PEAK POPULATION:

TIMING AND INFLUENCES OF PEAK ENERGY ON THE WORLD AND THE UNITED STATES

A Thesis

by

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ABSTRACT

Peak energy is the notion that the world's total production of usable energy will reach a maximum value and then begin an inexorable decline. Ninety-two percent of the world's energy is currently derived from the non-renewable sources (oil, coal, natural gas and nuclear). As each of these non-renewable sources individually peaks in production, we can see total energy production peak. The human population is tightly correlated with global energy production, as agriculture and material possessions are energy intensive. It follows that peak energy should have a significant effect on world population. Using a set of mathematical models, including M King Hubbert's oil peak mathematics, we prepared three models. The first approached the peak energy and population problem from the point of view of a "black-box" homogeneous world. The second model divides the world into ten major regions to study the global heterogeneity of the peak energy and population question. Both of these models include various scenarios for how the world population will develop based on available energy and per capita consumption of that energy. The third model examines energy and climate change within the forty-eight contiguous American states in order to identify some of the "best" and some of the "worst" states in which to live in the year 2050.

The black box model indicates that peak energy will occur in 2026 at a maximum production of 104.1 billion barrels of oil equivalent (BBOE). Total energy production in 2011 was 92.78 BBOE. Three scenarios of different energy consumption rates suggest a peak world population occurring between 2026 and 2036, at 7.6-8.3 billion. The regional model indicates that even as each region protects its own energy resources, most of the world will reach peak energy by 2030, and world populations peak between 7.5 and 9 billion. A certain robustness in our conclusion is warranted as similar numbers were obtained via two separate approaches. The third model used several different parameters in order to ascertain that, in general, states that are projected to slow towards flat-line population growth and to become milder due to climate change such as Rhode Island, New York and Ohio are far more suitable with regard to an energy limited world than states that are projected to grow in population as well as become less mild due to climate change such as Texas, Arizona and Nevada.

Each of these models in its own way foreshadows necessary changes that the world will experience as the 21st century progresses. The economies of the world have been, and continue to be, built on energy. When energy production is unable to continue growing it must follow that economies will be unable to grow. As the world approaches and passes peak energy, the standard of living in the less developed areas of the world cannot improve without sacrifices being made in the developed world.

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Finally, thanks are in order for my family, specifically to my nephews Crossett, Aaron and Rowan, my sisters Jackie and Kristen and my mother and father.

NOMENCLATURE

BOE	Barrels of Oil Equivalent
BBOE	Billion Barrels of Oil Equivalent
EIA	US Energy Information Administration
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt-hour
MBOE	Million Barrels of Oil Equivalent
MPG	Miles per Gallon
MW	Megawatt
NOAA	National Oceanic and Atmospheric Administration
UN	The United Nations
URR	Ultimate Recoverable Resource
USCB	The United States Census Bureau

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

In 1972 Ludwig Von Bertalanffy synthesized the systems approach to science. The general systems theory presents two main hypotheses: First - any component of the observable world exists within a system of other components and that all disciplines are not only interrelated but necessary for complete understanding of the system and its components. Second - that there are underlying principles that can be universally or near universally applied to all systems. It is perhaps all too common for humans to create a false dichotomy that elevates civilization and our species above the laws of the natural world. This thesis is an attempt to reconcile that dichotomy in order to predict the fate of the human populations of the Earth in a post-peak energy world.

Humans are the only species on Earth that use energy for purposes outside of metabolic and reproductive functions (Burger et al., 2011). Doing so has allowed humans to expand in a manner similar to population overshoot that occurs when a new species is introduced into a habitat of abundance (Price 1995). The inevitable outcome of overshoots in the natural world is a population collapse when the once abundant resources have been consumed. Under the systems approach to science, this collapse should then be true for the human population if global energy resources are limited. Attempting to predict the future trajectory of human populations on Earth is not a new science. Cohen (1995) reviewed the history of estimates that have been made as to the human carrying capacity. The extremes of these estimates range over three orders of magnitude, from one billion up to one trillion. Few studies (e.g. DeLong et al., 2010) have incorporated energetic constraints into their population projections. We here submit population estimates that take these constraints into consideration. Using a systems approach and three mathematical models, we provide an estimate that suggests that excess energy production (fossil fuels as well as expanding renewable energy sources) and the rate at which said excess energy is consumed will ultimately determine the human population on Earth.

The United Nations (UN) and the United States Census Bureau (USCB) update their world population projections on a one-to-two year cycle. The latest update of the UN 2100 population projection was published in 2010 (United Nations, 2010) with estimates ranging from 6.2 to 15.8 billion. The USCB world 2050 population projection of 9.4 billion was released in 2009 (Ortman & Guarner, 2009). Furthermore, in 2003 the UN released population projections to 2300 ranging from 2.3 to 36.4 billion (United Nations, 2004).

These population projections are based on trends in fertility, mortality and life expectancy within what the UN describes as “more developed regions” and ‘’less developed regions.” In addition the UN includes two alternative fertility scenarios, one higher and one lower than the present trend in an attempt to provide a range of possibilities going forward. The high and low scenarios are arbitrarily designed to deviate by 0.5 children above or below the medium scenario fertility. The UN’s medium scenario and the USCB’s projection are currently the figures most widely used by the global media. Unfortunately, those projections are not based on the constraints of a resource-scarce world. The question that must be addressed in order to better predict human populations into the future is what forcing function(s) dictate fertility rates, mortality rates and life expectancy?

The first influential writing on the ideas of the limitations to agriculture, energy and population growth was the Reverend Thomas Malthus' *An Essay on the Principle of Population* (1798), in which he expressed concern over the fact that world population seemed to be growing exponentially while agricultural output was increasing only arithmetically. Though Malthus failed to account for the dramatic increase in available energy (fossil fuels had not begun to be heavily exploited for use in fertilizers during his lifetime), his mathematical notation of population growth and food supply remain relevant today.

William Stanley Jevons wrote The Coal Question in 1866. This was one of the first studies to examine a nation's dependence on a non-renewable resource (i.e. Great Britain's exploitation of coal). This book contains some of the earliest thoughts about the topics inherent to resource scarcity. It is important to note what has come to be known as Jevons' Paradox on efficiency and consumption. The paradox states that in theory, the more efficient and readily available a resource is, the more it will be exploited. As an example, consider fuel mileage in your personal vehicle. If a person's vehicle gets very low gas mileage, that person will be inclined to drive it less or will at least have a greater selectivity in the use of the vehicle. If this person trades in the vehicle for a high fuel mileage vehicle, the selectivity of the use decreases and additional use become justifiable. In this case, the increased use tends to offset the increased efficiency

(Figure 1). Thus conservation efforts will not lead to any significant delay in the timing of peak energy.

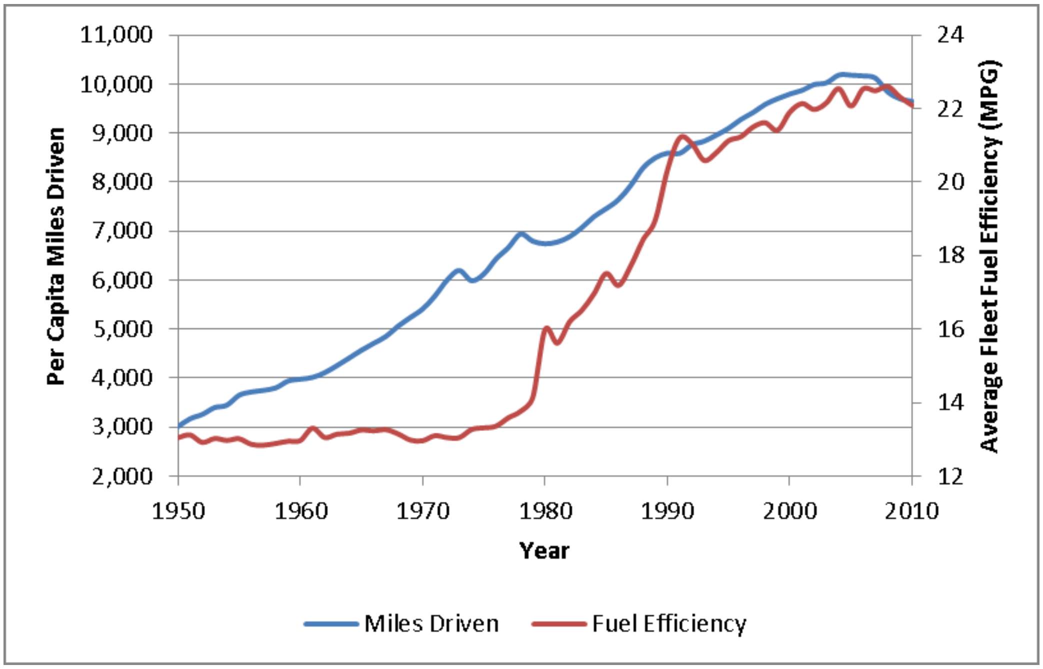

Figure 1: US per capita driving miles & average fleet fuel efficiency. 1950-2010. Sources – USCB (2010), Federal Highway Administration (2012) & Bureau of Transportation Statistics (2012)

By the time of the First World Power Conference held in London in 1924, scientific thinking of the time was beginning to link the ideas of Malthus and Jevons and relating population and economic power with fossil fuel exploitation. In *The Economics of World Power* (1924), Major-General Sir Philip AM Nash wrote, “Power has created in this country and in other industrial countries a capacity to produce in excess of actual requirements and this surplus…has made it possible for highly industrialized countries to support their present population.”

M King Hubbert's first paper relevant to this topic was published in 1949. The paper provides a brief synopsis of the history of non-renewable energy production. When combined with a look at population growth the paper suggests the ideas of limitations to the Earth. Hubbert (1949) includes a brief critique of the potential of renewable hydropower to sustain a modern world. Hubbert's 1956 paper investigated the limits to fossil fuel expansion into the future. This paper provided quantification of previously theorized limits to energy supplies. Hubbert (1956) believed that the nascent nuclear power sector of the 1950s would ultimately replace fossil fuels and that nuclear power would prove to be nearly limitless. His belief has remained, and will remain, unfulfilled.

A number of scientists, sociologists and others have attempted to expand Malthusian ideas to predict the future of world population, agricultural trends and resource scarcity. In 1968 Paul Ehrlich published The Population Bomb. The book, considered by some to be fear mongering (e.g. Rubin, 1994) and by others to be a dire warning (e.g. Kunstler, 2005), expressed concern over rapid population expansion. The book predicted massive food shortages that could result by the 1990s. Meadows et al. published The Limits to Growth in 1972, in which they used computer modeling to simulate scenarios of future population, resources, pollution and food production. Despite being criticized for being overly Malthusian in its approach at the time, and given the fact that world history has not unfolded as predicted, the use of modeling continues to be an essential practice in forecasting energy (e.g. Maggio & Cacciola, 2012) and population (e.g. United Nations 2010). Published in response to The Limits to

Growth, Cole et al. (1975) criticized the Malthusian approach taken by Meadows et al in their book Models of Doom. By examining several historical doomsday predictors including Malthus and Karl Marx, they concluded that The Limits to Growth was merely just another unfounded doomsday prediction.

In recent years, several papers have been published concerning the future of the human population. Lutz et al. (2001) sought to quantify the probability of global & regional peak population occurring during the 21st century. They estimated that there is an eighty percent chance that the world will reach peak population by the year 2100, though they did not explicitly factor energy production into their estimates. Hall and Day (2009) discussed the revitalization of interest in the topic of resource limitations after the oil boom of the late 1980s and 90s saw interest fade. Though global population was briefly discussed, their focus remained on peak oil and resource limitations. Boersema (2011) concluded that population will remain a key environmental issue until a sustainable population is achieved. Lutz and Samir (2010) provide a detailed summary and discussion (as well as a critique) of the most common population projections (UN, USCB etc.). Their conclusions suggest that there are additional demographic statistics (e.g. educational attainment) that should receive attention equal to age and gender distribution when projecting populations. Again, no explicit link with energy production was made.

Most recently, Maggio & Cacciola (2012) employed methods similar to those found in chapters II & III to predict the global peaking of oil, coal and natural gas in the 21st century. Their work on global fossil fuel peaks is an important intermediate step in linking the notions of peaking individual energy sources and a global peak population. Using similar methods (i.e. Maggio & Cacciola, 2012 and chapters II & III) and different data sets (EIA & BP respectively) both studies predict the peak of fossil fuels before 2050. By adding additional energy sources (nuclear, hydro, wind, solar etc.) we can predict global peak energy. It is after doing this that we can develop predictions about the peak in global population. World population is correlated to available energy (Figure 2). This correlation will be the focal point of the models found within this thesis. To the debate of future energy resources and world population we add our projection of the trajectory of global population to the end of the 21st century as a result of the peaking of world energy production.

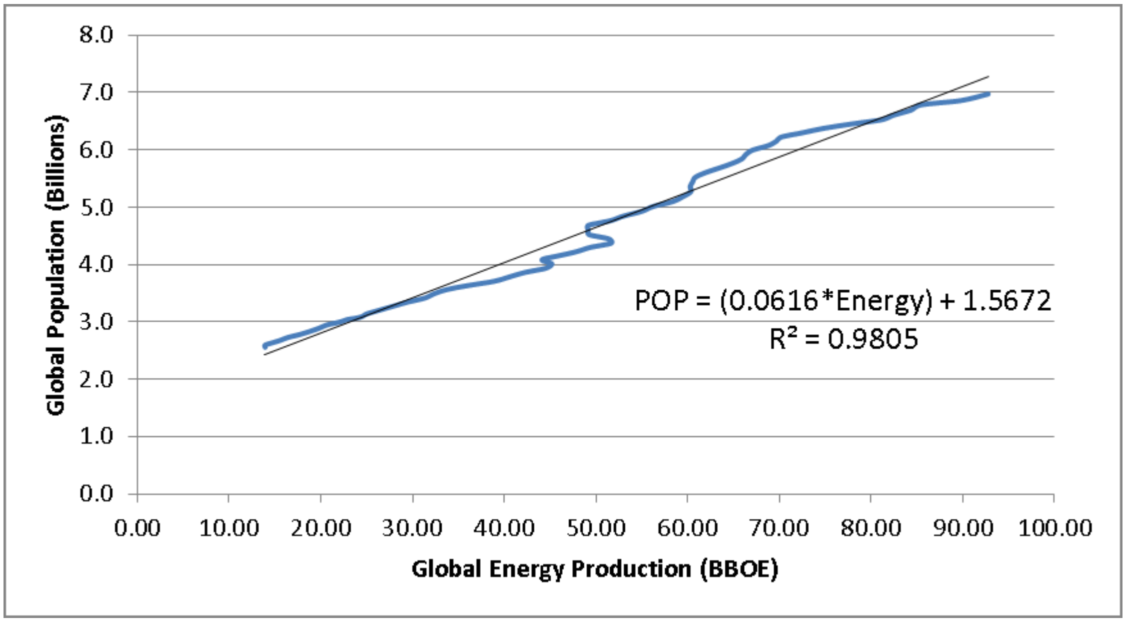

Figure 2: Correlation of global energy production and world population. 1950-2011.

