Collaborative Systems Modeling for Complex Energy Infrastructure: The Case of the Cape and Islands Collaborative Regional Energy Planning

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Abstract

Large-scale energy planning processes involve a large number of stakeholders with varying technical backgrounds, who nevertheless need to be involved. Given the complexity of the decision-support models that could take into consideration both the technical design of the energy system as well as its impacts on the regional economy, environment and social system, there is a need for a systems methodology that can serve as a collaborative modeling platform that can both capture stakeholder knowledge and concerns and at the same time lend itself to quantification. Using a Stakeholder Assisted Modeling and Policy Design (SAM-PD) methodology, the author facilitated the collaborative planning process for the energy future of the Cape and the Islands together with representatives of 22 stakeholder organizations. The resulting systems model has helped the participants in the planning process to gain a holistic view of the complex system and its inherent feedback loops and behavioral dynamics and can serve as a basis for exploring different options with regards to a variety of attributes of concern to the stakeholders.

Stakeholder Involvement in Modeling Complex Systems

The role of technical expertise in policymaking, specifically in the management of complex socio-technical systems has been increasing in the past two to three decades. According to Adler et al. (2000), due to increased public pressure to resolve complex, and often controversial issues dealing with large-scale natural or engineered systems, policymakers have sought better knowledge on which to base their decisions. However, there is increased concern that by its inability to reach out to stakeholders, science does not have a significant impact on the dynamics of the decision-making process and its outcomes, often resulting in technically-poor and politically charged decisions (Susskind, 1994). According to Venix (1990), many policy decisions are based on incomplete mental models of a few experts. The assumptions and reasoning underlying such decisions are often unclear to most stakeholders, and sometimes even other experts.

It is important to note that a modeling process that is conducted in support of a decision-making process should not be limited to designing systems that meet technical requirements. According to Dürrenberger et. al (1999), good models for science-intensive decision-making processes:

- should have manifest links to locally and/or personally tangible issues
- should have a high degree of visualization and interactivity
- should have simple structures, be transparent and have short operating/running times.
- should not be regarded as a substitute for other types of information outputs.

Therefore, while technical engineering models are often thought of as descriptive and predictive of a system's behavior, they can also help improve communications in planning processes for large-scale engineering systems. In other words, models can serve as "boundary objects". Boland and Tenkasi (2001) define a boundary object as a visible representation of individual or community knowledge or perspectives that enables the communication of those perspectives to others in a different community. This concept supports the idea that an artifact, such as a systems model that takes into account various perspectives, can mediate collaboration and serve as an interface among stakeholders, technical experts and decision-makers. This becomes particularly important in the case of regional energy planning process where a model will need to take into consideration both the complexities of the technical design as well as the impacts of the system on the regional economy, environment and social system. Therefore there is a need for a systems methodology that can serve as a collaborative modeling platform that can capture technical systems complexity, integrate stakeholder knowledge and lend itself to quantification. To address this issue, Mostashari and Sussman (2005) developed the Stakeholder-Assisted Modeling and Policy Design (SAM-PD) Process, which combines visual modeling with stakeholder input elicitation for analysis of complex

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engineering systems. In this paper the actual application of the SAM-PD process to the collaborative regional energy planning process for the Cape and the Islands region in the Commonwealth of Massachusetts is presented and discussed.

Collaborative Modeling for Complex Engineering Systems

System dynamics has been applied to a number of environmental studies, such as natural resource management, energy system planning, environmental impact assessment, and solid-waste management. According to Stave(2001), System Dynamics offers a consistent and rigorous problem-solving framework for identifying the scope of the problem, eliciting participant views about problem causes and system connections and identifying policy levers.

Hoggarth (1987) is one of the first people who suggested the merits of group model-building using System Dynamics. In his opinion however, we have to be careful when talking about eliciting knowledge from group members. First, we ought to be aware that people can easily be led to believe things and that the opinions they hold may be strongly affected by what others think and the context in which they find themselves. As Hoggarth points out: “It has been suggested, for instance, that illusory correlation persists in situations where people do not receive good feedback concerning their judgments and where others share the same illusions. Thus instead of feedback concerning actual outcomes, each person both reinforces and is reinforced by the illusions of the others. In many organizations, common beliefs are precisely of this nature”. He further indicates that group model-building using system dynamics can help in making the mental maps of participants explicit and put their problem definitions to the test, by surfacing implicit causal assumptions they may have for a given system.

