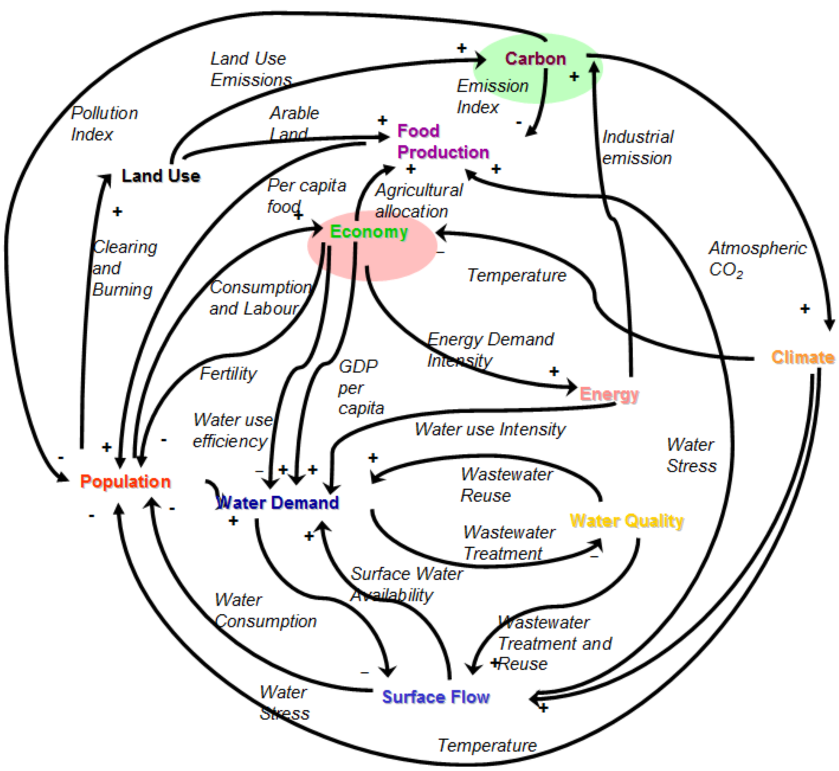

Figure 6: Scenario 2: Economic Growth Rate

As in the case of the previous scenario, the economic models being used include the global DICE model and modified Canada model being developed by UWO's team of economists. These are planned to be eventually embedded within the ANEMI model. Not only will embedding these models into the ANEMI model provide a wider range of outputs, but doing so will also address comments made by our key stakeholders, such as the need to examine more connections between the Energy and Economy sectors.

5. 3 Scenario 3: Water pricing

Key Question: What are the impacts on water resources by increasing the price per unit of water?

Canada is ranked as the second largest consumer of urban domestic water in the world, using 65 per cent more water than the Organization for Economic Cooperation and Development average (OECD; Brandes et al., 2005 in Morris et al. 2007, 5). In fact, overall residential water use increased by 21 per cent during the 1990's, despite the efforts of some municipalities in reducing water use levels (Brandes, 2005 in Thirlwell et al. 2007, 5). Several factors contribute to such high use, among them the price of water. The average Canadian municipal water prices in 1999 were the lowest in the OECD at US$0.70/1000 liters, and are only one quarter of European water prices (Forum for Leadership on Water).

