INTELLIGENT ENERGY CHOICES

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ABSTRACT

Intelligent Energy Choices is an energy education and outreach project designed to help people to discover the impact of their energy choices. We have developed an agent-based simulation in which the world's twenty-five most populous countries are represented by autonomous agents. Using initial data from the World Bank and other sources, the simulation shows the environmental and economic impact of continuing as we have. Changing parameters allows people to see what happens when different choices are made.

KEY WORDS

Global energy simulation, agent-based, environmental education

1. Introduction

Recognizing that scientific literacy requires more than learning facts, science educators have begun to address a range of socio-scientific issues that enable students to consider the impact of science on a personal, as well as global, level [1]. Within this context, the Nature of Science has emerged as not only a fundamental component of science education [2, 3] but also an interdisciplinary area of inquiry that draws its intellectual input from both the sciences and the social sciences.

Global energy use, with its interconnections to climate change, exemplifies a socio-scientific topic that requires consideration of these issues within a single complex system. Although this system is dominated by humans, it must be subjected to the same disciplined study that is applied to other physical systems: anchored by reproducible observations that give rise to theoretical understanding through testing and possible refutation through additional observations. The difficulty here is that the system is self-referring and somewhat unique in that we the investigators are part of the system that requires investigation. The fact that humans now have a major influence on this interaction requires that moral and ethical implications, which traditionally caused difficulties to scientists, be part of such a system. At least in a democratic society, steps taken to ensure sustainable planetary equilibrium will come through the political process. The only known way to translate the science into electoral issues is through the educational system. The Energy Choices project is designed to construct a building block in that system.

The Energy Choices simulation is an extension of an earlier program developed by Tomkiewicz [4]. The purpose of this simulation is to assist in generating credible scenarios for global sustainable development that are not only a mixture of projections of present growth patterns and wishful thinking, but are directly dependent on decisions made by the participants. Unlike the previous effort, the simulation described in this paper relies on real data from the World Bank [5] to establish both initial values and trends for determining future behaviors and results. The primary contribution of this work is the creation of a model that can be used to show students how choices made locally can have a long-term global impact, both environmentally and economically. The simulation is not intended to predict the future. It is intended to function as an entertaining educational game in which students resume the role of rulers of countries that make policy choices that have consequences for their countries and for the world at large. The results can be tested against future data and against predictions of more elaborate simulations.

2. Energy Choices Simulation

The essential role that both socio-economic human factors and the science of the physical environment play in modeling future climate changes makes the issue very complex. A methodology known by the acronym of IPAT [6, 7] simplifies the issue by presenting the increase in greenhouse gasses as a product of factors where the dimensions of the terms cancel out. Here, I stands for *Impact*, P for *Population*, A for *Affluence* and T for *Technology.* The *Impact* here is environmental (CO_2/Year), and *Affluence* is measured by Gross Domestic Product (GDP) per capita (GDP/Population). For emission of CO_2, the identity can take the following form:

$$CO_2 = Population\left(\frac{GDP}{Population}\right)\left(\frac{Energy}{GDP}\right)\left(\frac{FossilFuel}{Energy}\right)\left(\frac{CO_2}{FossilFuels}\right) \quad (1)$$

In its Median Scenario, the UN estimates that the world's population will stabilize at around 9 billion people in the latter half of this century [8]. The forces that will drive this stabilization include an increase in the standard of living that most probably will result in an increase in the education level of women in developing countries and major global decrease in infant mortality. In the remaining *Technology* terms, Energy/GDP describes what is often referred to as Energy Intensity. For a given population change, the policy goals are to minimize CO_2 production while at the same time maximizing the GDP per capita.

The Intergovernmental Panel on Climate Change (IPCC) makes predictions of anthropogenic climatic consequences of emission of greenhouse gases which are based on input derived from predictions of the various factors in equation (1) [9]. They list about 40 scenarios with different socioeconomic projections and patterns of energy use which are used to estimate global average greenhouse gas emissions as well as regional contributions to this emission. In all of these scenarios, economic development (GDP/capita) is balanced by the three technology terms in the equation. For example, the 2100 projections of the GDP/Capita of one set of scenarios ranges from \$16,000 to \$75,000. These projections are in constant 1990 dollars and should be compared with the 2000 value of \$4400. The projections also include distributional projections for developed and developing countries. What is significant about these various predictions is that the perceived future shape of the world will strongly affect our present behavior.

3. Input

Figure 1 provides a schematic presentation of the data flow in the simulation.