Vennix has been one of the proponents of group model-building in corporate decision-making, focusing on building system dynamics models that help tackle a mix of interrelated strategic problems to enhance team learning, foster consensus, and create commitment. In his view, as the "command and control" organization evolves into one of decision-making teams, these teams have become the critical building blocks upon which the performance of the organization depends. When the complexity of decision making and the interrelation of several strategic problems facing the company increases, different people within an organization develop different views on the problem definition. As a result, he emphasizes the importance of "learning teams" where different people converge on a single representation of a problem through testing their ideas and assumptions (Vennix, 1990).

Building models with a group of stakeholders has become an established approach to support strategic decision-making in many corporate settings. Involving relevant stakeholders helps generate a comprehensive set of information regarding the issue, fosters a feeling of ownership towards the process and the decisions and creates commitment to implement these recommendations among the different levels of management. (Richardson, 1994)

The Open design approach to multi-stakeholder participation in architectural design has been developed by Van Loon (1998) and Van Gunsteren and Van Loon (2000). The traditional expert design process for large, complex construction projects, has two fundamental shortcomings: (1) The possible contributions of layman-users and other excluded stakeholder parties are ignored; (2) Even if such contributions would not add to the value of the design, their exclusion has resulted in decreased acceptance of expert designs. The Open Design Process uses collaboration between experts and non-expert stakeholders to reach mutually acceptable choices (Van Loon, 2000)

Despite the extensive studies in the literature, in general the group model-building literature focuses more on the system representation and modeling, without emphasizing the negotiation process associated with high stake, high uncertainty issues. In this paper we combine collaborative modeling and fact-based negotiation as a basis for decision-making in energy planning processes.

Stakeholder-Assisted Modeling and Policy Design Process (SAM-PD)

An engineering systems decision-making process may require the use of multiple models, each dealing with a different part of the system. It is useful to have a system-wide model that combines results and models from the physical, biological, economic and social aspects of the system, and the interactions between them, to evaluate the how changes in any of these aspects can affect the system as a whole. These system-wide models constitute the core focus on models in this dissertation. Developing a system-wide model that can organize the different types of information about the system requires the presence of system modeler(s) in the decision-making process. The role of such an individual or group of individuals is to help integrate different models and types of information into a system-wide representation that will allow decision-makers, scientists and stakeholders to make decisions on the system as a whole. In SAM-PD, representative stakeholders, decision-makers and technical experts jointly engage in defining the scope of the energy planning process they have a direct interest in. They use a collaborative process to visually represent a systems diagram that addresses the issue at hand through a holistic systems analysis perspective, allowing them to better understand the interactions among different parts of the system and between the different technical, social and economic layers of a system. Based on that systems representation, they collectively explore design alternatives and evaluate their effects on the system using a quantified version of the system model they created. Finally in a consensus-seeking negotiation based on the quantitative results from the model as well as qualitative insights gained throughout the process, they negotiate solutions that address stakeholder concerns and requirements in the present while taking into consideration the uncertainties inherent in complex systems analysis and design. While the SAM-PD process allows for a variety of quantitative modeling methodologies to be used, Systems Dynamics is a preferred choice for systems with extensive feedback loops, tight coupling of sub-systems and behavioral delays. For the system representation step causal loop diagrams with distinct element shapes are used. Decision variables are shown in boxes, while system outcomes (attributes) are illustrated through circles. Linkages to other sub-systems are shown in grey. In the quantification of the system representation into a full systems model both standard systems dynamics stock and flow diagrams and other simulation tools can be used. The SAM-PD Process builds on the CLIOS process developed by Mostashari and Sussman (2009). Figure 1 shows the five stages of the SAM-PD process.

