Bottom-up Mitigation of Global Climate Change

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Abstract: The talk will be based on a new online/offline game/simulation (Intelligent Energy Choices (IEC)) that was designed to provide educators at high schools and college levels and engage general public with an interactive, interesting, tool that allows users to "control" their countries and by doing so, control the fate of the world. The conclusion from playing and observing IEC is that Millenium goals can be satisfied while the countries that they rule and the World at large prosper. IEC is an agent-based simulation/game in which the world's twenty-five most populous countries are represented either by autonomous agents (simulation) or players. IEC is focused on energy use and climate change and their global and national impact on climate and prosperity. The algorithm is based on choice between purchasing the lowest cost energy sources and Cap and Trade mechanism in which global emissions are regulated to constantly decline, and the price of a "unit" of carbon dioxide is collectively adjustable. The reference year is taken as 2003 so data are available for comparing the bottom-up results of the world controlled by the players and the top-down recent data.

Keywords: Climate Change, Game, Simulation, Independent Agents, World

BACKGROUND

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 (Commoner.1972) and (Ehrlich and Holdren. 1971) simplifies the issue by presenting the increase in greenhouse gasses as a product of factors where the dimensions of the terms cancel out. In the IPAT model, 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:

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

In its Median Scenario, the UN estimates that the world's population will stabilize at around 9 billion in the latter half of this century (UN. 2007). The forces that drive this stabilization include an increase in the standard of living that results in an increase in the education level of women in developing countries and major global decreases in infant mortality. In the remaining *Technology* terms, Energy/GDP describes what is often referred to as Energy Intensity, which refers to how efficiently a country uses its energy to produce GDP. For a given population change, the policy goals are to minimize CO_2 production while at the same time maximize the GDP per capita.

The International Journal of Climate Change: Impacts and Responses
Volume 4, Issue 1, 2013, http://on-climate.com/, ISSN 1835-7156

The Intergovernmental Panel on Climate Change (IPCC) (IPCC. 2007) makes predictions of the consequences to the global climate that are driven by emissions of greenhouse gases. The predictions are based on input derived from predictions of the various factors in equation (1)(SRES. 2002). IPCC lists about 40 scenarios with different socioeconomic projections and patterns of energy use. These predictions are used to estimate global average greenhouse gas emissions as well as regional contributions to these emissions. 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 projections is that the perceived future shape of the world is strongly affected by our present behavior.

The IPCC (IPCC. 2007) projects that a "typical" environmentally friendly scenario (B1) will stabilize the increase of the average global temperature to around 2.5^{o}C above the average temperature at the beginning of the 20th Century; while a "business as usual" (A2) scenario will result in a global temperature increase of an average of 4.5^{0}C with respect to the same reference point. Such an increase is not projected to be globally uniform, with temperature increases almost doubling around the poles but showing smaller increases around the tropics. Such an increase in average temperature is projected to result in an ice–free world most of the year and in the extinction of at least 40% of species and the collapse of global ecosystems.

The main differences between the two scenarios are (Tomkiewicz. 2010) that the "business as usual" scenario assumes population increase to be around 14 billion toward the end of the century and the fraction of energy derived from fossil fuels to remain approximately constant at 85%. The more "environmentally friendly" scenario assumes that the population will stabilize below 9 billion and the fraction of energy derived from fossil fuels is reduced to around 50%. In terms of the projected population increase, the difference in projected fertility rates between the two scenarios is about 0.5 children per fertile woman. The shift in energy use that will need to occur over this time scale requires major collective decisions. In democratic societies, collective decisions require popular support. There is broad recognition that a major obstacle to popular political support is a disconnect between the knowledge generated by the scientific community that investigates these issues and the general public's understanding of those issues (Sommerville and Hasol. 2011) and (Tomkiewicz. 2012).

Many years of educational research on how people learn (Bransford et al. 2000) and (National Research Council. 2005) has demonstrated that people learn best when they are actively engaged in the process, and when learning is linked to "meaning making", or seeing how the science being taught applies to their own lives. Furthermore, National Science Education Standards (National Research Council. 1996) recommends that "All students should develop understanding of science and technology in local, national and global challenges". As a result, there has been a growing focus on the combined context of science, technology, and society, stressing the impact of science and technology decisions on science (McComas and Olson. 2000) and (Van Eck. 2006). More recently, this idea has been extended to encompass a range of socio–scientific issues that allow students to consider the impact of science on a personal, as well as global, level. These issues include the nature of science, classroom discourse, cultural aspects, and moral issues raised on a case–by–case basis (Wilson. 1954). Within this context, the Nature of Science (NoS) has emerged as not only a fundamental component of science education (Kloper and Squire. 2008) and (Rogner. 1997) 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. In order to translate the science into electoral issues, the populace must be educated about the role of humans in the system. This project is designed to construct a building block in that direction.