CHAPTER II

THE BLACK BOX MODEL[1]

Background

M King Hubbert's (1956) original peak curve is an asymptotic cosine function (Equation 1) henceforth referred to as the logistic equation. The result is a bell-shaped normal distribution curve, "Hubbert's Peak" (Figure 3). The function uses the estimated value of the Ultimate Recoverable Resource (URR), historical production and (projected) maximum production. The URR is in effect the total exploitable quantity of a resource. It is assumed that when approximately one half of the URR has been extracted, the resource will peak in production. From this point on the production will begin an inexorable decline that approximately mirrors the pre-peak production increase rate. This creates a mirror-image normal distribution of production from discovery to depletion. The end result of Equation 1 is a year-by-year curve-fit of the production of the resource in question.

$$P(Y) = \frac{2 * (\mathrm{Pmax})}{1 + \mathrm{COSH}\,[\mathrm{b} * (\mathrm{Y} - \mathrm{Ypeak})]}$$

Equation 1: Hubbert's Equation. P equals production, Pmax equals the production at the peak year, Y equals the year, Ypeak equals the peak year and b is a coefficient equal to four times the maximum production divided by the URR

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[1] This chapter is to be submitted for publication under Jones & Warner. As such, the pronoun 'we' is used in place of 'I'.

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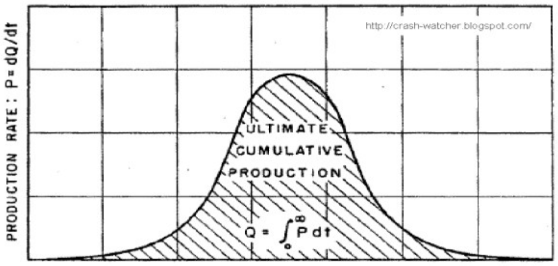

Figure 3: “Hubbert’s Peak”. From Hubbert 1956

While the validity of peak oil has been questioned (e.g. Huber & Mills, 2006), evidence of peaks can be found throughout the world. Figure 4 depicts examples of peak oil occurring in the United States (4a), peak coal in the United Kingdom (4b), and the uranium peak in France (4c). In addition to the historical production values, logistic fit curves have been superimposed. These figures provide evidence of production peaks that closely correlate to curves derived from the logistic equation. These are just a few examples of thousands of oil fields, coal mines, natural gas wells and uranium deposits around the world that have peaked and have closely followed the logistic curve in terms of their production history.

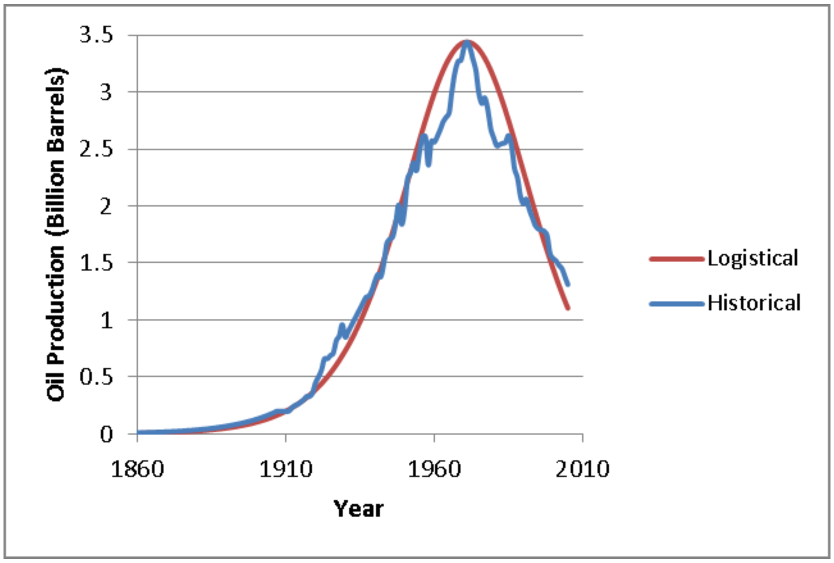

Figure 4a: Peak oil in the United States. Historical production source, BP (2009)

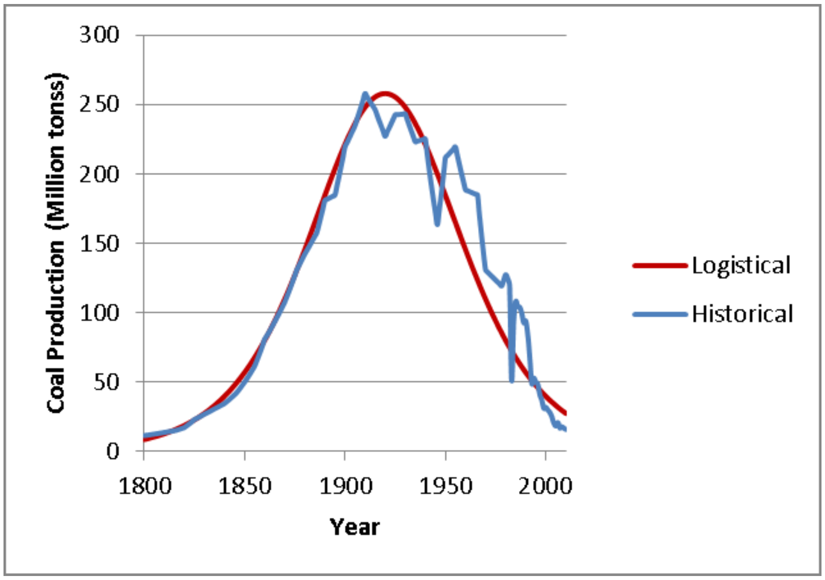

Figure 4b: Peak coal in the United Kingdom. Historical production source, Höök et al., 2010

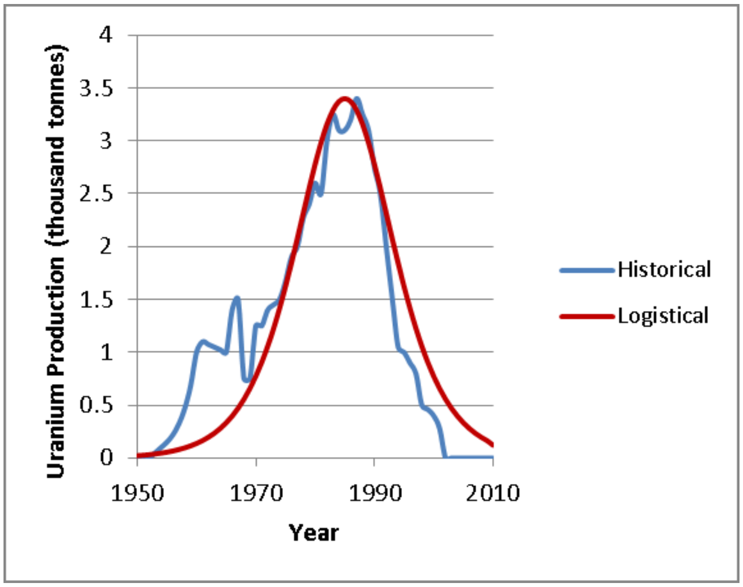

Figure 4c: Peak uranium in France. Historical production source, Zittel & Schindler, 2006

In seeking the date of global peak energy, we used historical and forward-looking data from a range of industry sources (BP 2009, BP 2011, Höök et al., 2010, World Nuclear Association 2009, Bodansky 1980) to build a model of oil, coal, natural gas, nuclear, hydropower and the other renewables (wind, solar etc.) production from the year 1800-2010 (Figure 5a). Each energy source production value was converted into barrels of oil equivalent using the conversion factors found in table 1. The model also accumulated the production of these six resources each year to provide the global total (Figure 5b). In order to determine the peak year for each energy source, we plotted historical production values and extrapolated production trends to the point at which approximately half of the URR value is reached. After we determined the peak year, peak production value and URR, we created a logistic curve of production using Equation 1. Our model includes peaks for the renewable resources as well, based on the assumption that while wind and solar energy are essentially limitless, the technology to capture the energy from these resources is not. The necessary materials cannot currently be efficiently constructed and maintained without non-renewable energy inputs (e.g. metallurgical coal for the energy needed to produce the high-quality glass required for solar panels (Meijer et al., 2003) and the blades for wind turbines (Kubiszewski et al., 2010)).

Table 1: Energy equivalence conversion factors. Note that production values for coal, nuclear, hydro and other renewables was provided in tonnes of oil equivalent. Source – BP (2011)

Production Unit	**Barrels of Oil Equivalent**
1 Tonne of Oil	7.33
1000 Cubic Meters of Natural Gas	6.6
1 US Gallon	0.0238
1 Megawatt-Hour of Electricity	0.61
1 Tonne of Coal	3.75

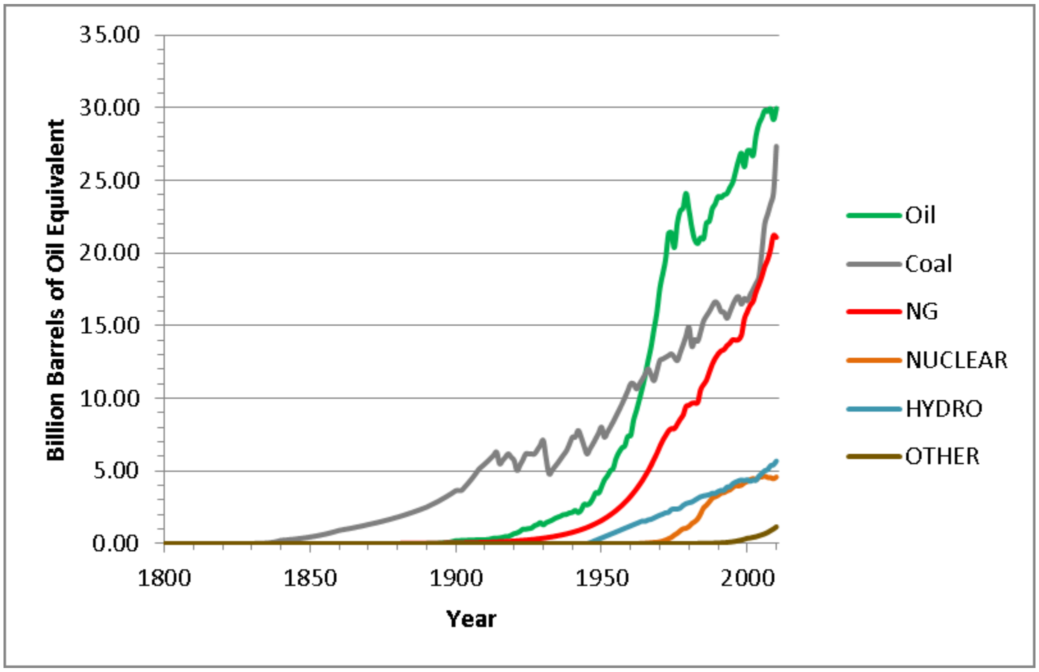

Figure 5a: Historical global energy production. 1800-2010

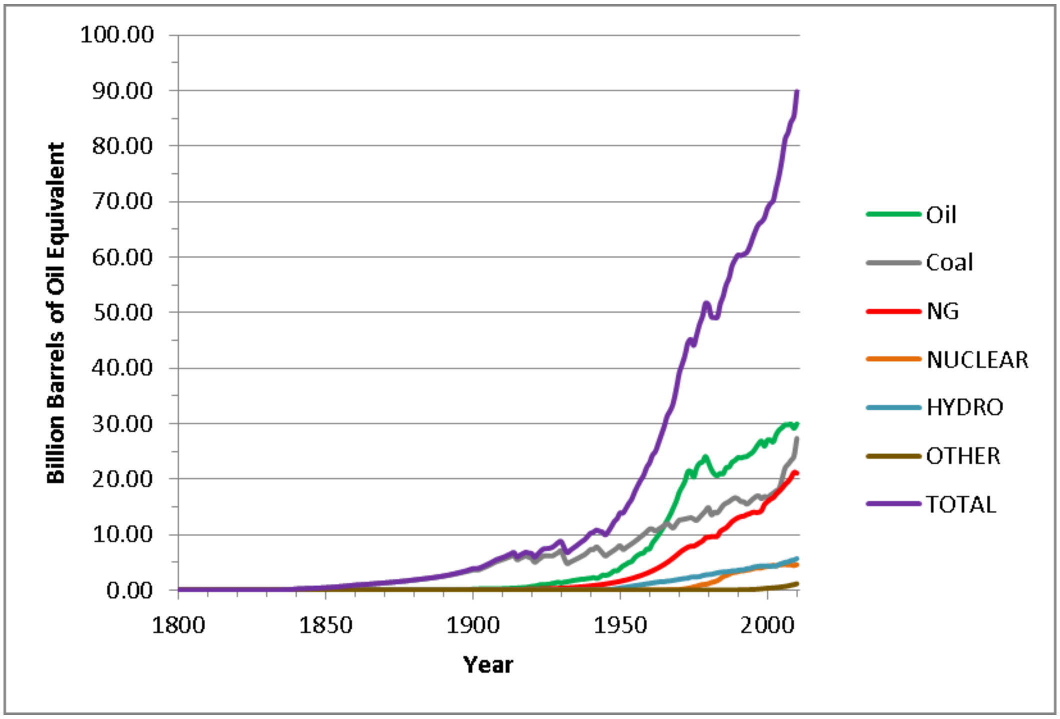

Figure 5b: Global energy production, including cumulative total. 1800-2010

We now turn to the population aspect of our energy-based model. Figure 6 depicts the historical world population (McEvedy & Jones, 1978 and the United States Census Bureau, 2010). as well as the three scenarios derived by the UN's fertility-based model.