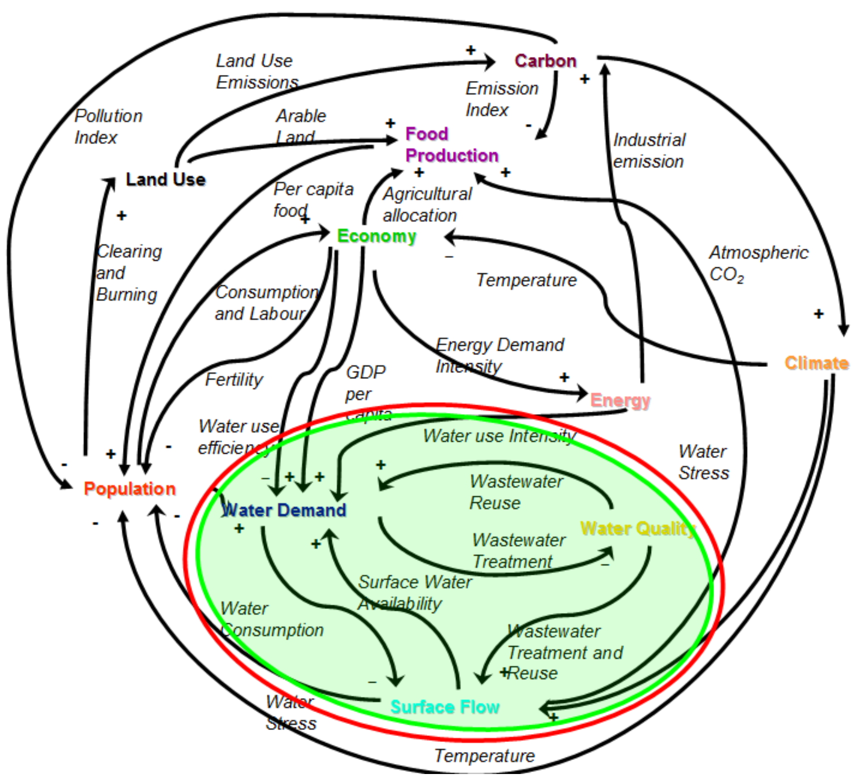

Figure 7: Scenario 3: Water Pricing

This scenario, shown in Figure 7, uses the regional version of the model and specifically looks at changes to the water sectors. It is designed to explore the impacts if the average Canadian price per unit of water was increased, examining things such as possible changes in water stress, demand change, etc. It is important to note that in a systems approach (as employed in this model), changes to system structure are usually made *endogenously*. In this case, however, we impose a price *exogenously*. This is simply due to the stage of model development. Once the other sectors within the regional version of the model are updated, this scenario will be tested using the full version.

From discussion, we will look into making more connections between the water sectors to the economy sectors; incorporating these important feedbacks will assist in more correctly pricing water. Nevertheless, this scenario will show important results as to the impacts and interplay of the water sectors when a price is imposed.

5.4 Scenario 4: North American water stress

Key Question: How will a change in temperature impact the water stress in Canada and the U.S.?

While the Canada-U.S. relationship has been mostly characterized by cooperation, climate change will undoubtedly add significant pressures to water management and institution building. IPCC assessments state that, "negative impacts of future climate change on freshwater systems are expected to outweigh the benefits" (IPCC 2008, 3). It highlights possible areas to be affected, including food availability, stability, access and utilization (IPCC 2008, 3). Canada and the U.S. will be affected differently but may be inclined towards conflicting reactive and adaptive measures. Thus it is important to understand the degree of water stress occurring in North America so that domestic and trans-boundary policy implications can be considered.