Intelligent Energy Choice–Game Simulation

"Intelligent Energy Choices" (IEC) 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 (25) most populous countries are represented by autonomous agents. These countries represent 75% of the world's population, living in both developed and developing countries around the world. Using the IPAT formula of equation (1) as a model for how autonomous behaviors affect the global system, and initial data from the World Bank and other sources, the simulation shows the environmental and economic impact of the agents' energy choices. Setting parameters in the simulation affects behaviors of the autonomous agents, which allows people to see what happens when different choices are made.

In addition to this simulation mode, which shows the results of worldwide changes in energy choices, IEC may also be run as a multi–player game. In this game mode, each autonomous agent can be controlled by a separate player, who is given the ability to make changes in choice parameters while the simulation is running, in response to feedback provided by the system. Agents that are not controlled by a player continue to operate autonomously. A point system reflects how well the player is doing, in terms of how well the economy is growing (GDP per capita) and carbon emissions are being cut (amount of energy from fossil fuels).

The IEC back–end is an agent–based simulation, written in Java and running on a server. Although the initial simulation was developed using REPAST (Recursive Porous Agent Simulation Toolkit), we have added management and communications classes to support the servlets forming the back–end of the game. Initial data, game state, and game results are stored in a MySQL database.

It is important to remember that the purpose of our simulation is to educate the general public, and not to predict the future. Although the IPAT model is too simplistic to be used for making precise predictions, this model is ideal for our purposes in that it shows the relationships between social and scientific factors in a way that can be readily explained to a non–scientific audience.

Input

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

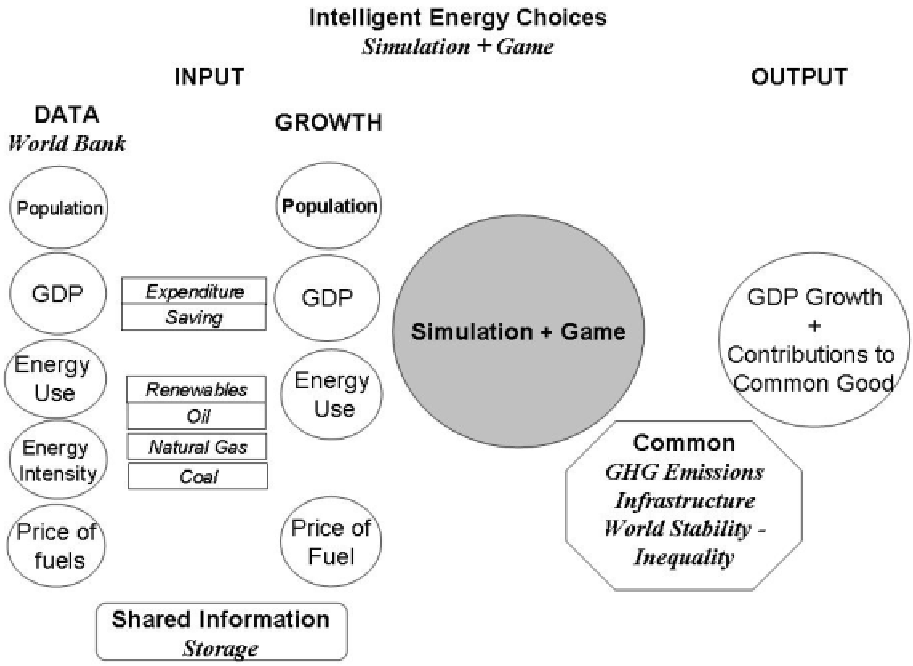

Figure 1: Outline of Input and Decision Making Steps

The initial data for the various countries, and for the world at large, are taken from databases such as the World Bank (World Bank. 2012), British Petroleum (BP. 2012) and the US Energy Information Administration (EIA. 2012). Expenditures, savings, and fuel choices are initially determined by the countries' past behaviour, but may be modified by parameters that are set when the simulation is run. These parameters include desired GDP growth, the decision to purchase the least expensive fuel, or imposition of a cap and trade policy. Although there are other ways that we might have represented policies for a country, we chose these because of their instructive value in the classroom. Growth in population, GDP, energy use and fuel 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 state of the world over time. Figure 3 shows the interface in game mode; figure 4 shows it in simulation mode. A color–coded map shows changes in GDP/capita over time. Accompanying graphs show the changes in GDP, fuel prices, and carbon output. The player's score is 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.