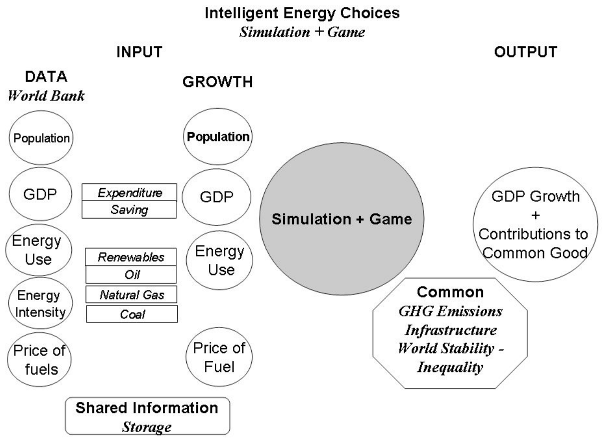

Figure 1. Outline of input and decision making steps.

The initial data for the various countries are taken from databases such as the World Bank [5], British Petroleum [10] and the US Energy Information Administration [11]. Expenditures, savings, and fuel choices are determined by parameters that are set when the simulation is run. Growth in population, GDP, energy use and prices are based on algorithmic projections of past growth. The work on these growth projections is continuing to evolve. The volatility of the fuel prices requires that the prices will be determined by long-term fuel contracts.

The output of the simulation is an animation showing the change in population and GDP/capita over time. Accompanying graphs show the changes in GDP, fuel prices, and fuel usage. We are also developing a point system to gauge the success of the various approaches represented by differing parameter values. This will be weighted based on contributions to the welfare of the country as measured by growth in GDP and to contributions to common good as expressed by minimizing carbon footprints and world's inequality.

4. Software Architecture

Intelligent Energy Choices (IEC) has been simulated using the Repast-J agent-based simulation model. Repast is a free, open source library of classes for creating, running, displaying and collecting data from agent based simulations. Repast is fully object oriented and seeks to support the development of extremely flexible models of agents with an emphasis on social interactions.

An agent-based simulation typically proceeds in two stages. The first is a setup stage that prepares the simulation for running, and the second is the actual running of the simulation. In Repast simulations the running of the simulation is divided into time steps or "ticks." For each tick, some action occurs using the results of previous actions as its basis. Intelligent Energy Choices has been designed to run in non-batch mode that requires a user to start and stop the running of the simulation through a graphical user interface.

A typical simulation written with Repast will have at least two classes written by the user: the agent class and the model class. We have supplemented this with an additional manager class to handle changes in parameters that come from making choices. Figure 2 shows the components in our Intelligent Energy Choices simulation.

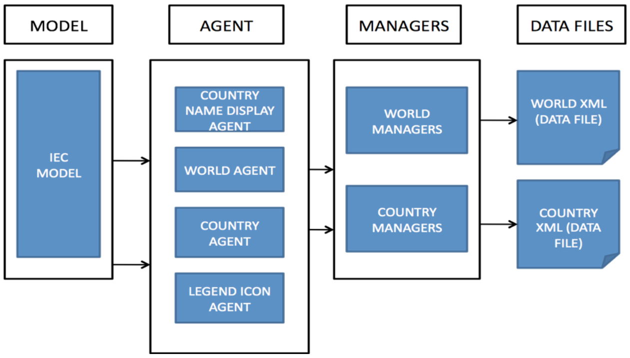

Figure 2. IEC Components

4.1 The Agent

Repast provides several display classes for visualizing the state of a simulation. In Intelligent Energy Choices we have developed four agents, each of which maps to a corresponding Java program implementation.

The *World Agent* describes the behavior of the agent whose purpose is to provide world-specific data in each of the iterations of the simulation. World Agent tries to keep track of the current state of the world in terms of population, GDP, energy reserves, and energy prices. All Country Agents are mapped onto the World Agent.

A *Country Agent* describes the behavior of individual countries, updating country-specific data in each of the iterations of the simulation. In our simulations, the Country agent re-calculates the country population based on data obtained from previous iterations. Country Agents have attributes such as GDP, population, and energy usage.

The remaining two agent types are used to support display of the data. The *CountryNameDisplay Agent* is responsible for setting the display name of countries on the GUI. The *LegendIcon Agent* is responsible for showing the legend on the GUI.

4.2 The Model

A model sets up and controls both the representational and infrastructure parts of a Repast simulation. In Intelligent Energy Choices we have the *IEC Model*, which is the foundation of IEC system on which we place layers of agents. The IEC simulation implements the SimModel interface, for which Repast provides an abstract class SimModelImpl that partially implements this interface.

A typical model class contains both infrastructure and representational variables. Infrastructure variables include a Schedule and collection classes such as Arraylists, which IECModel.java uses to store country agents as well as country name display agents. Representation variables are initial parameters for a run of the IEC model.

IECModel.java describes following methods:

1) `loadCountryList()` : In this method, we define aCountryAgentsList, which is an arraylist of country agents. One agent is generated for each country in the simulation.

