Transitions to Renewable Energy:
Modeling it from the Bottom-up and the Top-down

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1 Brief Description

The objective of this prposal is to examine the economy as a complex adaptive system undergoing the process of transition from nonrenewable to renewable energy resources while coupled with the natural system . As a complex adaptive system, the economy can exhibit path-dependence and discrete jumps in technology rather than smooth transitions. Because of the pervasiveness of energy consumption across all sectors of the economy, the capital-intensive infrastructure that energy production and distribution requires, and the time-lag between technological innovation in renewable energy and implementation, the economy is at risk of sub-optimal performance in the near-term transitions. At the same time, dynamics within the natural system impact and are themselves impacted by increasingly complex dynamics within the human-built system.

The schema in Figure 1 describes the ways in which these human and natural systems processes are coupled. Over the course of the 21^{st} Century, increasing social stressors, including increased global population, higher living standards, and improved access to modern energy infrastructure, will place strong pressure on the capacity of the biosphere to support such demands. In turn, biophysical stressors such as climate change, resource depletion, and ecosystem degradation will make those demands harder to meet. [3]. The modern industrial economy will be forced to undertake transitions in the near future to modes of operation that (i) use renewable resources (such as forest products) at rates lower than their rate of regeneration; (ii) emit wastes (such as carbon dioxide) at rates lower than their assimilation by environmental systems; and (iii) reduce the use of non-renewable resources (such as crude oil) to rates at which renewable substitutes can be deployed [4, 5].

Those transitions are going to happen. What is not known, is how those transitions will take place. In the words of the Shell Energy Scenarios, will there be an organized "blueprint" for the transition, or a chaotic "scramble?" [] Mainstream economic models and the corresponding policy planning cast ('top-down') infrastructure investment decisions within the economy as undertaken via a central agency, with perfect knowledge and perfect foresight, or with some randomly generated, exogenously defined level of 'uncertainty' [17]. The structure of such models is implicitly founded upon the existence both an equilibrium state for the economy and an optimal pathway to reach that state [].

In rejection to this perspective, researchers in non-equilibrium and complexity economics seek to understand the economy as a thermodynamically open system in a state of dynamic balance with both the social and natural systems within which it is embedded []. From such a perspective the notion of 'optimality' is lost, instead economic interactions must instead be understood 'bottom-up' via the transaction and investment decisions undertaken by multitudinous actors seeking to satisfice among multiple competing needs and wants [].

Within this new framework, agent-based modeling has become an important tool. This project will an agent-based model to capture the complex dynamics of infrastructure development and change during the transition in energy sources.

Creating a more resilient future relies on decision making informed by economic, social, and

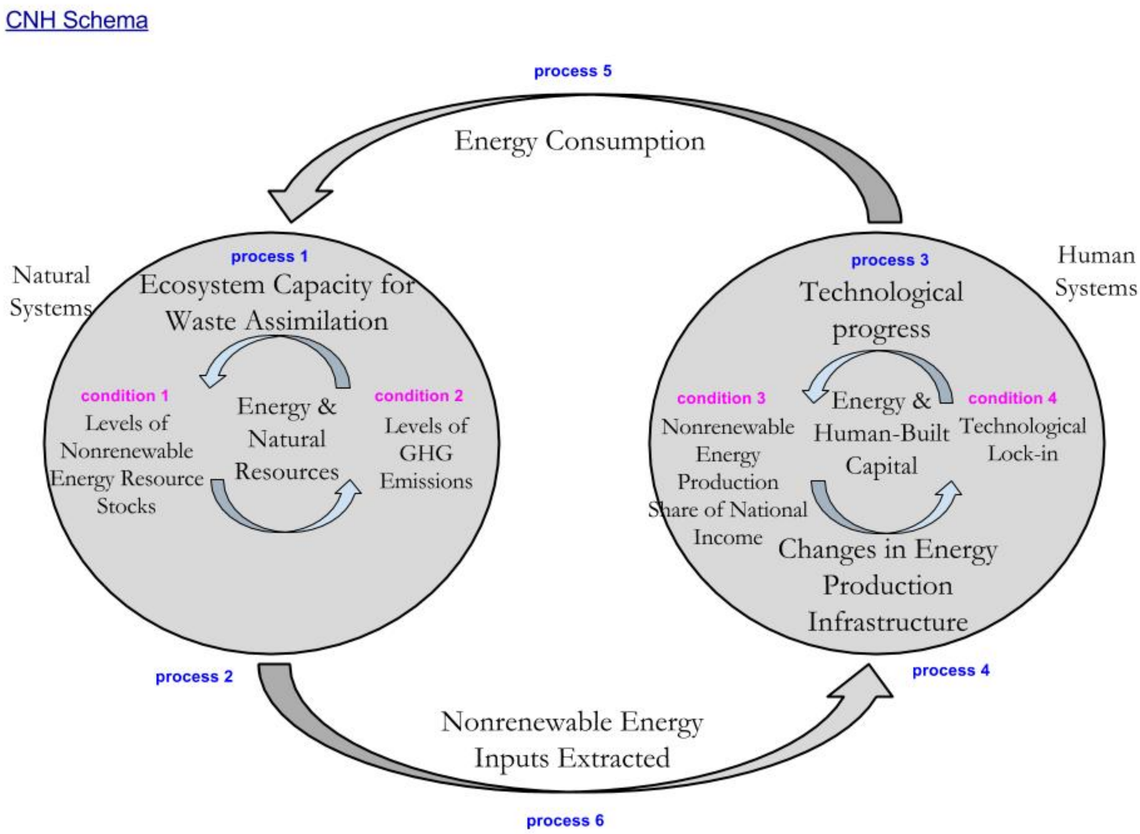

Figure 1: CNH Schema for Energy Transitions.

physical factors [10]. The new era of resource depletion requires new models of our economies that bridge the financial and physical and that account for their inherent complexity. Such models can guide advantageous (as opposed to optimal) asset investment and resource consumption strategies that are responsive to the constantly evolving social and environmental landscape.

The proposed project will build on an agent-based model developed by the project PI to answer the following questions:

1. are multiple, interacting agents able to collectively manage a transition from non-renewable to renewable resources to avoid negative impacts of resource depletion?
2. if yes, do there exist resource consumption and investment decisions that are more advantageous in managing this transition?

In order to answer these questions, this research will explore the behavior of agents in a resource harvesting and investment simulation where resource managers must forage for energy and natural resources while investing some of those resources towards the activities of foraging while also maintaining and building out critical infrastructure. In autonomous mode (agents act according to built-in algorithms), advantageous strategies for resource management can be 'evolved' through the process of 'natural selection'. In learning mode (researchers or learners take control of the agent behavior), successive rounds of the simulation will more closely resemble real-world locations. Researchers can better understand the context for resource and infrastructure management strategies with the aim of developing more informed policies.

Comparison of simulation results of agent-based models to real-world otucomes is key to assessing their validity. Matthew Heun, a Co-PI on the project, will be building a unique data on the South African energy infrastructure that will be a plumb line to compare and contrast the "top-down" and "bottom-up" models of the economy.

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