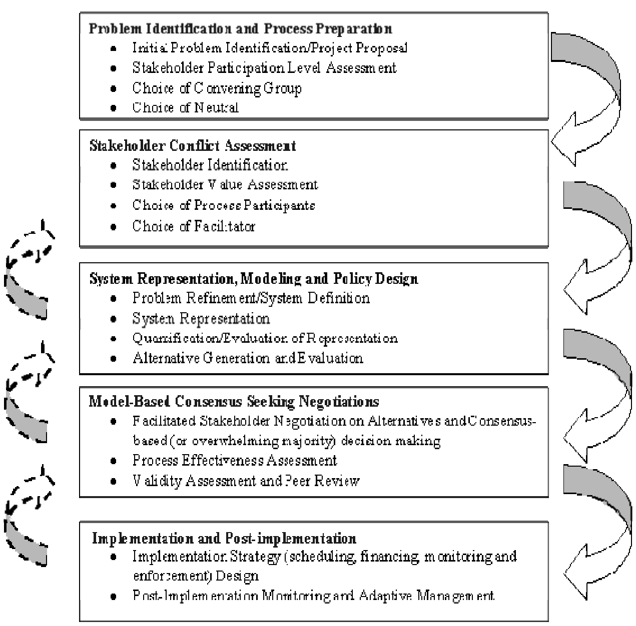

Figure 1: The Five Stages of the SAM-PD Process

The Cape and Islands Coordinated Community Energy Planning Process

From 2005 to 2006, the Cape & Islands Renewable Energy Collaborative (CIREC) initiated a coordinated community planning process geared toward managing and accelerating the local and regional transition to a sustainable energy future. The aim of the planning activities was to engage local, regional and national stakeholder groups (including government, citizen groups and experts) in characterizing the present energy situation, envisioning the energy future, and working together to promote adoption of cleaner and green supply and use options throughout Cape Cod, Martha's Vineyard, and Nantucket. At the outset, 22 stakeholder groups were invited to contribute to the systems definition using a comprehensive survey that addressed systems elements from the household level all the way to the regional and national levels. These included local, state and Federal government officials, business associations and citizen groups, regional and national environmental groups, and regional energy providers. Based on the results of the survey, an initial qualitative systems model was developed and presented to stakeholders at a face-to face meeting. At the meeting, stakeholders were put into different groups focusing on household/business energy consumption, community energy consumption, regional consumption, Cape and Islands energy supply, demand/supply equilibrium analysis, social and environmental impact and health impacts of the system. Participants also explored the promise of different renewable energy technologies such as wind turbines, solar panels, fuel cells, microturbines, tidal energy and biomass in reducing the demand for fossil-fuel and nuclear power.

The systems representation, including that of the pertinent sub-systems is shown in Figures 2-7. In representing the energy consumption sub-system, stakeholders explored the impact of the energy efficiency and demand reduction measures at the household/business (Figure 2), community (Figure 3) and Cape and Islands level (Figure 4-7).

The aggregation of the household/business level into community (town) and region (Cape and Islands) level sub-systems allowed the definition of different demand reduction strategies at each level.

On the supply side participants looked at existing energy sources such as the Canal power plant which currently provides much of the energy to the region and explored the impact of investments at the household and region level in renewable energy sources.

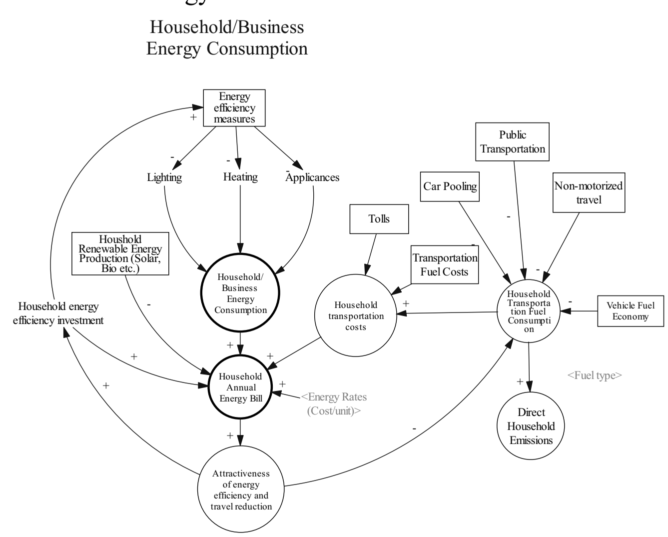

Figure 2: Household/Business Energy Consumption Sub-System

At the community energy consumption level (Figure 3), issues such as efficiency measures, community-level building energy consumption, community transportation fuel consumption, street lights and municipal electricity consumption were taken into consideration. The relationship between mobile source energy consumption and the environmental impact was also explored.

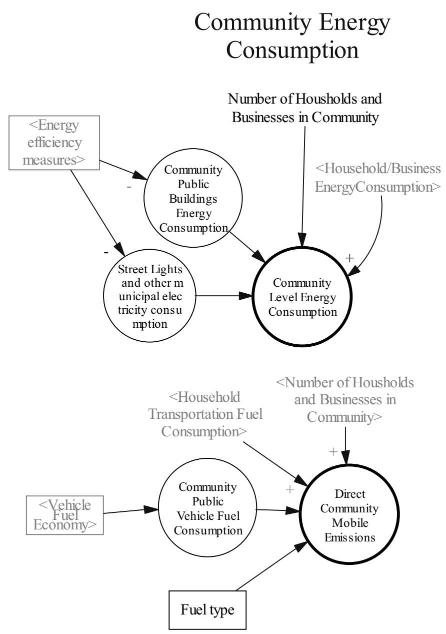

Figure 3: Community Energy Consumption Sub-system

At the Cape and Islands consumption level (Figure 4), the community-level consumptions were aggregated and industrial energy consumption at the regional level was added. Participants wanted to know the total energy bill of the region based on various energy sources and per unit costs.