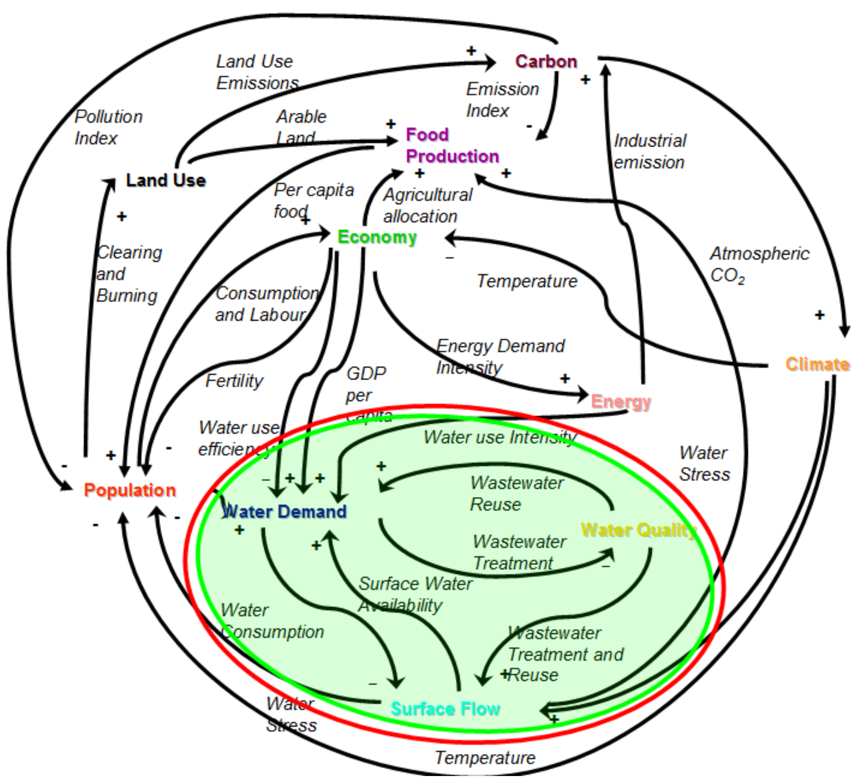

Figure 8: Scenario 4: North American Water Stress

This scenario (Figure 8) also uses the regional version of the model and specifically looks at changes to the water sectors. It is designed to test water stress from a rise in temperature. Again, temperature is imposed exogenously in this scenario, but because we are only utilizing certain sectors, the model remains disconnected. Once the other sectors are updated and the full version is used, population will likely play a role in water stress, adding a further set of feedbacks. Nevertheless, this scenario will show the impacts of water stress within the water sectors, and will play to the strengths of the model as identified by the stakeholders.

5.5 Scenario 5: Irrigation

Key Question: What are the impacts from an increase in irrigation?

In a news release by the Food and Agriculture Organization of the United Nations, it stated that "Producing 70 percent more food for an additional 2.3 billion people by 2050 while at the same time combating poverty and hunger, using scarce natural resources more efficiently and adapting to climate change are the main challenges world agriculture will face in the coming decades" (FAO, 2009).

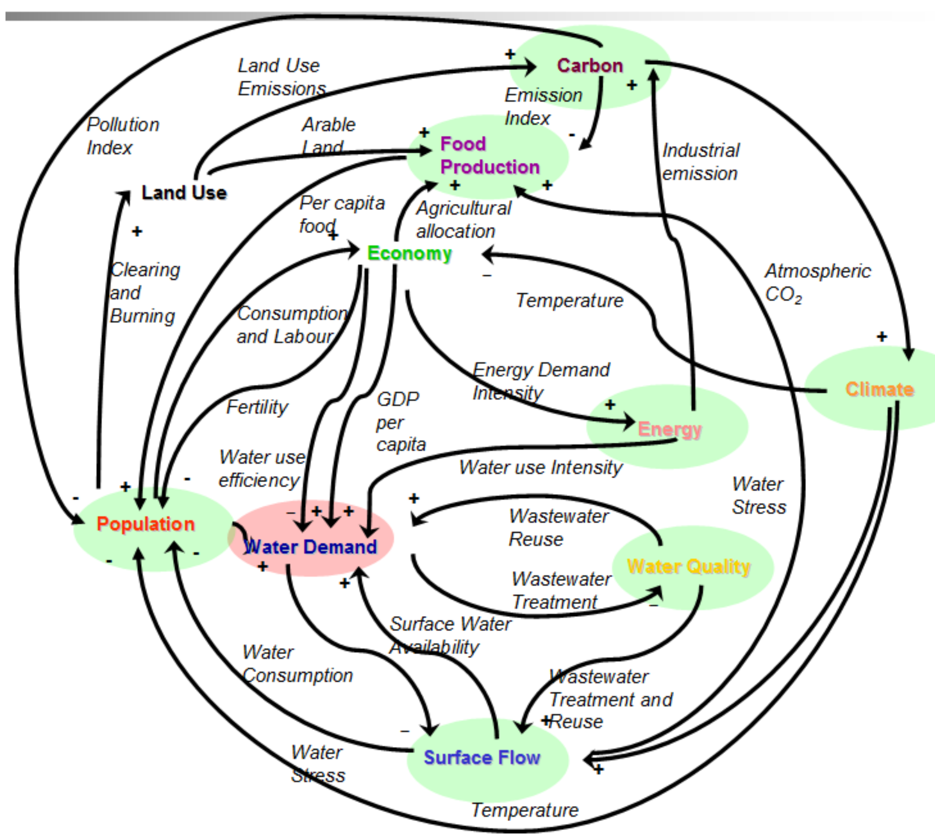

Figure 9: Scenario 5: Irrigation

This scenario (Figure 9) uses the global version of the model and looks more broadly at impacts to several sectors, including Surface Flow, Water Quality, Energy, Population, Climate, Carbon and Food Production. It is designed to specifically test the impacts on various sectors if irrigation were to increase to meet simultaneously increasing water demand for irrigation. This is where the full global version of the model is at play, in which multiple outputs are possible (all scenarios will eventually have multiple outputs as sectors are updated).

5.6 Scenario 6: Energy subsidies and pricing

Key Question: What are the impacts of providing subsidies and changing prices for various fuels?