Software Architecture

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. IEC has been designed to run in non–batch mode that requires an instructor to start and stop the running of the simulation through a graphical user interface. Figure 2 shows the main components:

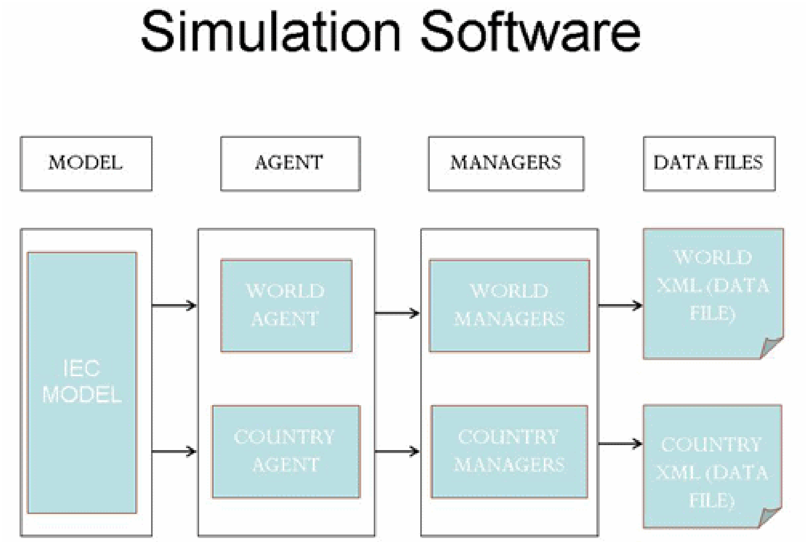

Figure 2: IEC Components

Program Flow

IEC uses the following World Bank energy related indicators for each country:

- GDP (Constant 2000$)
- Energy Use
- Energy Mix (Fossil, CRW, and Renewables–as %)
- Population
- Population growth
- Energy Intensity
- Savings rate (% of GDP)

IEC also uses British Petroleum and US Energy Information Administration data for the world:

- Fossil fuel reserves
- Initial fuel prices

IEC uses the 2003 data as a reference and monitors development based on individual and collective (class) decision makers. Students can validate assumptions based on comparisons of outcome with "future" data from 2003 to the present. Individual and collective decision making is specified below:
Collective (class) Choices

- Cost of carbon footprints (for cap and trade)
- Target dates for carbon reduction (for cap and trade)
- Desired increase in GDP growth (for autonomous agents)
- Whether to buy the cheapest fuel, or use the current mix of sources (for autonomous agents)
- Distribution of carbon bank

- Price increase of fossil fuels
- Price decrease of alternative fuels

Country (individual) Choices

- Desired growth of GDP
- Changes in energy mix (% fossil and renewable)
- Changes in savings rate, consumption rate, and fuel expenditures
- Whether to buy the cheapest fuel, or use the current mix of sources
- Changes in carbon emissions

Play includes the following:

1 st. Step

1. Energy cost of the GDP = (Price_Fossil*InitialPercentFossil + PriceAlternatives*Percentalternatives + PriceCRW(0)*PercentCRW)*TotalEnergy.
2. Carbon footprints = PercentFossil*TotalEnergy*0.07 in tons
3. Calculate cost of carbon footprints and add to Energy Cost
4. Consumption = GDP–Energy Cost–Savings
5. Minimum consumption 1$/day per person (PPP); adjust savings and energy expenditures as necessary
6. Calculate actual CRW
7. Make initial choices, such as GDP growth (in the simulation mode it might be decent attempt at increase 2% of previous growth (5% to 5.1% for example)–in the game mode this is the key choice of players).
8. No subsidy in the first step[1].