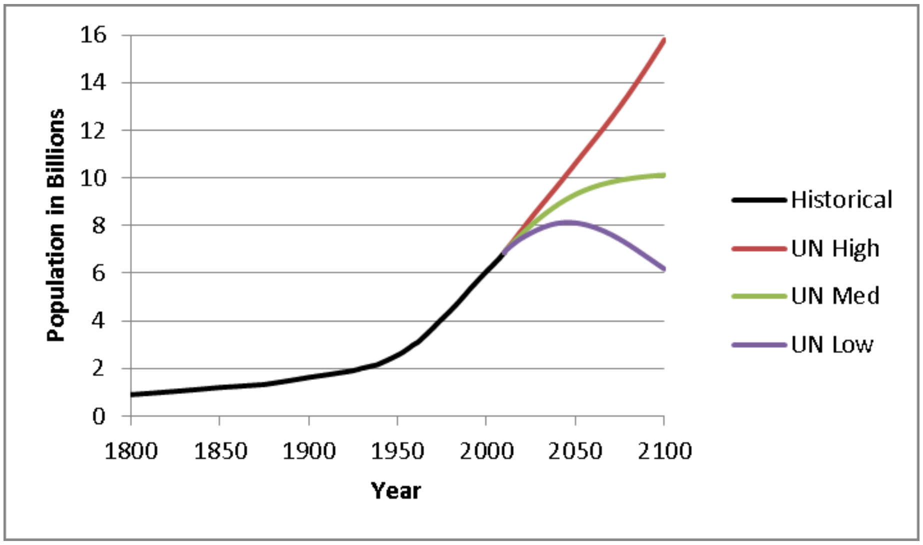

Figure 6: Historical global population and UN scenarios. 1900-2100. Sources – McEvedy & Jones (1978), USCB (2010) & UN (2010)

Using the historical energy production (Figure 5b) and historical population (Figure 6), we were able to derive global-scale historical per capita energy consumption (Figure 7). From the year 1900 until the end of the Second World War, global per capita energy consumption remained relatively steady at about 4 BOE/person. The same can be said of the time from about 1970 to the present, when per capita energy consumption was about 11 BOE/person. The twenty-five years between World War II and the 1970s included a dramatic rise in per capita energy consumption. The global average per capita energy consumption more than doubled in that time period (from 4.2 BOE/person in 1945 to 10.5 in 1970). This growth in energy consumption was influenced by the post-World War II Keynesian economic revolution as described in Fletcher (1989). Seifritz and Hodgkin (1991) determined that dramatic increases in global per capita energy consumption have occurred cyclically since the industrial revolution and predicted that another doubling may occur by the middle of the 21st century. We do not feel that their optimistic prediction is either feasible, or possible to achieve in a resource-limited world.

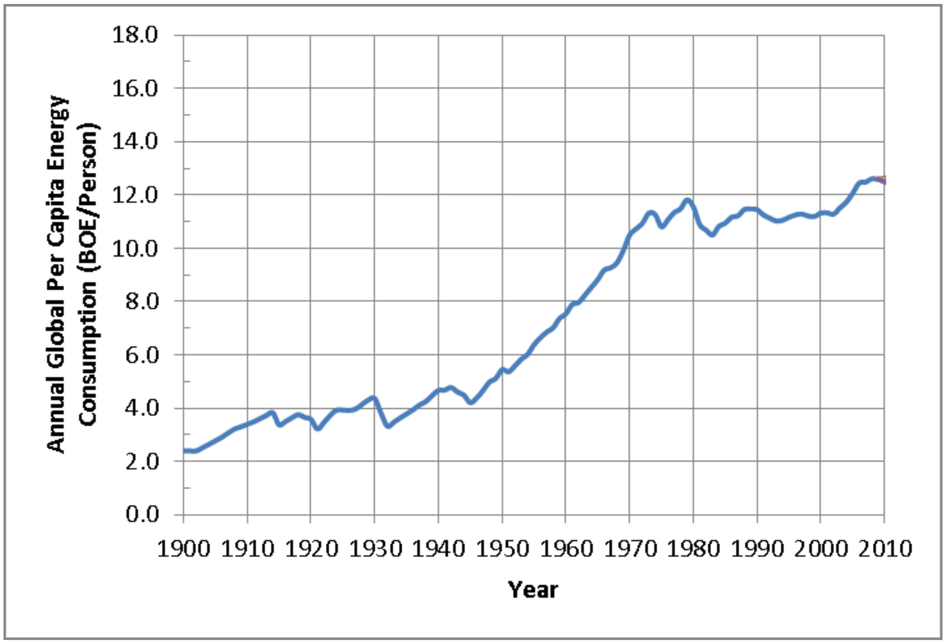

Figure 7: Global per capita energy consumption. 1900-2010. All sources of energy converted to barrels of oil equivalent. Note three phases of energy consumption: 1900-1945 relative flatline; 1945-1970 rapid growth; 1970-Present relative flatline

Model Assumptions

Our global peak energy model is subject to five main assumptions. First, that the peak of any non-renewable resource will occur at or around one half of the estimated URR and the decay in yearly production values after the peak will follow a logistic decay curve. We made this assumption based on Hubbert (1956) (Figure 2), the analysis of the logistic curve found in Höök et al. (2010), as well as the examples of empirical evidence shown in Figures 3a-3c. Second, that the energy that each of these sources provides is interchangeable with any of the others at 100% efficiency and that the energy will be allocated as needed, regardless of political borders. This assumption is not realistic; however, it is used in order to provide an optimistic bound on the use of global energy. Third, that infrastructure capability constraints will cap the maximum production of coal. For a detailed discussion of this assumption, see Höök et al. (2010). Fourth, in light of peaking resources, we assume that the lowered production of a peaked resource will be compensated by the increased exploitation of the next most abundant resources (e.g. the peaking of oil production increases the production of coal and natural gas at an accelerated rate). This assumption reflects the neoclassical economic theory of perfect substitution. Fifth, that the peaking of the non-renewable energy sources will mark the inflection point in the growth of the renewable sources. That is, peak non-renewable energy production will mark the significant escalation of renewable energy production. The renewables production is modeled on a logistic curve; however, the model does not include a decline after the peaking of renewables in 2082, but rather assumes an upper asymptote. This assumption sets a reasonable bound for the other renewable energy sources and replacement/maintenance energy costs in light of the fossil fuel limitations discussed earlier.

In predicting future population we created three scenarios. The first is a status quo model that assumes a "business as usual" approach. This scenario is reasonable because it assumes that per capita energy consumption will follow the general trend set forth since 1970. Our second scenario assumes that global per capita energy use remains forever at the 2009 level. Our third scenario involves a global reduction of per capita energy consumption to one-half of the 2010 level by 2100. We calculated that in 2010, the per capita energy consumption in the United States was 54 barrels of oil equivalent (BOE) per person, China averaged 13 BOE/person, 3 in India, and the global average was 13.

Given such disparity in per capita energy consumption, scenario three could unfold as either a result of global cooperation or a return to the Age of Empires. In the former interpretation, the world works together, recognizes the global threat of energy limitations, and sets the goal of limiting consumption per person. The latter interpretation is one that suggests that the most powerful nations of the world, in an effort to maintain high energy consumption potential for their citizens, use military power to seize remaining reserves. Historical examples of the possibilities of the third scenario include Japan before World War II, North Korea after the Cold War and Cuba after the Soviet oil cutoff (Friedrichs, 2010). Figure 8 and Table 2 represent our three scenarios of per capita energy consumption out to 2100.

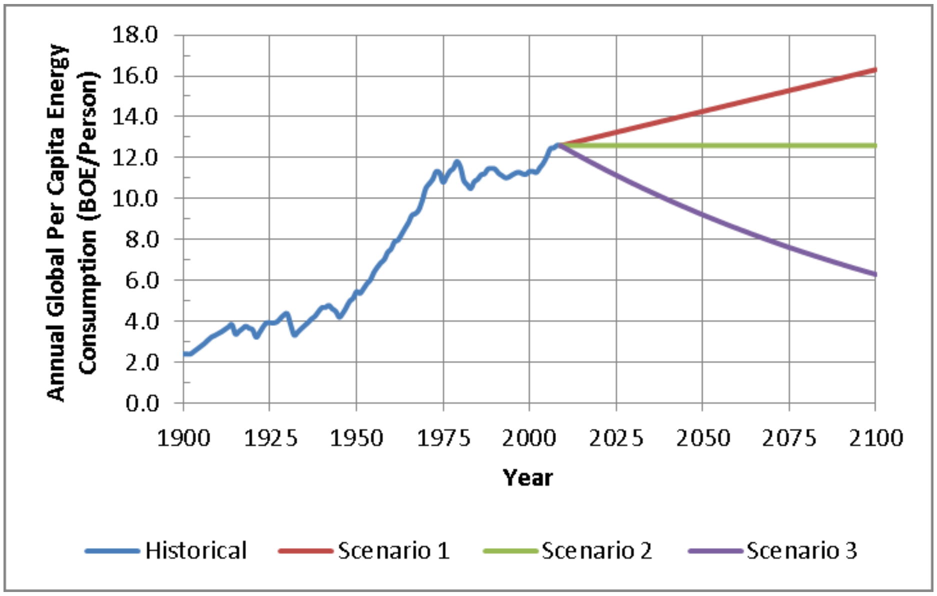

Figure 8: Energy consumption scenarios. 2010-2100. Scenario 1 – Status quo consumption. Scenario 2 – 2010 constant consumption. Scenario 3 – ½ global average consumption by 2100

Table 2: Black box model per capita energy consumption scenarios.

Scenario	Description
1 - Status Quo Consumption	Global average per capita consumption continues along the trend set forth since 1970, exceeding 16 BOE/person by 2100
2 - 2010 Constant Consumption	Global average per capita energy consumption remains constant at the 2010 level (13.1 BOE/person)
3 - 1/2 Global Avg. consumption by 2100	Global Average per capita energy consumption falls to 1/2 of the 2010 level by 2100 (6.5 BOE/person)

Model Results

Our model results indicate that the production of the world's major energy sources will peak within the next twenty years (Table 3 & Figure 9). The results of our model are used as the drivers for the population section of the black box model. As such, these results are independent of the energy use scenarios. We used the energy production numbers for each year, 2011-2050, and the per capita energy demand from each scenario to derive the population that the energy production could support. For example, the model predicts that in the year 2050, 86.58 billion barrels of oil equivalent energy will be produced. The per capita energy demand in population scenario two is 12.82 BOE/person. Therefore the world energy production can support approximately 6.8 billion people. While the likelihood of major discoveries is decreasing, this model assumes only what is considered to be economically viable at present. It is possible that presently unfeasible resources may in the future become available via technological advances. As such, the black box model represents a low-end estimate of future recoverable resources.

Table 3: Black box model results. All production figures in billion barrels of oil equivalent. All population figures in billions.

Energy Resource	2010 Production	Peak Production	Peak Year
Oil	29.96	31.25	2013
Coal	27.35	29.88	2044
Natural Gas	21.08	29.83	2026
Nuclear/Uranium	4.59	6.49	2044
Hydro	5.69	7.04	2026
Other Renewables	1.16	15.14	2082
Total Global Energy Production	89.93	*104.05*	*2026*
Population Scenario	**2010 Population**	**Peak Population**	**Peak Year**
1 - Status Quo	6.86	7.58	2026
2 - 2009 Consumption Constant	6.86	7.83	2026
3 - 1/2 Consumption rate by 2100	6.86	8.83	2036

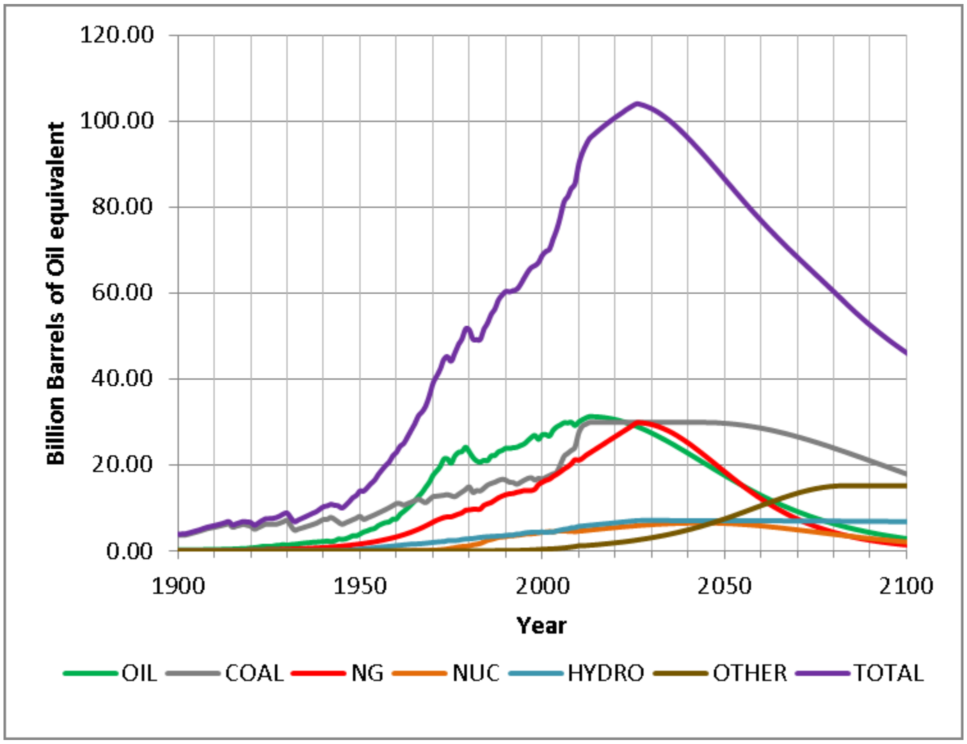

Figure 9: Global energy production by resource. 1900-2100.