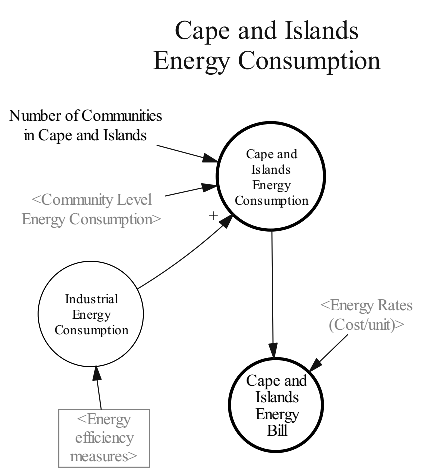

Figure 4: Cape and Island Energy Consumption Sub-system

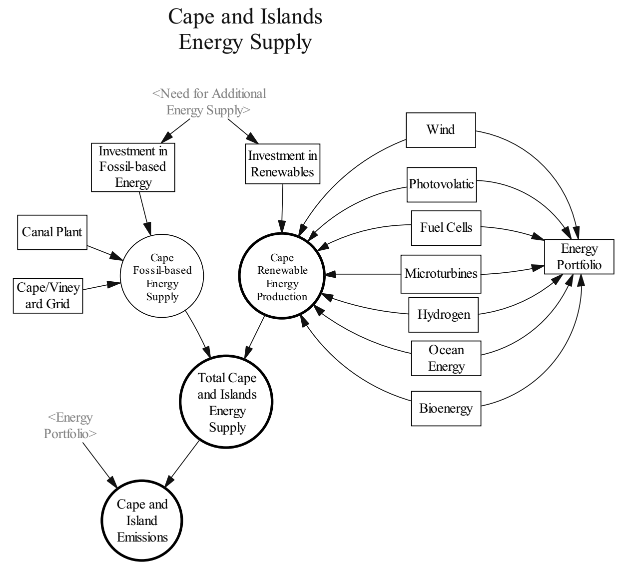

Figure 5: Cape and Island Energy Supply Sub-system

In the demand/supply equilibrium sub-system (Figure 6) the participants explored the impact of energy costs, taxes, service reliability and a variety of others on the demand/supply equilibrium. The annual growth in population as well as average household energy demand would then create the dynamics of the system at hand.

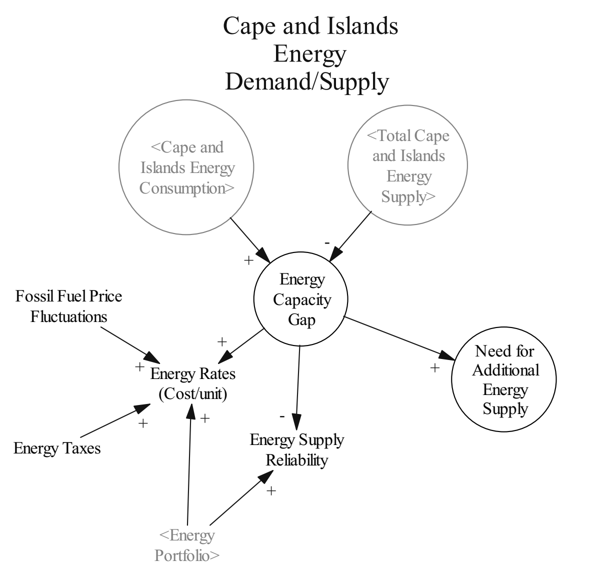

Figure 6 – Cape and Island Energy Demand/Supply Equilibrium Sub-system

In the social and environmental sub-system (Figure 7) the impact of different patterns of energy usage on community health, emissions, global warming (through green house gas emissions) and wildlife were identified. Additionally the impact of oil spills on the environment and oil dependence on national security issues were seen as key factors in the decision-making process.