Next–STEP

1. Calculate Energy Intensity and population growth–based on the algorithm above and the previous GDP/Capita.
2. Calculate new population.
3. Calculate how much additional energy the increase in GDP will require based on the energy intensity.
4. Calculate the cost of the energy mix. This will change only in game mode, where individuals can alter the default values.
5. Calculate the carbon footprints and their cost.
6. If qualifies–calculate the subsidy based on the accumulation from the previous round. Add to GDP to cover expenses.
7. Calculate minimum consumption. If GDP + subsidy is not sufficient to cover everything, reduce savings first, then energy cost if necessary. This will result in a lower GDP growth rate.
8. Update world parameters, including fossil fuel reserves and fuel prices.

[1] Subsidy is calculated for countries that have less than average GDP/capita, with the most going to the poorest countries.

Figure 3. shows a typical student interface.

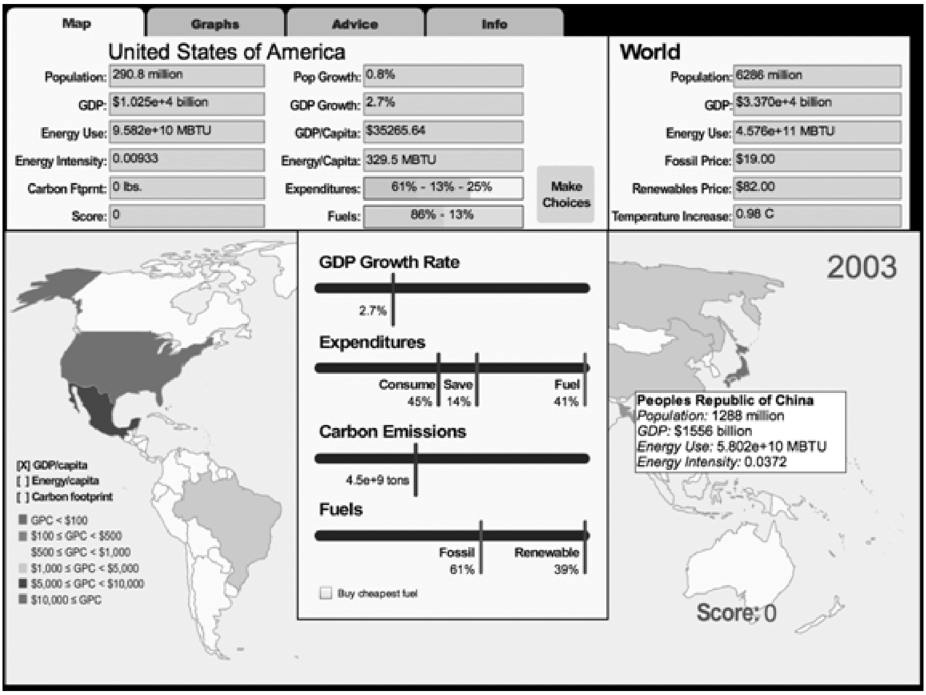

Figure 3: The Interface

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. We are now exploring two modes for the energy purchase: In the first mode, each country purchases the least expensive energy available, although we include a parameter that allows the simulation to reflect a conscious decision to use one over the other. The alternative mode runs employing the cap–and trade–system: We set caps for the total emission of CO_2. Present parameters require that developed countries cut present emission by 80% in 2050 and developing countries cut emissions by the same amount by 2080. Countries have to pay for the allocated emission units. Money from the cap goes to subsidize purchase of alternative energy sources by developing countries. 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. The global temperature rise was calculated based on the climate sensitivity parameter (temperature rise upon doubling the atmospheric concentration of CO_2 from the 280ppmv level) of 2.5^0C[4].

Figures 4 and 5 show snapshots from running IEC in a simulation mode in both energy purchase modes: figure 4 in the least expensive energy mode and figure 5 in the cap–and–trade mode. One can see that with the chosen parameters one can get rich with minimum of global impact.