OTHER refers to renewable energy sources i.e. wind, solar, biofuels etc.

Hirsch et al. (2005) and Davis et al. (2010) suggest that the infrastructure momentum of our current fossil-fuel-based society will require twenty to forty years to transition to a more sustainable energy grid. Under this assumption, a plan starting, even unrealistically, as early as 2012 in the United States would not be ready until 2032-52. Given the results of the model it is clear that most of the non-renewable energy sources will have peaked before this realization can be made.

Global population surpassed seven billion in 2012 (Goodkind, 2011). The medium scenario in the UN's fertility-based population model suggests that global population will peak and stabilize around ten billion by the year 2100 (United Nations, 2010). In contrast, our energy-based model suggests that the global population will peak at 7.6 to 8.8 billion between 2026 and 2036, shortly after Peak Energy occurs (Figure 10a). This population (7.6 to 8.8 billion) is in close agreement with the United Nations population estimates for the years 2020-2030 (7.5 to 8.8 billion); however, figure 10b depicts the sharp discrepancy between the UN fertility-based medium population scenario and the three energy-based black box model population projections beyond 2030 to 2100. In order for the world population to follow the UN medium population scenario, world energy demand would have to be in excess of what is projected to be possible via the black box model. In fact we calculate that the energy demand for the year 2100 would need to be 145.3 BBOE in order to meet the UN medium population number. This is 40% higher than the black box model peak energy value of 104.1 BBOE in the year 2026.

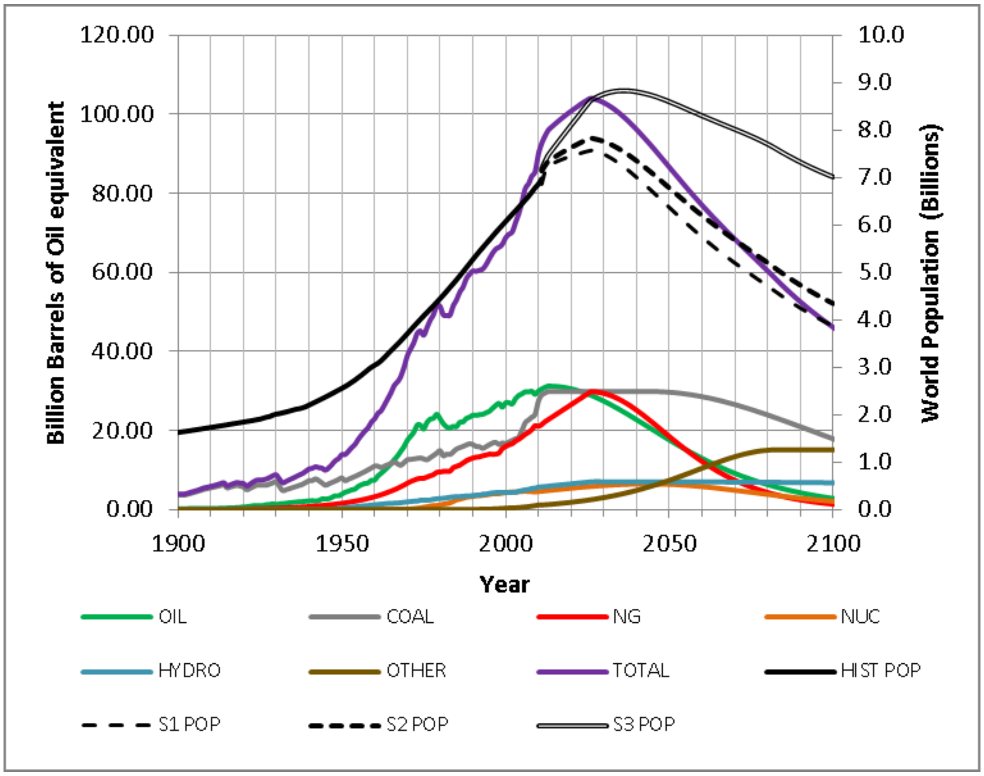

Figure 10a: Results of the black box model, population and energy. 1900-2050.

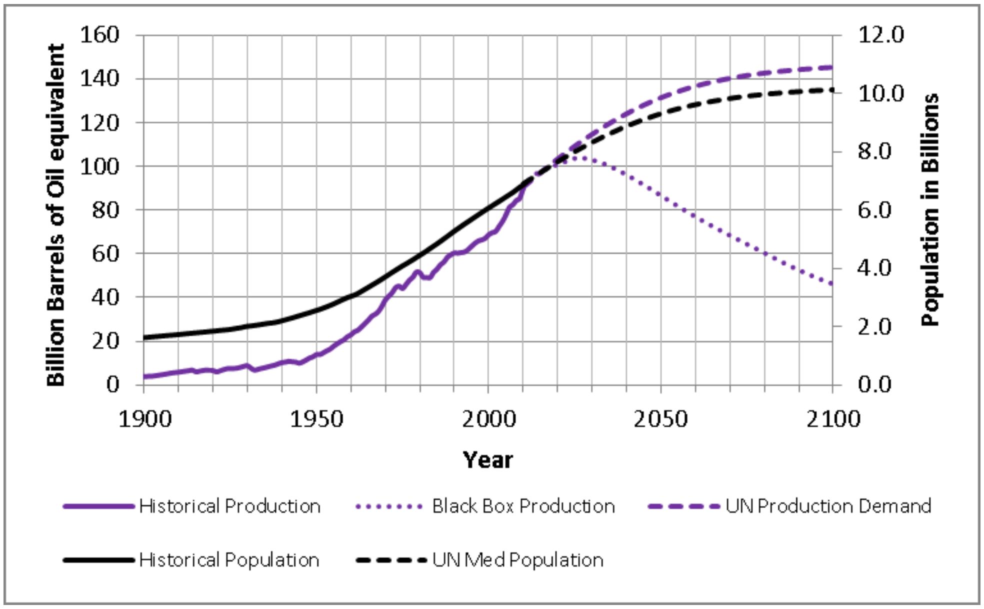

Figure 10b: Black box model and UN medium scenario energy demand discrepancy.

Given the projected trajectory of the non-renewable energy sources (oil, coal, natural gas and nuclear) as well as hydropower, our model predicts that the other renewables (e.g. biofuels, solar and wind) would have to be scaled-up from 1.16 BBOE in 2010 to 114.3 BBOE by the year 2100 in order to reach the UN medium population projection of 10.1 billion. In this scenario we assume that 1/3 of this 114.3 BBOE (38.1) is contributed each from wind power, solar power and biofuels. In the case of wind power, a 5MW wind turbine operating at 20% efficiency (Kubiszewski et al., 2010) produces approximately 5,000 BOE in one year. The world's largest solar farm (Solar Energy Generating Systems in the Mojave Desert, USA) has a capacity of 354 MW and operates at 25% efficiency (NextEra Energy) to produce about 62,000 BOE per square kilometer. One acre of algae biomass produces approximately 3300 gallons of fuel (~100 BOE) on average (Chisti, 2008). This converts to approximately 25,000 BOE per square kilometer.

To provide 38.1 BBOE of wind power at today's efficiency will require over 7.5 million 5MW equivalent wind turbines. Providing 38.1 BBOE of solar power at today's efficiency will require over 612,000 square kilometers of solar panels. This is an area comparable to the state of Texas. Providing 38.1 BBOE of biomass fuels from algae at today's efficiency will require over 1.5 million square kilometers (roughly the land area of Alaska) of ponds.

As of 2011 the global installed wind power capacity (Observ'ER, 2011) is equivalent to about 47,000 5MW wind turbines. To reach 38.1 BBOE would require a 160-fold increase in wind turbine capacity from the 2011 installed capacity (an annualized net-growth rate of 6%). The global installed solar panel capacity (European Photovoltaic Industry Association, 2012) was equivalent to about 840 square kilometers of Solar Energy Generating Systems equivalent solar panels (the Solar Energy Generating Systems solar farm is 6.5 square kilometers). To reach 38.1 BBOE would require a 700-fold increase in solar panel area from the 2011 installed capacity (a net-growth rate of 8% annualized). Algae biofuels production remains in the testing phase (commercial production is essentially zero) (Chisti, 2008). As such roughly 17,000 square kilometers (about 3.5 times the size of the Great Salt Lake in Utah) of algae ponds will have to be created in each of the next 90 years.

On paper any form of scaling up is simply a matter of numbers. In reality it would be a monumental task to develop these energy sources to provide for 10.1 billion people in 2100. If this is to be achieved, governments need to start vigorous renewable programs now while there is still the dense energy available from the non-renewables to build out the renewable technology. The scaled-up other renewables production as presented in the black box model (Figure 9) is more feasible. The other renewables are scaled-up to produce approximately 15.1 BBOE, or ~5 BBOE each, in the black box model.

To provide 5 BBOE of wind power at today's efficiency would require about one million 5MW equivalent wind turbines (approximately a 21-fold increase from today's total). The solar power demand at today's efficiency would require 80,000 square kilometers of solar panels (about a 92-fold increase from current installed capacity). This is an area comparable to the state of South Carolina. Providing 5 BBOE of biomass fuels from algae at today's efficiency will require over 200,000 square kilometers (roughly the land area of Nebraska) of ponds. Under this assumption of renewable energy growth, the three energy consumption scenarios in this model project world population to be 3.8 to 7.0 billion in the year 2100.

Our model post-peak energy world population declines at an annualized rate of 0.67% in scenario one, 0.60% in scenario two and 0.32% in scenario three rather than stabilizing at the peak population value. The only "agreement" between our energy-based model and the UN fertility-based model is in their low fertility scenario (the only UN scenario in which birth rates are lower than the current average) and our scenario three (in which the global average per capita energy consumption is halved). In the UN low fertility scenario world population peaks at 8.13 million in 2046 and declines at a rate of 0.45% annually out to 2100. In our third scenario population rises throughout the first part of the 21st century, peaks at 8.8 billion in 2036 and declines to approximately 7 billion by 2100 (a population equivalent to the global population in 2012). In all other scenarios, our energy-based population projections are significantly lower than those projected by the UN model.

Our model projects a long-term decline in world population lasting 60+ years. Zhang et al. (2011) reviewed records of historical plagues, wars and famines. During such times, nations have experienced long-term population declines at rates similar to those projected by our energy-based model. For example, Clark (2007) estimates the population of England was six million in 1316, and that by 1450 the prolonged effects of the Black Death and subsequent minor plagues had lowered the population to two million. During that 134 year interval, the population declined at a rate of 0.50% annually. As a result of the Great Famine in Ireland, famine, disease and emigration resulted in a population drop from approximately 8.2 million in 1849 to about 4.1 million in 1930 (Vaughn, 1978). During that eighty-one year timespan the population of Ireland declined at a rate of 0.62% annually. In 1989 the population of the Ukraine was approximately 51.5 million (Epiphany, 1999). The 2012 mid-year estimate of the population of the Ukraine provided by the CIA World Factbook (2012) is approximately 44.9 million. Over the last twenty-three years, declining fertility has caused the population of the Ukraine to decline at 0.56% annually.

In conclusion, we believe that the post-peak energy world beyond 2026-36 will lead to the inevitable decline of the human population towards a sustainable maximum, declining to between 3.5 and 7 billion by 2100. This decline will mark the beginning of the end of the Anthropocene Epoch as defined by Steffen et al. (2007). Our study is one of the first to link the 21st century trajectories of energy production and human populations. Given the results presented here, we believe the United States must immediately begin a major effort to transition from non-renewable energy sources and seek out a more sustainable population and lifestyle. Even if initiated immediately, there will still be major global economic and social disruptions. We now turn from a global black-box view of the world to a regional model of world energy and population in order to examine how different populations of the world may be affected by peak energy.

CHAPTER III

THE REGIONAL MODEL[2]

Background

World population exceeded seven billion in 2012 (Goodkind, 2011), global production of oil may have already peaked (Murray & King, 2012), and total energy production is projected to peak by 2030 (Chapter II). Despite the tight correlation between energy production and population (Figure 2), the UN medium growth scenario projects a world population of over ten billion by 2100, whereas the black box model (Chapter II) projects a population of 3.5 to 7 billion by 2100. We now divide the world into ten regions in order to better understand how global energy trends could affect these regions. Figure 11 is a map of our global regions based largely on British Petroleum's energy regions (BP, 2011).

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[2] This chapter is to be submitted for publication under Warner & Jones. As such, the pronoun 'we' is used in place of 'I'.