2) `loadWorld()` : In this method, we define aworldList, an arraylist with a single world agent.

3) `step()` : This method is responsible for running the IEC simulation. This method performs the task of loading all countries and forwarding country requests for energy resources (fossil or renewable) to their respective country managers. The country managers, in turn, request the world manager to sell resources to them.

4.3 World Data

Two XML data files define initial parameters for the simulation. Using XML files allows us to quickly update the real data values, and even include/exclude countries from the simulation. The first file, *Country-Data.xml*, is used to store initial parameters of all the countries including population, gdp, energyUsage, gdpGrowth, populationGrowth, energyIntensity, energyUsageGrowth, latitude, and longitude. The second file, *World-Data.xml*, provides initial parameters for the world including global population, global GDP, global energyUse, fossilEnergyResources, renewableEnergyResources, fossilPrice, and renewablePrice.

4.4 The Managers

The Business logic resides on the fact that for World and Country agents we have corresponding World and Country Managers. By separating the calculations of simulation values from the agent definitions, we are able to experiment with different algorithms without affecting the integrity of the agents.

The *World Manager* is responsible for selling energy to countries that request it, and then re-computing the prices of both fossil fuels and renewable energy sources. The WorldManager is able to carry out these tasks by implementing the following functions.

1) `calculateFossilPrice()` calculates the following:

```
fossilPrice = 7.*Math.exp
       (initialFossilReserve /
       remainingReserve);
```

2) `calculateRenewablePrice()` calculates the following:

```
renewablePrice = (2 *
       initialFossilPrice) +
       initialRenewablePrice * Math.exp
       (-7 * (renewableUsed /
       (fossilUsed + renewableUsed)));
```

3) `sellEnergy()`is used to decide whether a country can buy fossil fuel or renewable resources. The current implementation has countries purchasing fossil fuel whenever the price of fossil fuels is less than renewable resources. It also decides the quantity of the resources available to be bought by each country. This method is responsible for keeping track of the amount of resources remaining and used.

The *Country Manager* is responsible for placing requests for resources to the World Manager on behalf of the countries. Its standalone tasks involve computing the country population and GDP as it changes over time.

1) `calculatePopulation()` calculates the following:

```
double initPopulation =
      aCountry.getInitialPopulation();
double td = 70 /
      aCountry.getPopulationGrowth();
double population = initPopulation *
      Math.exp(iteration/td);
```

2) `calculateGDP()` calculates the following:

```
double energyPurhcased =
      fossilPurchased +
      renewablePurchased;
double gdp = energyPurhcased /
      (aCountry.getEnergyIntensity());
```

4.5 Program Flow

Figure 3 shows the steps taken by the IEC simulation.

