Exploring the dynamics of the world energy system: An agent-based - system dynamics model

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Abstract

Due to limitation of some energy resources, there are concerns whether the world energy system (WES) can supply sufficient energy for societies in the future. Scientists develop models to gain insights into the system. GEMBA is a system dynamics model developed by Dale to explore the global energy supply using biophysical economics approach. Biophysical economics theory analyzes the economy based on the physical properties and structures of real economic systems and it considers natural resources and their impacts on the economic processes.

GEMBA like other system dynamics models adopt a top-down view on the WES. The top-down view assumes that all elements of a system have global knowledge about the system. Many of such models do not capture some characteristics of a WES such as geographical resource distribution and demand diversity. In addition, it is often not possible to analyze the emergent effects from variations in low-level elements on the system behavior in top-down analysis.

We developed an exploratory agent-based model, by taking a biophysical economics lens, for bottom-up analysis of a WES and relevant natural resources. We decomposed the world into a number of geographical regions to capture resource distribution and demand diversity in the WES. Our Multi-Region World Energy Model (MRWEM) combines the GEMBA with the concept of energy-return-on-investment (EROI) for imported energy. So, in MRWEM the internal behaviors of the world regions are modeled with GEMBA and the system dynamics approach while the inter-regions behaviors are modeled with agent-based modeling approach.

MRWEM exhibits a number of advantages over GEMBA. First, it provides insights on the inter-regions energy movements and trade which is impossible in GEMBA. Second, MRWEM provides flexibility in analysis as changes in the model can be done at the level of regions not the whole world. Also, MRWEM facilitates analysts to analyze the WES using different geographical decompositions. Moreover, it shows that the hybrid adoption of agent-based modeling and system dynamics is possible and insightful when the level of abstraction is very high.

Miguel, Amblard, Barceló & Madella (eds.) Advances in Computational Social Science and Social Simulation
Barcelona: Autònoma University of Barcelona, 2014, DDD repository <http://ddd.uab.cat/record/125597>

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An Agent-based - System Dynamics model

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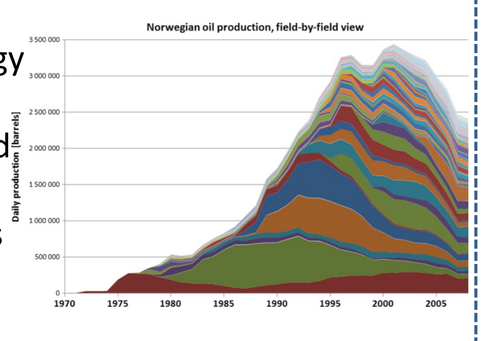
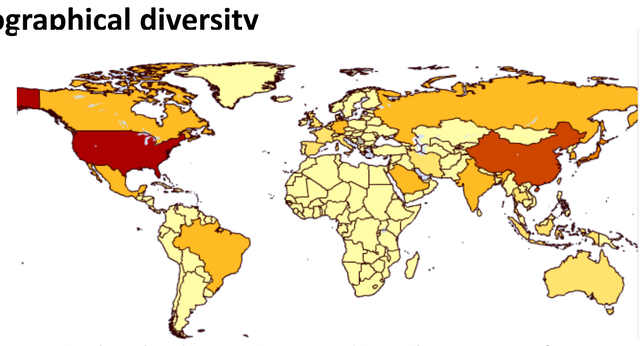
World Energy System Challenges

Peak in oil production

Production of energy from non-renewable resources is expected to peak due to finite size of the resources



Geographical diversity



There is high diversity in distribution of energy resources and pattern of energy consumption across the world

There is no universal control over the production, and consumption of energy due to political diversity of nations and regions across the world

Research Objective

To develop a model to explore the world energy system considering limitations of natural resources, and interactions among the geographical regions of the world

Theoretical Perspective

Biophysical Economics

B.E. is based on the biological and physical properties, structures and processes of economic systems. It enables us to consider limitations of natural resources in the economy.

Complex Adaptive Systems (CAS)

CAS perspective enables bottom-up modeling of the world energy system.

Theoretical Perspective	Biophysical Economics	CAS
Analysis View	Top-Down	Bottom-Up
Modeling Paradigm	System Dynamics	Agent-based Modeling

Multi-Region World Energy Model (MRWEM)

The Hybrid Agent-based – System Dynamics Model

11 geographical regions

Each region is composed of 5 agents

Four agents (*Renewable Supplier*, *Non-Renewable Supplier*, *Energy Consumer*, *Energy dispatcher*) operate using System Dynamics paradigm as proposed in GEMBA