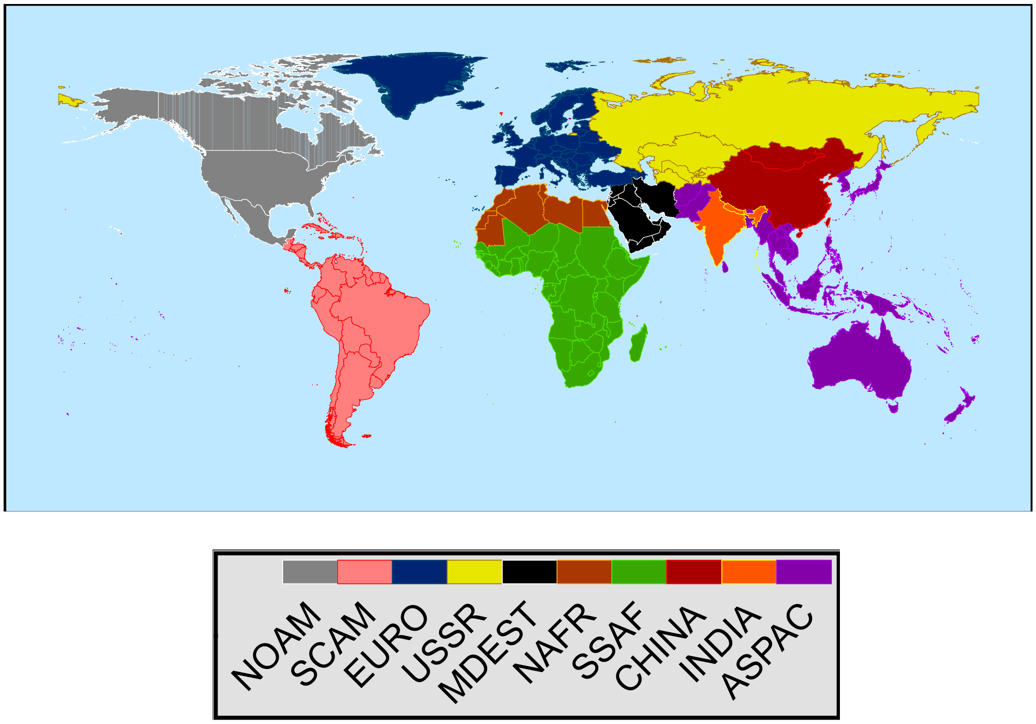

Figure 11: The ten energy and population regions used in this study.

By fitting the Hubbert logistic curve (Figure 2) to each regional non-renewable (oil, coal, natural gas and uranium) and renewable (hydro, solar, wind, biofuels etc.) energy sources, we modeled when peak energy will occur in each of these regions. As in our black box study, the regional model includes peaks or asymptotes for both the renewable and the non-renewable resources because we hypothesize that while wind and solar energy are essentially limitless, the technology to capture the energy from these resources is not.

To determine "winners" and "losers" in the year 2100, our model ranks each region of the world by percent population change from 2010 as well as percent change in per capita energy availability. The model output represents the percent change in each region's population as well as the percent change in per capita energy use from 2010 to 2100 on a logarithmic scale (Figure 12). Each region in 2010 is located at (0,0). Shifts left and right from this position represent decreasing (left) or increasing (right) energy use and shifts up and down represent population growth (up) or decline (down). The definition of "winner" or "loser" is subject to interpretation. Some view continuous population growth and energy consumption as desirable (e.g. Simon, 1981), whereas others view limiting growth and consumption as a better approach for the future (e.g. Davis, 1973). There is no right or wrong answer and it is not the charge of this thesis to place value judgments.

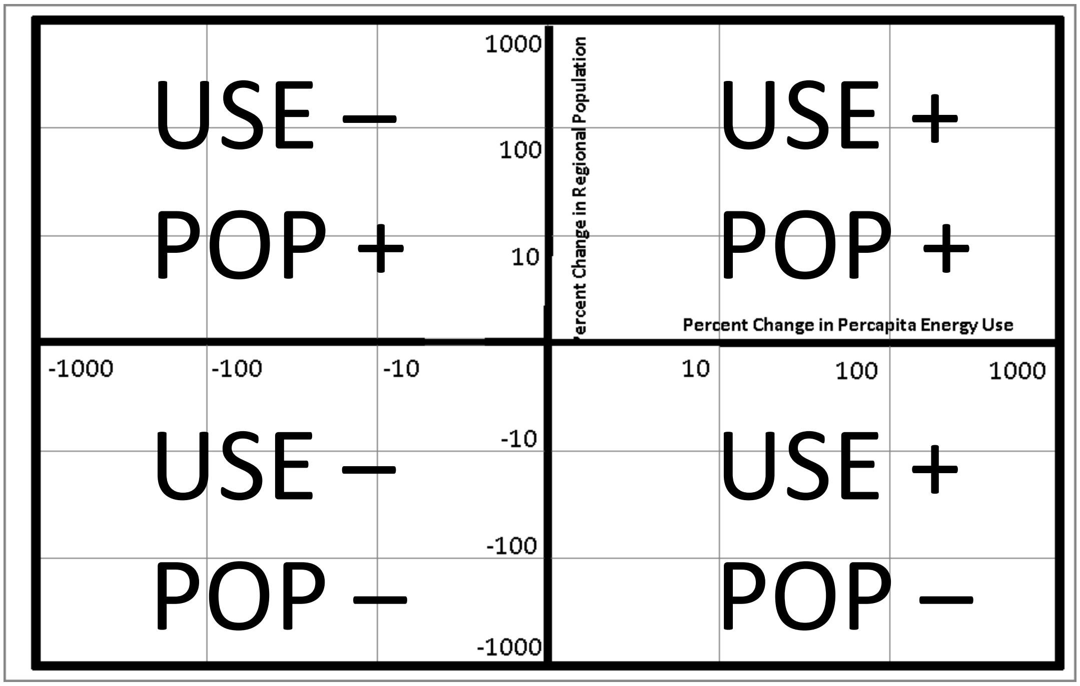

Figure 12: Regional model quad. Each quadrant represents a region's change in energy use (USE) and population (POP) from 2010 to 2100 on a logarithmic scale.

Model Assumptions

In seeking the peak of each resource and indeed the overall peak energy date for each region, we used historical and projected data from BP (2011) and Höök et al. (2010) to build a model that includes the six major energy sources for each region in a similar manner to, and using the same sources as, the black box model. Oil, coal, natural gas, nuclear, hydropower and the renewables were once again modeled from the year 1900-2010 (Figure 13a). The model also accumulated the production of all six sources from each region for each year to provide the global total (Figure 13b). In keeping with the other renewable energy source assumption from Chapter II (15.1 BBOE asymptote), renewable energy is divided proportionately to each region's contribution to global renewable energy production in 2010.

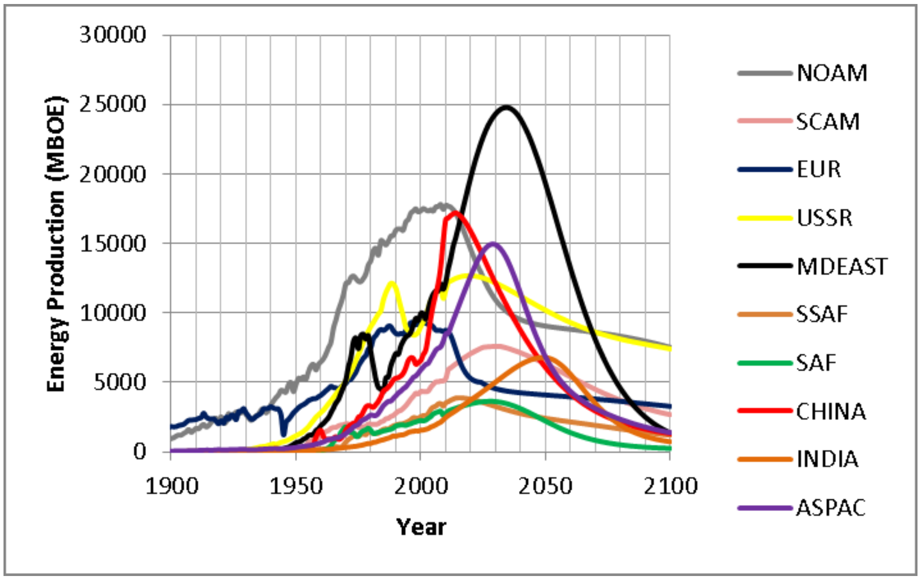

Figure 13a: Total energy production by region. 1900-2100.

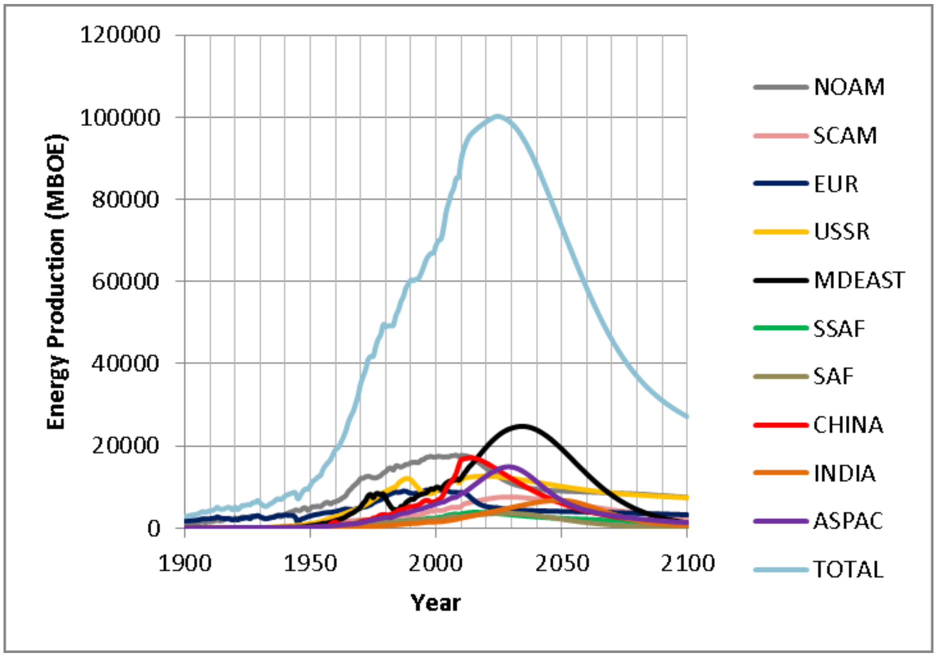

Figure 13b: Cumulative regional energy production. 1900-2100.

It is important to note that in the context of this model there is no trading of energy resources between regions. Each region is restricted to **only** the resources within their borders. There are no imports or exports of energy resources after 2010. This assumption (albeit unrealistic) is made because the goal of the model is to ascertain the sustainability of each region in a world in which the trade of energy may be limited. To this effect, the term per capita energy consumption is assumed to be equal to per capita energy production. In other words, it is assumed that every BOE produced in a region is used only in that region.

In predicting future regional populations we first established a historical database of each region's population (McEvedy & Jones 1978 & The World Bank 2011). Next, we created three potential future scenarios. Our first two population scenarios are the same as the population scenarios in the black box model, where in the first per capita energy consumption follows the region's trend over the last twenty years and in the second scenario the per capita energy consumption remains constant at that region's 2010 value. In the case of the third scenario, regions below the global 2010 per capita consumption average of 13 BOE/person were elevated to this level by 2100. Regions above the global average had their averages halved by 2100 (to a minimum per capita consumption of 13 barrels). For example, in 2010 the former Soviet Union averaged 58 BOE/person, so by the year 2100 the average declines to 29 BOE/person. In contrast, India averaged 2 BOE/person in 2010, so by the year 2100 the average rises to 13 BOE/person. Wolfram et al. (2012) examined the trends and EIA projections in energy consumption within the developed and the developing world. They suggest that the major growth in energy demand in the 21st century will result from the developing world initially accessing energy-consuming devices such as automobiles and basic appliances. A summary of each scenario can be found in Table 4.

Table 4: Regional model per capita energy consumption scenarios.

Scenario	**Description**
1 - Status Quo Consumption	Regional average per capita consumption continues along the trend set forth since 1990
2 - 2010 Constant Consumption	Regional average per capita energy consumption remains constant at the respective 2010 level
3 – 13 BOE/person consumption	Regions averaging below 13 BOE/person climb to 13 BOE/person by 2100. Regions averaging above 13 BOE/person have the average cut in 1/2 by 2100 (to a minimum of 13 BOE/person)

Model Results

Six of the regions reach peak energy by 2030. Our regional model suggests that the global population will peak at 7.5 to 8.8 billion (Table 5). Our post-peak populations decline at rates again that are not anomalous within historical records of population decline (Chapter II). Both the peak populations and the 2100 world populations in each scenario were similar to the respective scenarios in the black box model (Chapter II). This result lends a degree of robustness to each model and serves to increase our confidence in the results. The global peak energy curve is skewed in this model due to the assumptative restriction on exportation of resources. The former Soviet Union republics for example could support a population significantly larger than present due to their abundant energy resources and relatively small per capita energy consumption. It is important to note that Europe and China (and North America in scenarios 1 & 2) cannot support their respective 2010 populations with “domestic” energy resources. Therefore these regions are currently obligate energy importers in order to sustain their current populations. For example, in 2010 China imported 1.72 billion barrels of crude oil and the United States imported 3.34 billion barrels of crude oil (BP 2011).

Table 5: Regional model results. All population figures in millions. Note that the populations that peak in 2010 have not peaked in reality due to energy imports not available in this model. An asterisk denotes that the region's population does not peak within the timescale of the model. As such, the 2100 population is presented

Region	**Peak Energy Year**	**2010 Population**	**Peak Population - Year**			**2100 Population**
			Scenario 1	***Scenario 2***	***Scenario 3***	
N. America	2010	468.0	819.5 – 2100*	468.0 - 2010	488.7 - 2014	201.9 - 1140.2
S. & C. America	2030	480.9	562.7 – 2025	625.3 - 2032	721.4 - 2033	221.0 - 417.3
Europe	2001	693.3	892.4 – 2100*	693.3 - 2010	693.3 -2010	530.6 - 782.4
Former USSR	2019	201.6	204.3 – 2013	207.2 - 2019	1268.8 - 2100*	169.2 - 1268.8
Middle East	2034	166.2	304.8 – 2033	329.8 - 2034	753.1 - 2047	15.8 - 172.2
N. Africa	2028	839.8	245.4 – 2025	263.5 - 2028	312.2 - 2032	22.2 - 39.1
Sub-Saharan Africa	2015	205.5	914.3 – 2016	908.0 - 2015	898.4 - 2015	280.4 - 387.1
China	2014	1338.3	1338.3 – 2010	1338.3 - 2010	1391.3 - 2016	847.4 - 858.2
India	2049	1200.2	2143.0 – 2047	2478.2 - 2049	1996.1 - 2045	562.2 - 651.4
Asia Pacific	2029	1265.9	1679.2 – 2028	1852.7 - 2029	2010.0 - 2030	565.6 - 712.7
Total	2025	6859.7	7469.6 – 2027	7824.2 – 2032	8729.0 - 2034	4175.1 - 6310.0

Typically, peak energy and peak population in each scenario occur within a few years of each other. Differences emerge because this model is not explicitly driven by energy production, but rather populations are more influenced by the individual per capita consumption rates. The greatest differences in peak energy date and peak population date are found in scenario three within the regions with the highest 2010 per capita energy consumption. The dramatic cuts in consumption allow for the offsetting of peak populations in these regions. Table 6 compares the black box model (Chapter II) population scenario results with those from the regional model.