The energy sector is comprised of the "production, sale and distribution of energy, including fuel extraction, manufacturing, refining, transformation and transportation" (GSI and IISD, 2010). Of the various primary sources of energy, the leading type is fossil fuels (oil, natural gas and coal). Other sources are nuclear energy, traditional biomass fuels, such as firewood and charcoal, and renewables, including hydroelectric, geothermal, wind and solar power (GSI and IISD, 2010).

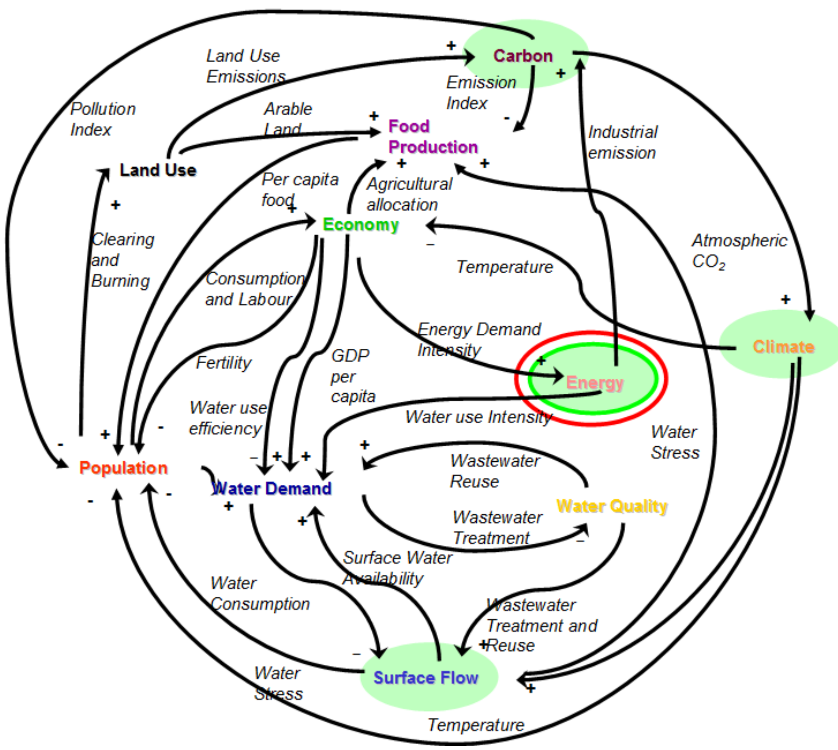

Figure 10: Scenario 6: Energy Subsidies and Pricing

In the context of a changing climate, our energy sustainability is significantly affected by the way we produce, transport and use energy. Simply put, all economic activities are reliant on a sustainable source of energy (GSI and IISD, 2010). Since governments intervene in energy markets, a key question arises: what are the impacts of providing subsidies and changing prices for various fuels?

This scenario (Figure 10) uses the global version of the model and looks more broadly at impacts to several sectors, including Surface Flow, Carbon, Climate and Energy. It is designed to specifically test the current experimentation with fossil fuel use. Any solution to our over-dependence on fossil fuels will come from some combination of fuels and renewables. Due to the impact that price has on the speed of change and transformation, the scenario tests where impacts may arise if the price of certain fuels is changed or subsidies are implemented.

5.7 Scenario 7: Land use changes

Key Questions: What are the impacts from increased conversion rate of forests to agricultural land?