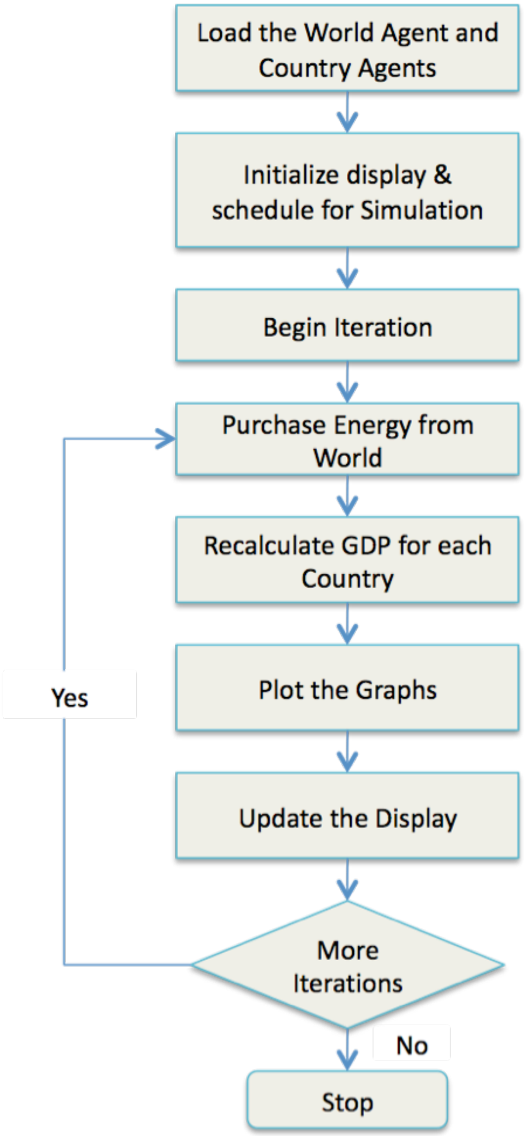

Figure 3. IEC Program Flow

5. Results

We ran the IEC simulation using World Bank data from 2003 for the initial country parameters, and data from British Petroleum for initial costs of fossil fuels. Energy Intensity for each country, which represents how efficiently energy usage is converted to GDP, is based on initial GDP and energy usage. In the simulation, it is assumed that all countries spend $1 per person per day for every $1000 in their GDP, for basic consumption. The rest is divided between energy spending to support GDP, based on the country's current energy expenditures as a percentage of GDP, and savings, part of which is used for future reduction of the energy share. Although savings do not contribute directly to GDP, our simulation considers the savings rate in adjusting energy intensity, reflecting the idea that improvements in infrastructure lead to more efficient conversion of energy to GDP.

When countries purchase energy, they can choose between fossil fuels and renewables. By default, each country purchases the cheapest energy available, although we include a parameter that allows the simulation to reflect a conscious decision to use one over the other. Over time, as fossil resources are depleted and renewables are used more, the price of fossil fuels increases while the price of renewables falls. GDP for the next year is based on the amount of energy purchased (measured in MBTU) and the country's energy intensity. Energy intensity improves as GDP is invested in savings. Countries that have nothing left of their GDP after investing in "survival" go bankrupt.

Figure 4 shows a snapshot resulting from running this simulation. Here, we can see the wealthy countries becoming wealthier, while the poorest countries go bankrupt. It is interesting to note that countries with lower populations tend to prosper more over time.

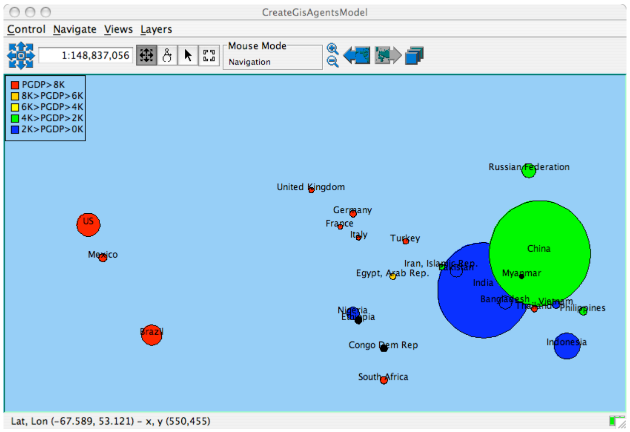

Figure 4. Snapshot of the IEC simulation

Figures 5 and 6 show examples of the graphs we generated from running this simulation. The graphs show changes in GDP/capita and in consumption over time. We show only five countries here, to reduce clutter.

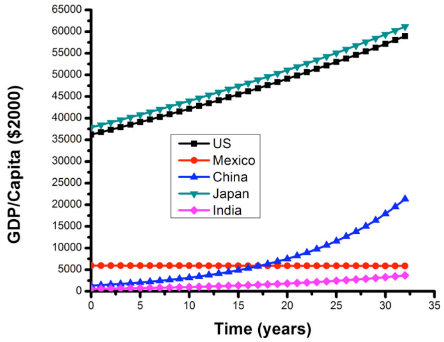

Figure 5. IEC simulation output

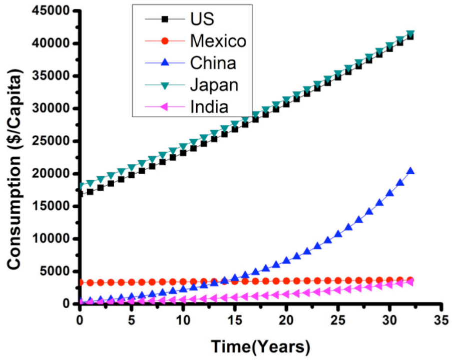

Figure 6. IEC simulation output

We are currently using extrapolations from recent history to refine the parameter values, to make the simulation more realistic.

6. Conclusions

The Energy Choices simulation clearly demonstrates that, without changing current behaviours, the wealthiest countries are likely to continue to be wealthy, while countries with lower GDPs and higher populations are likely to go bankrupt. The only mechanism presently available for countries to increase their wealth is through lowering their energy intensity, which is balanced by their need to spend on consumption. Since the consumption spending of 1$/person/day constitutes a large fraction of many countries' GDP, there isn't much left for energy purchases designed for economic growth.

We are currently extending this simulation to create a web-based multi-player game that will be incorporated into a general science curriculum for high school and undergraduate students. In this game, students will have the option to change how countries make their investments, and then observe the impact. Game scores will be based on both the global impact (i.e. carbon footprint) and local impact (i.e. improvements in GDP/capita) of the students' decisions. Students will have the opportunity to play the game several times over the course of the semester.

Acknowledgements

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