Table 6: Comparison of black box model and regional model population results.

All population figures in billions.

Model	Scenario 1			Scenario 2			Scenario 3		
	Peak Population	**Peak Year**	**2100 Population**	**Peak Population**	**Peak Year**	**2100 Population**	**Peak Population**	**Peak Year**	**2100 Population**
Black Box	7.58	2026	3.84	7.83	2026	4.34	8.83	2036	7.0
Regional	7.47	2027	4.57	7.82	2032	4.18	8.73	2034	6.31

Populations cannot continue their current growth patterns in a resource-limited world. Note that in Figure 14, no region is able to increase both its population and its per capita energy consumption. We have chosen not to explicitly label "winners" and "losers". There are competing theories about population growth and development (energy consumption) and it is open to the interpretation of individuals to determine whether or not a particular region is "moving in the right direction" according to the model. That said, in 2010 the renewables accounted for only 1.3% of total global energy production. This increases to 7.6% with the inclusion of hydropower. These renewables (including hydropower) would have to be scaled up over 1100% to cover the 2010 production of fossil fuels. This is an annualized increase of 12.7% for 90 years. Renewable energy (including hydropower) would have to be scaled-up 100-fold to support a global population of 10.1 billion in the year 2100. Without significant changes made by the developed regions of the world, less developed regions of the world will not have an opportunity to "live the American way." The "American way" is energy intensive and includes luxuries such as car ownership, suburban stand-alone housing, an omnivorous diet, personal computers, iPods etc.

Published in 1974, Garrett Hardin’s *Lifeboat Ethics: The case against helping the poor* imagined the world as a metaphoric lifeboat. Within the lifeboat could be fifty people (the developed nations). There is room in the boat for ten more people. With hundreds of other people swimming around the boat (the less developed nations), those in the boat are faced with a dilemma. If everyone is allowed into the boat it will be overcapacity and everyone starves. If the additional capacity is filled, then two more dilemmas arise. First, who is chosen? Second, if the boat is at maximum capacity then there is no built-in safety against famine or disease. To survive, the members of the lifeboat must be willing to allow the others to suffer and die. In the end Hardin argues that greed will have to prevail if the boat is to remain floating and populated.

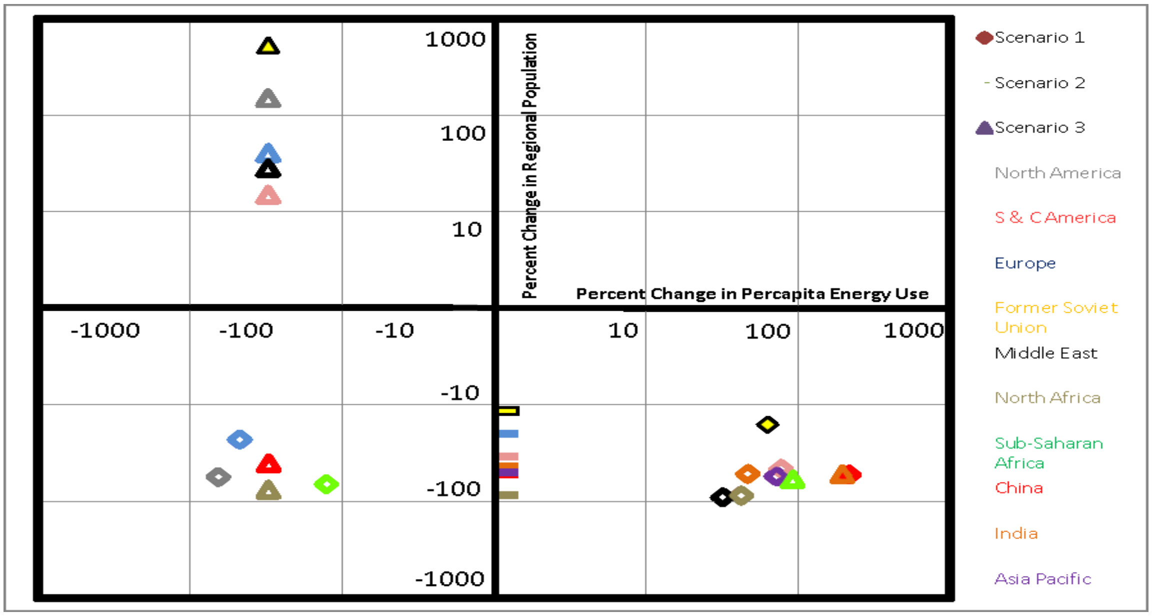

Figure 14: Graphical representation of percent change in each region’s population. 2010 to 2100, and the percent change in per capita energy use for each

Each of the regions in this model could be considered as an individual lifeboat. Each region's total energy URR determines the size/capacity of each lifeboat. The swimmers outside of each lifeboat represent potential future population additions to each region. Depending on how the resources in each boat are utilized (per capita energy consumption), more or less people can occupy the boat. Eventually the regions with higher consumption rates, such as North America, will have to kick people out of the lifeboat in order to maintain the average lifestyle (scenarios 1 & 2). In a region that is resource rich and has a near zero growth population (no regions have a historically declining population), such as the former Soviet Union (2010 population – 201.6 million), could support a population of over one billion people (not accounting for anything other than energy sustenance); however, this population number from scenario three requires a drastic cut in per capita energy consumption from 58 BOE/person to 29 BOE/person. This is still approximately double the 2010 global average. Figure 15 displays the results from the three black box scenarios as well as the three regional scenarios. The regional model scenario three population explodes towards the latter half of the 21st century due to the excessive (and unlikely) cuts in per capita consumption, primarily in the former Soviet Union and North America (from about 37 BOE/person to 18.5 BOE/person).

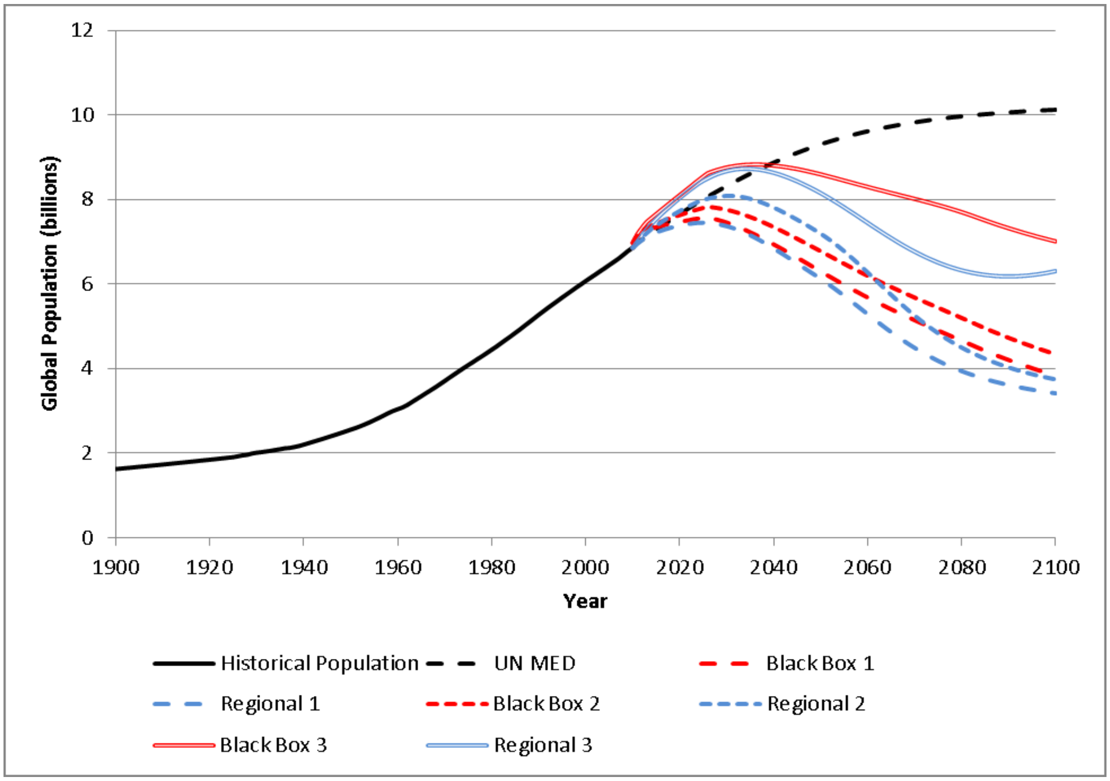

Figure 15: Black box and regional population projections. 2010-2100.

The black box model (Chapter II) assumes that energy production is distributed where it is needed regardless of borders. In contrast, the regional model restricts energy production and consumption only to within the region. Despite the difference in assumptions, the populations projected in both the black box and the regional models are similar. The difference between the models lies in determining where the global population is distributed. We now further focus our study to the effects of resource scarcity on the United States.

CHAPTER IV

THE 48 STATES MODEL[3]

Background

As the United States has experienced droughts and record temperatures in the summers of 2011-12, the climate change (and perhaps the buzzword "global warming") question is becoming increasingly difficult to ignore. There have been dozens of articles, op-eds and blogs about climate change in the New York Times within the last year (www.nytimes.com). One particular op-ed, entitled "We're All Climate-Change Idiots" lists several problems innate to the human condition that prevent action on climate change (Gardiner, 2012). An example of this is North Carolina House Bill 819 which prevents state scientists from using any predictions of accelerated sea level rise in the 21st century until 2016 (General Assembly of North Carolina House Bill 819 §2b, 2011). Climate change combined with energy scarcity will affect the United States. Therefore the question can be asked, which states in the US are most prepared for/immune to these changes? To anticipate "winners" and "losers" in the year 2050, the 48 states model was developed that takes into account each state's energy production and population projections in order to determine state-by-state as well as national energy demand for the year 2050. As opposed to the regional model (Chapter III), our 48 states model can anticipate "winners" and "losers" based on criteria such as economic impact and change

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[3] This chapter is to be submitted for publication under Warner, Jones & Condon. As such, the pronoun 'we' is used in place of 'I'.

in energy demand. By any standards it is apparent and perhaps self-serving that states with both lower populations and per capita energy demands would be better off in a nation with lowered energy availability. Second, the model uses climate change projections from the Intergovernmental Panel on Climate Change (IPCC) for each state (IPCC, 2007) to determine the change in energy demand in 2050 based on changes in heating and cooling degree days. Third, given average miles driven per capita in each state, the model determines the required national average fuel efficiency given the effects of peak oil as discussed in chapter II. There are multiple criteria that determine each state's long-term viability. Among these will be population change, energy demand, demand per capita, climate change effects, etc. Alaska and Hawai'i are not included in the model because the data from these two states varies significantly in quantity as well as quality when compared to the contiguous forty-eight states.

Model Assumptions

Our first assumption in the 48 states model is that each state's population will follow the United States Census Bureau projections from 2010-2030, and that said trend can be extrapolated out to 2050. The USCB has made state-by-state projections for 2020 and 2030, as well as a national population projection for the year 2050. Our model incorporates the USCB state-by-state projections and extrapolates each state's population out to 2050. This assumption is reasonable because the sum of each state's 2050 population in our model (423 million) is within the range of the USCB national projections for 2050 (423 to 458 million). The second assumption is that energy available in each state is proportionate to its share of the 2010 US energy production in to maintain the 2010 per capita energy consumption. Though clearly unreasonable, this assumption is intended to determine the necessity, not the feasibility of energy production for each state. The third assumption is that by extrapolating state populations, we can forecast the energy production necessary in each state for the year 2050 in order to keep the per capita consumption (an indirect measure of quality of life) at the 2010 level. Although the previous forty-five years have seen an increase in per capita energy consumption in the United States from 48 BOE/person in 1965 to 54 BOE/person in 2010 (and we have no reason to believe that it will not continue to increase), we use the 2010 value for 2050. This allows our model to provide an estimate of 2050 demands under the assumption that the average American will consume at least as much energy in 2050 as was average in 2010.

The second goal of this model requires the assumption that the current National Oceanographic and Atmospheric Administration (NOAA) definition of heating and cooling degree days (NOAA, 2012) remains the same in 2050 as it is in 2010. That is, the ideal temperature is 65^{o}F. For each degree above this ideal figure, a cooling degree day is added and for each degree below the ideal figure, a heating degree day is added (NOAA, 2012). For example if the average temperature in July 2010 is 87^{o}F, then thirty-one days multiplied by 22 degrees is a total of 682 cooling degree days in the month of July. Likewise if the average temperature in January 2010 is 32^{o}F, then thirty-one days multiplied by 33 degrees is a total of 1023 heating degree days in the month of January.

In order for us to determine how climate change will affect individuals, we also had to assume that the price of electricity per kWh in 2010 would remain the same in 2050.

Our next assumption is that the IPCC climate scenarios for 2050 (Solomon et al., 2007) are adequate and that combining the climate change scenarios with each state's 2010 heating and cooling degree data (NOAA, 2012), we can project each state's 2050 heating and cooling degree day totals. In addition we assume that the only change to the 2010 per capita average monthly electricity bill in the US will be the electricity used for heating and cooling. This assumption was made in order to isolate the effect of potential climate change on the average American's wallet.