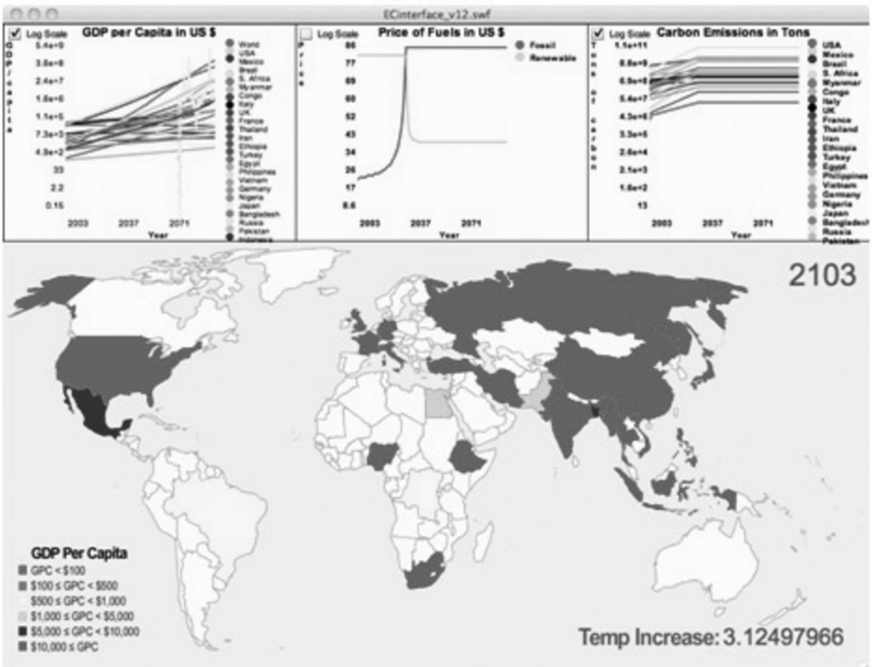

Figure 4: Snapshot of the IEC Simulation Based on Lowest Fuel Price Purchase

Figures 4 and 5 also show examples of the graphs we generated from running this simulation.

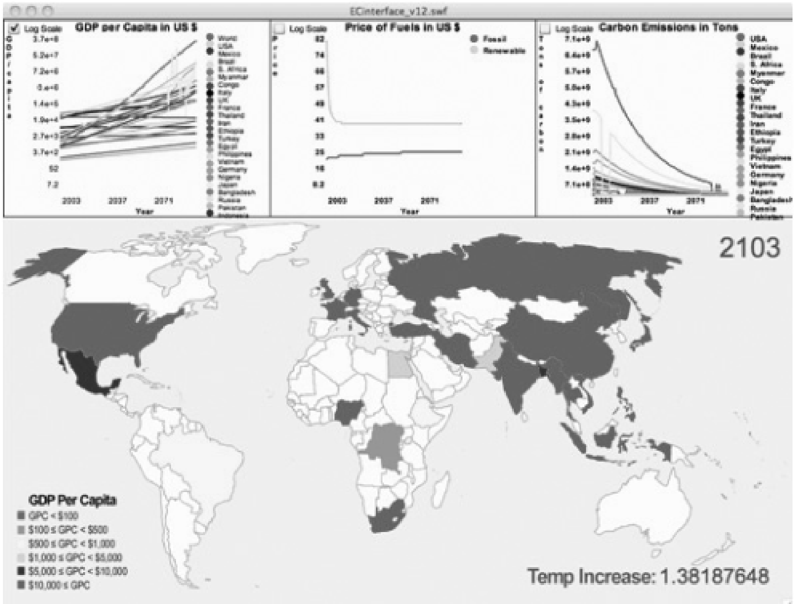

Figure 5: Snap of the IEC Simulation Based on Cap and Trade Restrictions

Continuing Efforts and Testing

Refinement of the IEC software is continuing. One obvious extension is to seperate the use of fossil fuels into the three major fuels that are in use (oil, gas, and coal) with their own price structure and carbon footprints. In addition, we have found to our amazement that there is no limit to greed. Countries can get very rich with a minimum of environmental consequences once they completely shift to alternative energy resources. We are exploring remedies to this through inclusion of a need for time and money to construct the infrastructure needed to expand availability of energy resources. The IEC 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. Our mechanism for cap–and–trade rectifies this situation to a certain degree. We are exploring additional mechanisms to achieve the same objective through attempts to lower energy intensity, which is balanced by the 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 planning to test the educational value of this simulation by incorporating the web–based multi–player game version into a general science curriculum for high school and undergraduate students. Students will have the opportunity to play the game several times over the course of the semester. We are currently working on ways of making the game more engaging–by increasing the choices available, level of player interaction, and feedback mechanisms–while maintaining the integrity of the data–based simulation.

Acknowledgements

This work is being supported by a seed grant from the Advanced Energy Research and Technology Center and by CUNY–PSC grants.

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