An Open Model for Climate Behaviors

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October 20, 2010

1 Introduction

Anthropomorphic climate change is among the most pressing issues of our time, and while an impressive array of new green technologies and strategies have been developed in recent years, the human behaviors that cause climate change remain frustratingly intractable. Within the United States, carbon tax and cap and trade legislation has stalled, environmentally damaging farm practices continue to be the norm, industry and agricultural subsides obscure the costs of business, and consumers continue to favor heavily processed, packaged, wasteful, and polluting products. Politicians are unwilling to advocate policy changes they fear would be unpopular; companies are hesitant to take climate change action on their own; and efforts on the part of consumers are difficult and time-consuming without the support of business and government.

These problems stem from systemic motivations deeply embedded in our society, economy, and government. Moreover, these influences are mutually reinforcing. If the U.S. raises environmental standards on one industry, it can just encourage more imports from countries with lower standards. If years of research help make a new green technology, like compact fluorescent bulbs, economically attractive by saving businesses money, the total effect may backfire as businesses use the money saved to increase production and invest in dirtier industries. Localized policy changes can shift the balances in counterintuitive ways.

However, it is exactly these counterintuitive, systemic, and cybernetic effects that suggest the approach for this project. All complicated systems consist of interwoven feedback loops, often held in an overdetermined homeostasis. That homeostasis is characterized by both minimizing feedback loops, and maximizing ones. While the effects of some actions, whether they are new laws, citizen movements, or business decisions, are minimized and effectively dismissed, other changes will be reinforced and amplified. These "leverage points" are places where small changes can make big differences. Due to the structural nature of all systems, from ecosystems to economies, leverage points are pervasive [von Bertalanffy]. In addition, the persistent pressures involved in Westernized societies, driven by economic growth and efficiency, place us in a "critical state", which can accent small changes [Ubiquity].

The behaviors that cause climate change, including the use of outdated energy-generation technology, wasteful agricultural practices, and unsustainable transportation habits, are mutually reinforced by our entire economic, social, and political systems. The goal of this project is to identify the leverage points in the social system surrounding U.S. behaviors that produce climate change and environmental damage. In developing this model, there are a variety of opportunities to advance the field of human system modeling, using contributions from the field of computer science.

2 Approach

The U.S. accounts for 20% of carbon dioxide emissions, and almost four times the per-capita emissions of China. The international production of imported goods for American consumers is responsible for additional greenhouse gasses, deforestation, resource extraction, and waste. While global warming and climate change are by no means a problem solely of the developed world, we currently have a disproportionate impact, and a corresponding large share of the responsibility. This project focuses on the American consumer, through the policies, businesses, imports, environment, and political economy surrounding and influencing their actions.

A large number of fields inform a study of the factors that influence our habits, from psychology to economics. The framework of system dynamics provides a number of advantages exploited by this work: it explicitly describes feedback loops and policy conditions, provides analytical and intelligible results, and a variety of existing models, such as the Club of Rome's World3 model and Jay Forrester's urban dynamics model, are available as a baseline.

One weakness of system dynamics is that it is hugely aggregative. In system models, distinguishing even between demographic segments (say, children and adults) requires reproducing all of the relevant relations that influence the both, as well as creating the dynamics between them. In addition, system models handle space poorly, tending to treat a distributed stock, such as a working population, as a single lump sum.

This project attempts to combine system dynamical modeling with the emerging techniques of fractal network theory. The world of social interaction is a networked and a spatial world, where different rules apply to different regions. Without this added complexity, the model would not be able to function on a sufficiently fine-grain to identify the particular institutions at the heart of climate change leverage points. Rather than applying a single model to a system distributed in space, each region (represented as a node in a network) contains its own model. However, unlike climate models where each cell's model is independent except at its boundaries, certain properties of the various elements of the model can be shared between all of the nodes that use it. For example, a state's institution for monitoring water quality influences many districts, but activities in each district draw from a single budget.

Another property shared by each model component is its aggregate behavior. For example, pollution levels in each district in a state combine to form that state's aggregate pollution stock. This relationship between scales of resolution motivates this project's goal to build self-similarity deeply into its model framework. In many cases, data series are only available at one scale– such as the state scale– but similar dynamics (that is, self-similar models) apply to all scales. In network theory, this self-similarity is called a fractal structure. Self-similar dynamics apply to all levels and societal institutions.

There is one more contribution from computer science used in this project: an open interface for contributions. To describe a large number of the factors that influence climate changing behaviors, this model may need to be immense. By creating a way for other researchers to contribute to it, along with providing a meta-analysis of those contributions to help in their evaluation and review, the project becomes both more manageable and more useful. As a platform for researches to run their partial models within a larger context, this framework can help to identify both strengths and contradictions between existing models of society.

The remainder of this document focuses on the characteristics of the framework needed to support an open, self-similar, networked system dynamics model. Each component represents a variety of prior work, but their combination is one this project's significant contributions.

A Framework of Partial Models : The Open Model consists of two major pieces: a framework, and partial models. The aspects described here are properly aspects of the framework, which forms the basis upon which relationships can be described and modeled. Because the model as a whole will describe behaviors in a large number of heterogenous regions, we say that the model as a whole is composed of "partial models", which overlap, interact, and reinforce each other. Below, the terms "framework" and "partial models" are used to keep these aspects distinct.

Conditional Self-Similarity : The basis for the partial models will be an existing system dynamics model, which can be applied regionally by building the concept of self-similarity deeply into the framework. In human systems, many of the same principles and behaviors are exhibited at many different scales: globally, nationally, within an metropolitan region, and within a single institution. Rather than explicitly duplicating the partial models to each of these and many other levels of specificity, the framework will use a kind of fractal analysis, where global dynamics are modeled with global principles, but with the potential to "drill down" to arbitrary levels of detail, data permitting. In drilling down, the dynamics at a particular scale can be modified (with a distinct partial model) to reflect that sub-region more accurately.

Multiple Maps : Different dynamics work upon different networks. For example, the United States can be modeled for climate change by placing it on a grid, but people travel on roads, where the effective distance between two points is determined largely by the properties of the roads between them. Information and culture flow in ways that are even more removed from the physical landscape, and the structures of many of these networks are readily available. The framework will allow each region to be represented by multiple maps, and each partial model to apply to different coexisting networks.

Open Exploration and Contributions : The framework will have an interface on the Internet, where people can explore its predictions, download the entire system to experiment with its parameters, and upload partial models as proposed additions. The framework will use the libraries in FreeMat, an open source implementation of the MATLAB language and environment, so that making both data and model contributions is easy.

Meta-Model Evaluation of Contributions : One of the purposes of the framework is to inspect the behavior of partial models to see how well they match historical data and other predictions.

Meta-Model Identification of Leverage Points : The framework will also be able to intelligently seek-out and propose leverage points. A number of techniques could come into play, but the two simplest are hill-climbing algorithms and Monte Carlo methods.

Memetic Transfer of Partial Models : Most human behaviors are determined by habits and conceptions which reside in peoples' minds, and some of these ideas have the potential to spread and replace other ideas. Indeed, changing people's climate-change behaviors will partly happen only by this propagation of new ideas. Therefore, the regions of applicability for partial models must be able to change, and other partial models must have the capacity to describe this memetic transfer.

Integration with Climate Models : Actual changes in climate will have a strong effect on people's behavior, so climate prediction must inform the model as a whole. The framework may include a modified version of the Community Earth System Model (CESM) to do this.