The final goal of our 48 states model was inspired by President Barack Obama's mandate that all new model passenger vehicles in the United States will need to achieve a fuel efficiency of 54.5 miles per gallon by the year 2025 (The White House, 2012). We used the US Department of Transportation's statistics for each state's per capita miles driven in 2005 (Bureau of Transportation Statistics, 2011) and the average vehicle fuel efficiency in 2005 (Bureau of Transportation Statistics, 2012) in order to determine total gallons of gasoline consumed in each state. We assume, based on the black box model, oil consumption in 2025 will be almost equal to the 2005 value (29.30 billion barrels in 2005 & 29.26 billion barrels in 2025) and in 2050 oil production will be 53% of the 2005 value. This section of the 48 states model determines the necessary vehicle fleet fuel efficiency under the assumption that population increases as per the USCB and oil supply decreases per the black box model. The 48 states model also proceeds under the assumption that each state's per capita driving mileage does not change. In essence, given increased population and decreased oil supply, will President Obama's goal of 54.5 MPG by 2025 be sufficient if the average person drives the same amount in 2005, 2025 & 2050?

Model Results

The 2010 US population (contiguous 48 states only) was 307 million. Our state-by-state prediction is that the US population will grow to 423 million in the lower 48 states by 2050. This figure is comparable with projections made by the USCB (Figure 16). Solely as a function of population growth, our model predicts that US energy consumption will increase 38% from 2010-50. Eight states (NY, CT, WV, WY, PA, OH, OK & IA) are projected to see a decrease in total energy consumption by 2050 (average of 5% decrease). This is because the populations in these states are trending towards a future plateau or decline (Figure 17a). Similar figures for non-plateau states Texas and California can be found in Figure 17b for comparison. Nevada, Arizona and Florida are projected to more than double in energy demand (average of 130% increase).

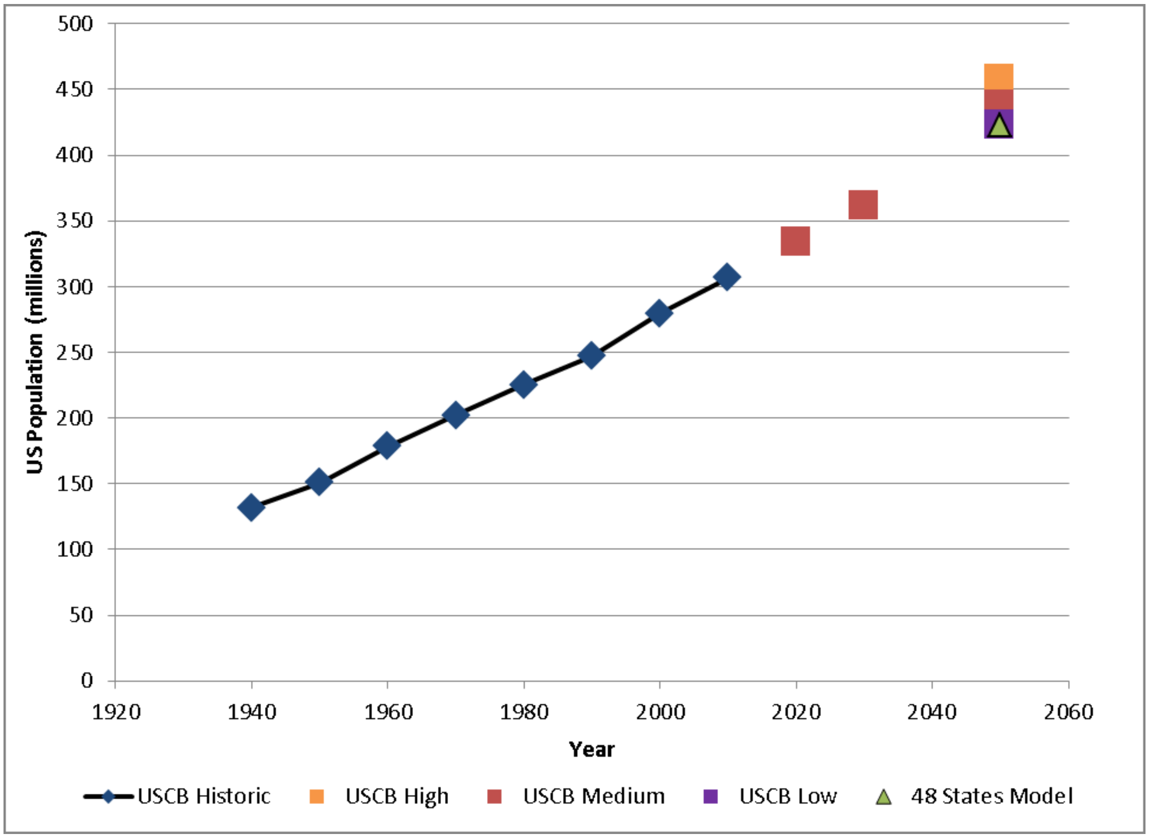
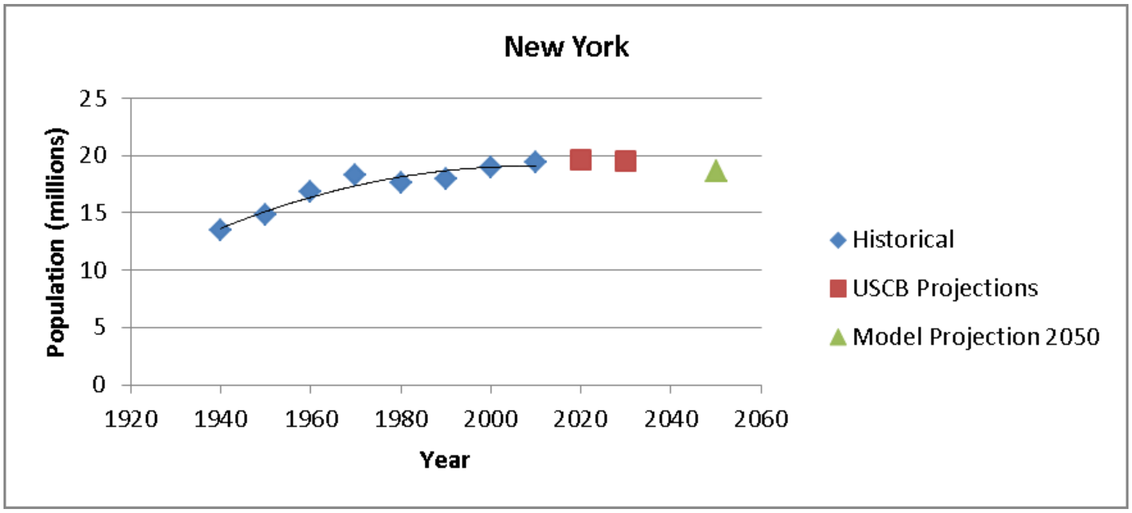


Figure 16: US population (1940-2010) and projections (2010-2050). Includes USCB & 48 States model. The USCB does not provide high or low estimates for 2020 & 2030. As such, the medium estimate is provided for these dates



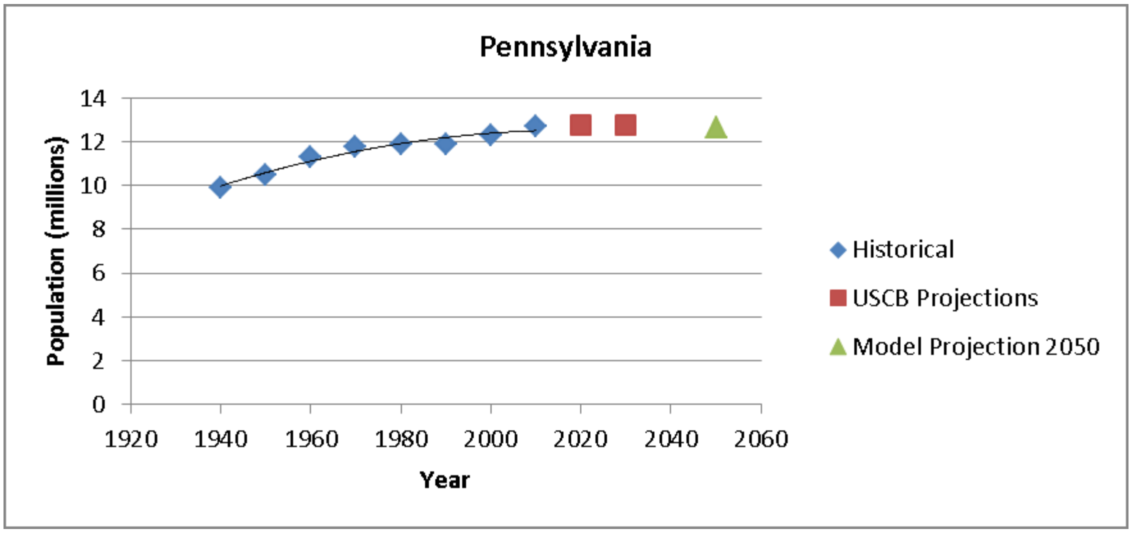


Figure 17a: Historical and projected population examples of “plateau” states.

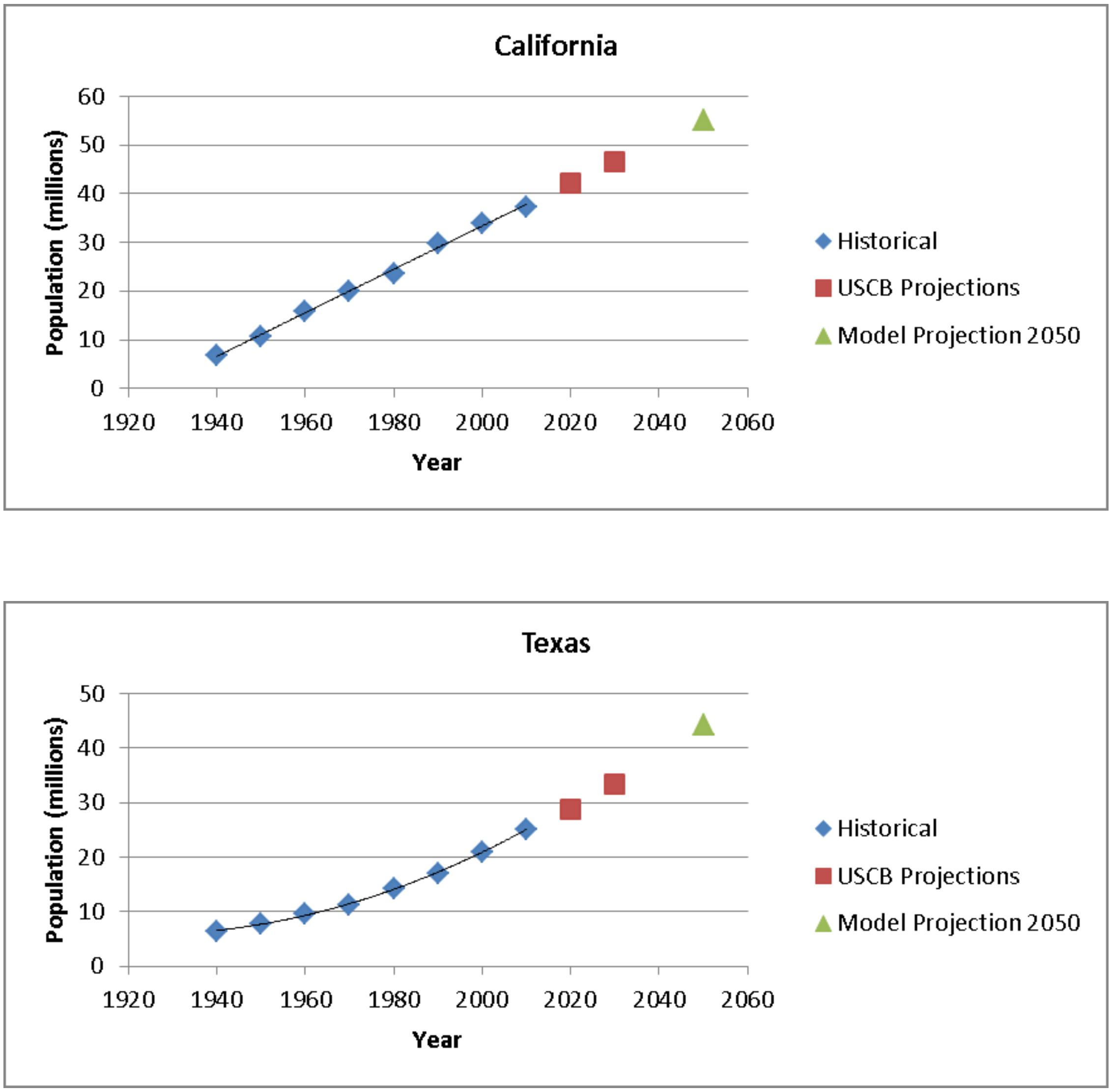


Figure 17b: Historical and projected population examples of "non-plateau" states.

The model predicts a 28% drop in the number of heating degree days in year 2050. The US average heating degree day requires 1.02 kWh of energy at an average cost of \$0.097 per kWh (approximately \$0.10 a day for each degree below 65^{o}F) (NOAA, 2012). The model predicts a 76% rise in the number of cooling degree days in the year 2050. The US average cooling degree day requires 6.02 kWh of energy again at an average cost of $0.097 cents per kWh (approximately $0.58 a day for each degree above 65°F) (NOAA, 2012). When worked out to per capita monthly energy bill effects, the average American could spend as much as an additional $75 (real dollars, inflation adjusted to 2010) a month (Figure 18). This $75 is figured using the 2010 kWh pricing and does not include price changes due to inflation or any of the energy supply issues discussed in chapters II & III.