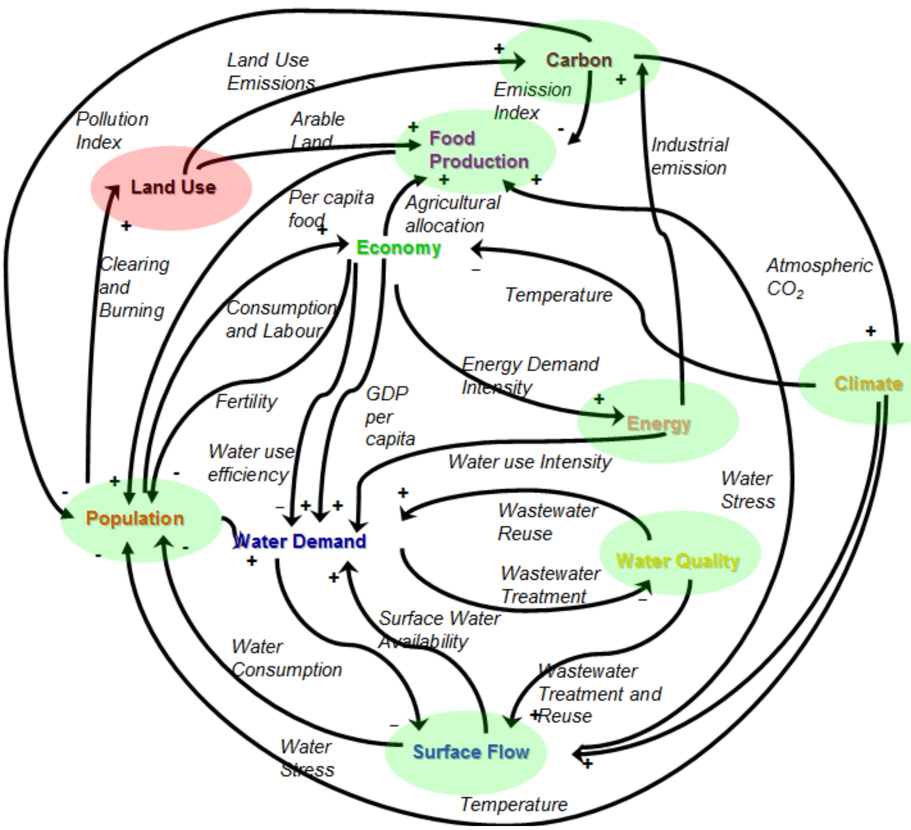

Figure 11: Scenario 7: Land Use Changes

This final scenario (Figure 11) is closely based upon the context of Scenario 5, in which the demand for food production is expected to increase. Whereas Scenario 5 tested the impact of increasing irrigation to cope with rising food demand, this scenario tests the impact of redistributing land use; by converting land from forests to agricultural land. This scenario also uses the global version of the model, making a more general set of conclusions for the world's capacity to meet global food demand. It also shows the sink capacity of the land, and will produce output in various sectors, including Population, Surface Flow, Water Quality, Energy, Climate, Carbon and Food Production.

6. Conclusion

Through engagement with key stakeholders in the Canadian federal government, the research team aimed to bridge science to policy. Research first began by establishing a diverse research team, comprised of engineers, economists, social and natural scientists. Efforts were then focused on establishing key partners in the federal government. The critical element of research, however, was fostering an effective link between the research team scientists and policy officials. In so doing, the unique research could be made policy-relevant. Thus, a recent addition to the research team included a 'policy communicator'. With a background in political science and an understanding of government policymaking, the 'policy communicator' was able to relate and understand the biases, pressures and interests of the government partners; this addressed the communication from *policy* to *science*. However, to ensure effective communication from *science* to *policy*, the 'policy communicator' underwent significant training in modeling approaches and systems dynamics methodology. Furthermore, a policy-relevant understanding of the technical aspects of the model was required; this included an understanding of the type of outputs that were desired, how the different sectors related to each other, where the key feedbacks in the model were and what the limitations were as they would relate to partner interests. Thus from a methodological perspective, the research was fundamentally based on a multi-disciplinary approach that assisted in bridging the research domain to the policy domain. Ultimately, the feedback from the interviews and workshops were embedded in the development of the model and its scenarios, and made it possible to transform policy questions into model scenarios. In other words, by linking science and policy domains, the research team was able to produce a science-based and policy-relevant tool.

Limitations to the work mainly reflect the current stage of model development. For example, the model requires refinement of individual model sectors, better integration of the economy and energy sectors, the full integration of the modified Canada economy model and completion of the regional version of the model. Without these key developments, the full extent of the scenarios cannot be tested. As strategic research continues on the *integrated system dynamics model of the social-economic-climatic system*, these limitations are likely to be overcome. The other key limitation is in regards to the selection of the government partners. While the current group of partners has provided valuable insight, further research will aim to expand the group of partners across different departments. This will not only reflect a broader range of interests, but will also more accurately represent a systems view of government. Furthermore, a broader range of disciplinary biases will be consulted, including government policymakers who work more intimately with science *and* policy research.

This summary report has sought to describe the unique NSERC-funded research being done on *An integrated system dynamics model of the social-economic-climatic system.* It has identified the niche in which the research exists, the justification for it, the process that the research team has undergone and the preliminary outputs. It has also identified key areas for future work. In sum, grounding the research on a multi-disciplinary systems methodology ensures reliable and useful output. The steps taken thus far represent strides towards fostering an effective science-policy interface, and ultimately, strides towards producing a science tool that is relevant for Canadian federal government policymakers.

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