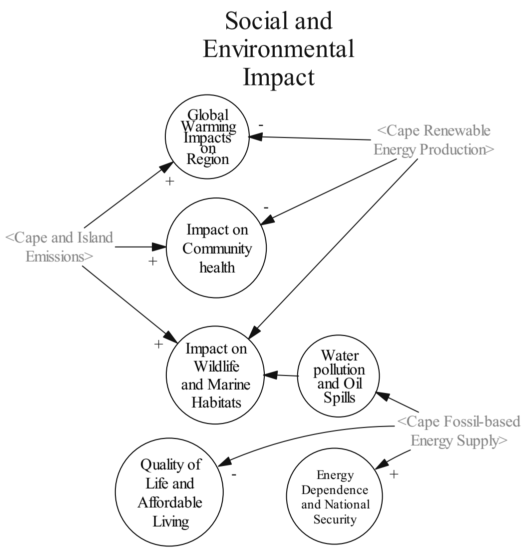

Figure 7: Social and Environmental Impact Sub-system

Once all the subsystem elements were identified, the linkages between the consumption, supply and equilibrium sub-systems with the social and environmental were developed. Each of the relationships then lent itself to existing calculation models that could be integrated into a larger systems model. While the majority of elements could be modeled quantitatively through more or less known relationships (for instance aggregate electricity demand and supply and equilibrium calculations as well as health and environmental impacts based on household, community and regional data), quantification of some of the social and environmental impacts the way the variables were defined proved challenging. This could be overcome by using proxy indicators. For instance in assessing the impact on national security, the total dependence on foreign sources of fossil fuel would serve as a general indicator. The combination of emissions data, total energy bills over average income and health impacts would be a good proxy indicator for quality of living and affordability. Due to time limitations the group decided not to go fully into quantitative analysis during the session.

Impact of SAM-PD Process on Stakeholders' Cognitive Understanding of the System

The act of system representation was intuitive to most stakeholders. It took stakeholders very little time to familiarize themselves with creating systems representations. Most stakeholders found the term "system representation" to be misleading. They preferred the term model. Many said they would not distinguish between a qualitative model and a quantitative one, because a qualitative model could later on be quantified or mostly quantified. Some stakeholders had problems in understanding the concept of polarities, or the signs on the directional arrows. In a system representation a positive arrow going from one component to another means that an increase in the effect of the first component will lead to an increase in the effect of the target component. In other words, it is an issue of directionality of change rather than a positive or negative influence. While this had been described to stakeholder during the presentations, some stakeholders in found this to be non-intuitive. While polarities are crucial to understanding the dynamics of a system, it may be better to introduce them at later stages, when stakeholders are comfortable with the basic concepts of systems representation.

The ability of stakeholders to look at different parts of the system as a whole rather than at individual issues in a laundry list provides an opportunity to assign different working groups to evaluate different parts of the system. In the workshop, stakeholders initially defined ideal working groups that could be assigned to various aspects of the system. Many had suggestions on how to lump different linkages into one working group, due to the similarity of expertise and resources needed. Overall stakeholders found that having a systems representation would allow them to make sure that all the important aspects of the problem were covered and could be assigned to different working groups. Nearly all stakeholders assumed that the current system representation would have to be quantified in order to be useful. Parts of the representation dealing with institutional issues could be left as contextual and qualitative considerations, but stakeholders seemed to see one of the advantages of the system representation in the VenSim environment to be the possibility of quantification. What seemed attractive to stakeholders was the ability to look at dozens of alternative strategies and potentially compare their impacts across the different performance metrics identified. For this reason, stakeholders see the system representation and its subsequent quantification as a promising tool throughout the decision-making process.

Conclusion

The application of the Stakeholder-Assisted Modeling and Policy Design (SAM-PD) process to an actual regional energy planning process for the Cape and the Islands in the Commonwealth of Massachusetts highlights the significant potentials of using visual systems representations as a basis for the collaborative modeling of complex infrastructure systems and their social and environmental impacts by stakeholders. An intermediate survey of the participants shed some light on the usefulness of the approach. Around 92% of stakeholders indicated that a system representation can be a good way to structure dialogue about an energy planning problem, while 8% believed it would rationalize the process too much. Many stakeholders had experiences with past collaborative processes where extensive laundry lists were created, but never put into context. For most stakeholders (86%) it was refreshing to see how their views fit into the larger picture of the physical energy system and interacted with other components.

By not specifying a particular tool for quantifying or evaluating different relationships in the system representation, SAM-PD allows the integration of many different subsystem models into an integrated system model. By linking the different inputs and outputs of various subsystem models, SAM-PD can help evaluate the impact of different alternatives on the overall system. Another insight was that not all of the system representation need or can be quantified. Social and institutional components and interconnections can be evaluated with social science frameworks, and many quantifiable components with a lack of baseline or predictive data may be considered in the decision-making, but not quantified. Still, having these components allow us to monitor and measure them at later times, or understand an emerging impact on the system.

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