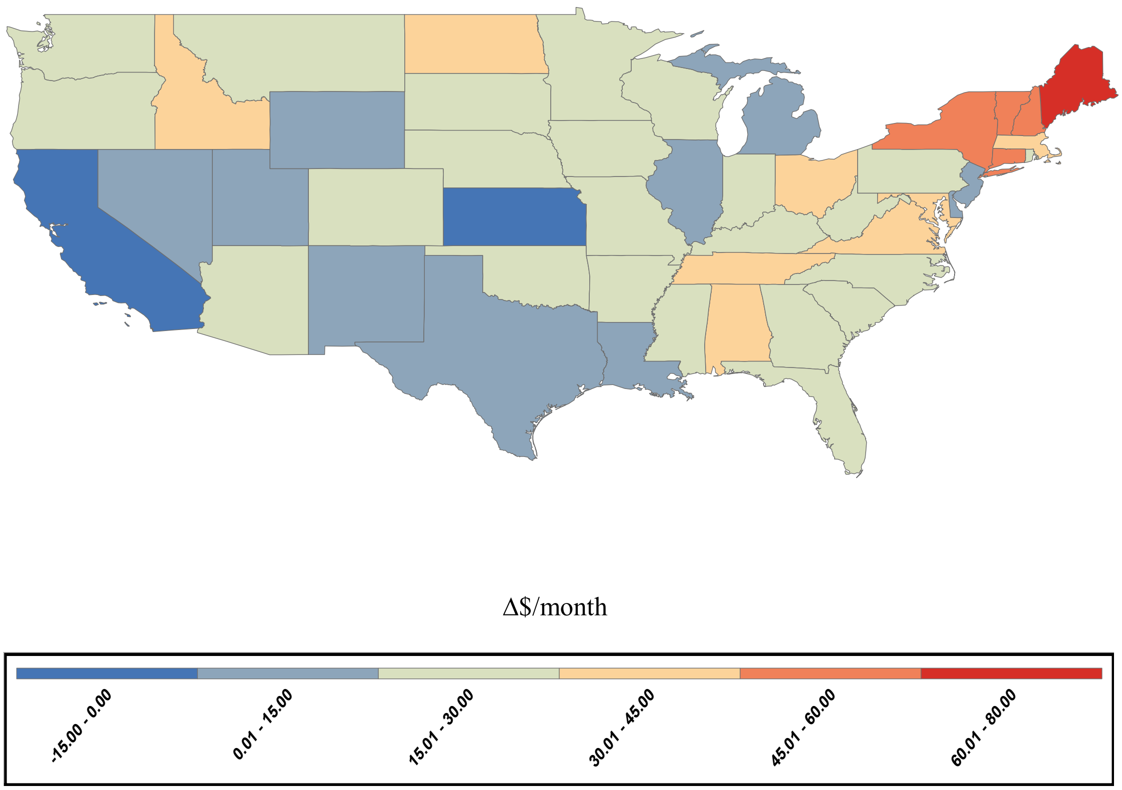


Figure 18: Change in monthly electricity bill with respect to climate change. 2010-2050.

In order for each American to drive the same number of miles in 2050 as each drove in 2005 the American vehicle fleet will need an average of 53 MPG (assuming the oil results from chapter II). When population increase is compounded into these numbers, the American fleet will require MPGs of 27.8 by 2016, 32.3 by 2030 and 73.0 by 2050. President Obama's call for 54.5 MPG would be sufficient for the year 2035. The President's call would also be sufficient for the year 2050 if there was no population change in the contiguous states. However, Figure 19 depicts the Corporate Average Fuel Economy (CAFE) standards for new vehicle MPG in the United States and the actual fleet average MPG from 1980-2005 (Bureau of Transportation Statistics, 2012). There is promise that new vehicles will be able to meet President Obama's goal; however, given the average 9.7 year lifespan of passenger cars and light trucks in the US (Davis et al., 2010), the new vehicle efficiency and the overall fleet average efficiency will likely take more time to reconcile.

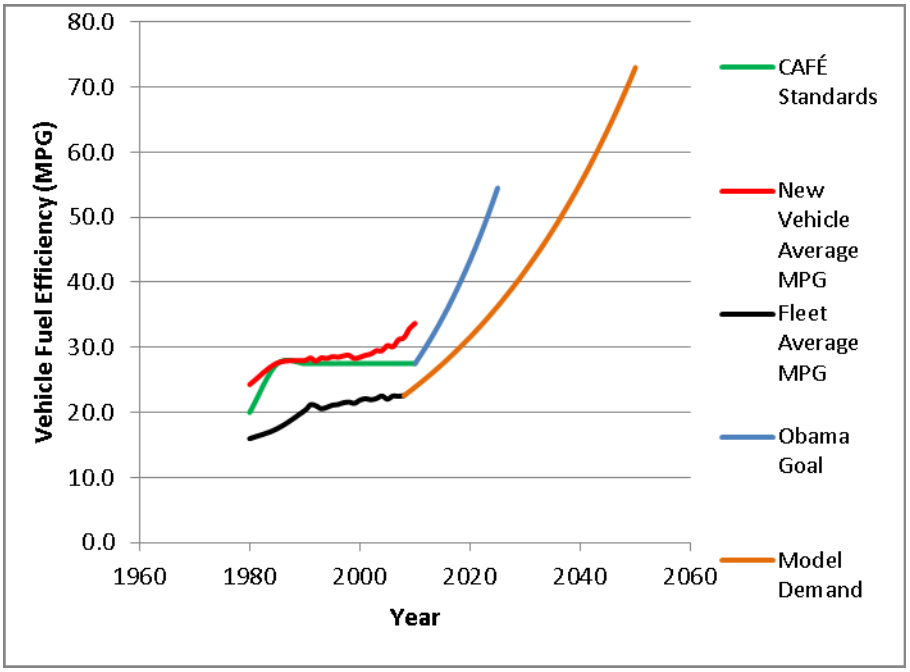


Figure 19: Fuel efficiency standards and practice. 1980-2010.

In a future of decreasing energy availability, "winners" and "losers" in regards to states may very well be defined by projected changes in energy consumption (Figure 20). The states that are projected to change little or even decrease energy demand can be considered to be those states best suited for the uncertain future. Ohio, North Dakota, West Virginia, New York and Iowa make up the top five best suited states according to the models. Nevada, Arizona, Florida, Texas and Utah are the bottom five states. This is due to a combination of rapidly growing populations and warming climates. If one considers the change in monthly energy costs, the New England states, including New York, would be the "losers." By the definition of total projected energy demand in 2050, Texas, Florida and California are "losers" and Vermont, Rhode Island and South Dakota are "winners." Wyoming, North Dakota and West Virginia are "losers" with respect to

2050 energy demand per capita and by the same measure Vermont, Rhode Island and California are "winners."

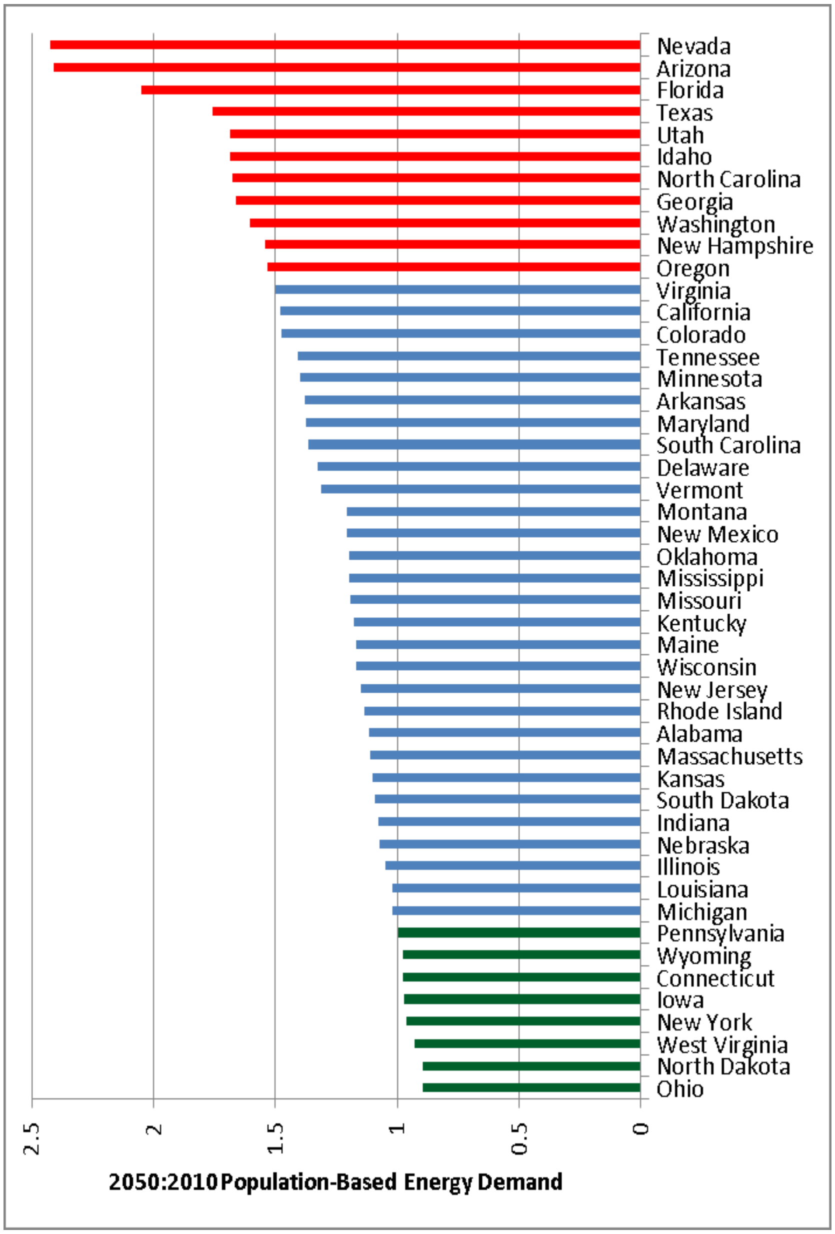


Figure 20: Projected state-by-state population-dependent energy demand. 2050:2010. Green indicates lowered demand. Blue indicates moderate demand growth. Red indicates significant demand growth

Winners and losers can thus be determined in many ways. Though as a nation the United States is in a far better position than most of the world in terms of population density and energy availability (see chapter III), the issues of warming climates and a high per capita energy consumption will have to be addressed in order to ensure the long term sustainability of each state and the nation as a whole.

CHAPTER V

THESIS DICUSSION & CONCLUSIONS

Discussion

It has now been 214 years since Thomas Malthus published *An Essay on the Principle of Population*. Since then the world has witnessed the industrial revolution, the discovery of oil, the Haber process that provided an artificial means to mass-produce nitrogenous fertilizers using natural gas and Norman Borlaug's short stem wheat that gave birth to the green revolution (for details see Evenson and Gollin, 2003). Though not universal, the global average human life expectancy at birth has grown since the middle of the 20th century, from 52.6 in 1960 to 69.6 years in 2010 (World Bank, 2012), and the world population has increased from 0.9 to 7 billion since 1800 (Goodkind, 2011). Malthus could not help being wrong.

The results of the three models presented here should serve warning that the world is progressing along an unsustainable trajectory. A rational mind must accept that there cannot be an infinite supply of a non-renewable resource. The United States is in a better position to handle this than most countries. That said, luxuries enjoyed in 2012 may become increasingly rare into the future.

The doomsday predicted by Malthus has thus far been delayed by technology. The results of our models may well be delayed or prevented by technology as well. Perhaps in the near future hydraulic fracturing will delay the peaking of natural gas and thus delay peak energy. Shale gas can only delay the peak as it is still a non-renewable source. A significant delay, however, may allow for the required timescale as mentioned in the Hirsch Report (2005) to develop a renewable energy infrastructure.

However, questions remain as to the future of nuclear, hydro, solar, wind and biofuels power (Lior, 2012). It is unknown whether or not these energy sources can be scaled-up at some future time to replace current fossil fuel production (87% of 2010 global energy production). Fthenakis et al. (2009) concluded that given advancements in the concentration and storage of solar power, sixty-nine percent of US electricity could be generated via solar plants by 2050. Delucchi and Jacobson (2011) contend that the barriers to renewable energy development are political and social, not economic or technological. Somewhat in contrast, Marvel et al. (2012) concluded that there is more than adequate wind power potential on Earth, but that economic, political and technological factors limit utilization. This century will witness worldwide changes perhaps on a scale never before realized. Fortunately there is still time to make these changes positive.

Unfortunately a status quo approach to the 21st century seems more likely. The other renewable energy sources (not including hydro) provided 1.7% of total US energy consumption in 2010. We argue that while the conclusions made by Delucchi and Jacobson (2011) are valid at present, as time without action continues into the 21st century, the barriers to renewable energy development will become increasingly physical. The infrastructure required is not feasible without the energy subsidies that fossil fuels contribute. China and India account for one third of the world’s population. Currently, these nations use very little energy per capita compared to Europeans or

Americans. However, these economies are growing rapidly and their thirst for resources grows in concert. With the developing world demanding more energy in the 21st century in order to “live the American dream” (Wolfram et al., 2012) and energy fuels on the decline, Garrett Hardin’s question of lifeboat ethics will no doubt soon step into the spotlight.

Conclusion

The Hirsch Report (2005) and Davis et al. (2010) both independently concluded that any developed nation will require twenty to forty years to make a smooth transition away from the problems presented by a peak in non-renewable energy. As of late 2012, any plan would not be ready until almost 2032 and the far-end of the estimates could reach past 2050. Even if the dates found within these models are given wide errors of ten to fifteen years, global peak energy would still occur around 2039-44.

There are opportunities within this text to find optimism and opportunities to find despair. There is no more disparaging a fact to be found here than the fact that despite the warnings in the Malthus (1798), Jevons (1866), Hubbert (1956), von Bertalanffy (1972), the Hirsch Report (2005), Davis et al. (2010), or even the numbers found here, the United States government does not have an official plan for peak oil or peak energy.

In the world of modeling there is one factor for which we cannot account: technology. The future will no doubt include breakthroughs that will affect the overall accuracy of the models found here. The certainty of these models includes a certain status-quo limitation. That is, because we cannot predict breakthroughs, the dates and numbers serve as approximations. We do not account for factors such as food and strategic resource reserves. It is because of this that the models include an instantaneous cause-and-effect between energy and population. In reality there will likely be a lag between peak energy and peak population.

Without major innovations similar to those that have relegated Malthus to the sidelines in the past, these models should serve as a warning to this and future generations. It is our hope that, like Malthus, we are wrong. At this point in time, as the situation is presented before us, these numbers cannot be ignored. We cannot foresee, even most optimistically, that 21st century energy production will allow for global populations to exceed 9 billion and we see a populations at the end of the century ranging from 3.5 to 7 billion.

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