Energy Dispatchers make strategic decisions e.g. investments in energy resources

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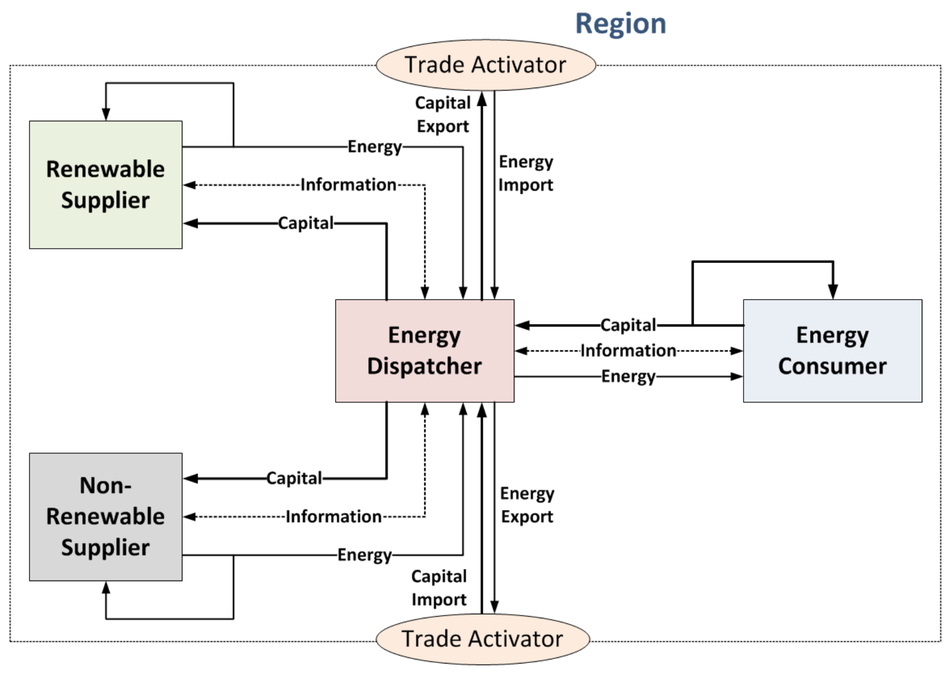
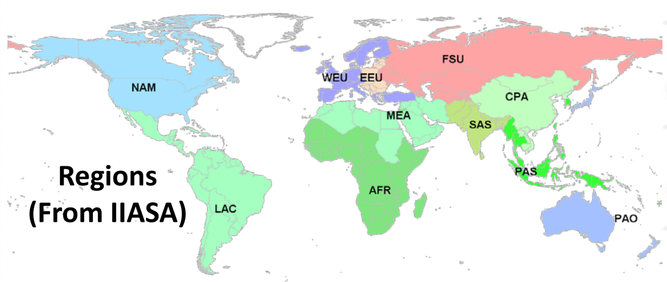
Interactions among regions are done through Trade Activators



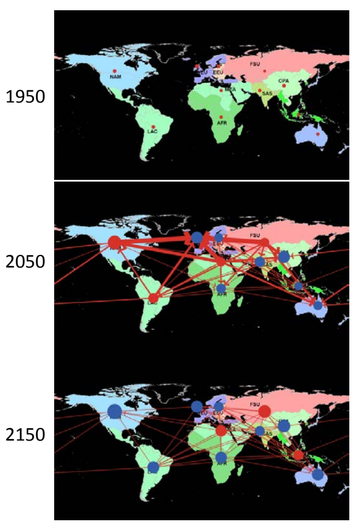


Energy-Return-on-Investment (EROI) is an important variables in biophysical economics

EROI of energy resources within each region measured using the Dynamic EROI function Developed by M. Dale.

EROI of energy trade in MRWEM is calculated using the formula for EROI of imported fuel developed by Hall et.

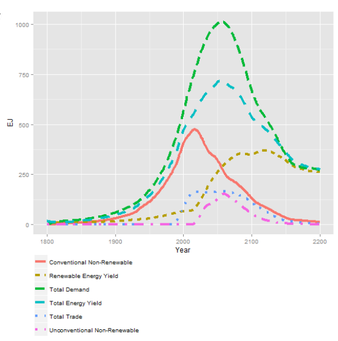
Model Results



The total non-renewable production and the total energy trade will experience peak and decline

The total renewable production will experience peak and plateau

Advantages of MRWEM over GEMBA:
- It provides insights on the inter-regions energy movements and trade
- Provides flexibility in analysis as changes in the model; and can be done at the level of regions



Methodological Insights

- In MRWEM, SD becomes the rule-base of agents ABM. This combination is different from so-called multi-paradigm
- When the level of abstraction is very high, the differences between the top-down view and the bottom-up view decreases which enables the hybrid use of ABM and SD
- There is no hard boundary between SD and ABM as long as they can be programmed in programming languages without being trapped in regularities of software applications.

GEMBA

Global **E**nergy **M**odeling – **B**iophysical **A**pproach

A system dynamics model developed by M. Dale for exploring the global energy supply

GEMBA decomposes the world economy into "energy sector" and "the rest of economy"

Main parameters of the model are:
- Ultimate Recoverable Resources
- Technical Potential for renewable resources
- Capital intensity of the economy
- Parameters of the "Dynamic EROI function"

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